Strategies for Independent V&V of the MSL Fault Protection Software

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MSL FP/SFP Strategy (Idealized and Actual)

**Fault Analyses**
- FMEA or FFA Interface FMECA
  - One for each FCR
  - Identifies credible faults
  - Used by FDDs to ensure complete set of fault monitors

**ACTUAL**
- We deferred any analysis on the Fault analysis for Launch Build. Surface And EDL fault analysis presented at Delta CDR (Oct 2011) and used for Surface analysis

**Monitors and Local Responses**
- Cross-Cutting FDDs, plus Cruise, ACS, Prop
- Off-Nominal FDDs

**Monitors**
- Condition 1: Local Response Only
- Condition 2: Local Response and send to SFP
- Condition 3: Send to SFP

**ACTUAL**
- Complexity here due to the distributed nature
- Additional complication is schedule (many capabilities already developed in absence of SFP, compounded by ad hoc fault analysis)
MSL Fault Protection – Context

• The MSL FP strategy utilizes a two tier approach: local fault protection and system fault protection (SFP)
  – Local fault protection isn’t very sophisticated, but 1st tier of defense
  – SFP is fed fault monitors from various parts of the system. All monitors generated locally
  – Based on what monitors are triggered, SFP will take appropriate action
• All FP Documentation goes through the standard validation (completed)
  – New SFP monitor handling and response approach requires IV&V regression (Jan 11)
• Due to the distributed nature and lack of consistency in documentation, IV&V decided to apply monitor mining techniques to arrive at a FP architecture baseline
  – This baseline became the basis for our code and fault analysis IV&V work
Hybrid Fault Protection Architecture Implementation Approach

Fault Protection Architecture (hybrid)
- System Fault Management
  - Subsystem A e.g. C&DH
  - Subsystem B e.g. Power
  - Subsystem C e.g. GN&C
  - etc

Associated Artifacts
- System Fault Protection Functional Design Description
- Subsystem Functional Design Description

Requirements/Design Implementation
- Fault Monitor Descriptions
  - Yes, unique monitors, plus subsystem monitors with system responses
- Fault Response Descriptions
  - Yes, system fault responses for all appropriate monitors
  - Yes, local fault responses, plus anticipated system response

Code Implementation

Test
IV&V “Monitor Mining”

Objectives:

• Ensure that each monitor description in an FDD has a requirement and associated fault scenario
• Ensure that each monitor had associated local and/or anticipated system responses described
• Ensure consistency of the monitor requirement, fault scenario and response description
• Ensure that system fault protection identified monitors existed in subsystem FDD descriptions, and vice versa
• Ensure that monitors are implemented in the code
• Ensure consistency of the monitor and associated response implementations between requirements, design and code
• Provide a basis for the IV&V verification analysis
Monitor Mining (FDDs, Code)

Objective:
- Within iDDs, line up requirements, fault scenarios, monitors and responses (system and local), evaluate for goodness
- Mine code for monitor implementation

Approach: Manual extraction and alignment

Summary: identified inconsistent approaches within FDDs, monitors with no responses, incomplete requirements, etc
Code work in progress.

FDD Monitors – SFP Compare -- Code Implementation

Objective: Ensure SFP identified monitors are being generated at local level and FDD indicated SFP used monitors are used by SFP
Assess consistency in the code

Approach: Automated matches (mnemonics), followed by manual matches

Summary: Identification of orphans and inconsistencies

Monitor Database

Objective: Detangle distributed (across artifacts and time) nature of monitors and responses

Approach: Access Database

Summary: Facilitates ongoing analysis (e.g. code trace, new FDDs, change impact and test analysis)
# IV&V Monitor Mining Process, Results

<table>
<thead>
<tr>
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<th>Description</th>
</tr>
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<tbody>
<tr>
<td>IV&amp;V Monitor Mining Work Instructions</td>
<td>• Search the entire FDD for keywords - fault, monitor, response  &lt;br&gt;• Review diagrams for fault monitors and responses  &lt;br&gt;• Document fault monitors and applicable information  &lt;br&gt;• Document fault management requirements with no monitor</td>
</tr>
<tr>
<td>IV&amp;V Monitor Mining Result Types</td>
<td>• Missing fault management requirements and/or responses  &lt;br&gt;• Incomplete requirements in describing fault scenarios  &lt;br&gt;• Requirements with no fault monitor/response  &lt;br&gt;• Unclear response descriptions - local or system response  &lt;br&gt;• Occasionally, pre-existing requirement map to fault monitor is incorrect</td>
</tr>
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<td>Observations resulting from the IV&amp;V Monitor Mining</td>
<td>• Lexicon: SFP FDD and code uses mnemonics, but subsystem FDDs do not in any consistent fashion. In some cases, monitors are not explicitly named (though fault conditions and responses are provided)  &lt;br&gt;  - Lack of a consistent lexicon across documentation meant that judgment needed to be applied as to 1) whether a response was truly a fault response or just defensive programming, and 2) uncertainty in the results (though we reviewed and reviewed our work to reduce errors to extent possible)  &lt;br&gt;• Different approaches to FP were applied across the FDDs. Faults and associated response descriptions varied across the project. The tables and spreadsheets had the most logical presentations. In some cases faults were only provided in PDF pictures. In other cases, we inferred faults due to telemetry provided</td>
</tr>
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</table>
Entity Relationship Diagram (ERD)
- Boxes are tables in the dbase
- Lines are relationships
  - infinity indicates many
  - 1 indicates 1
- Many to many come from concatenations
- Monitor Table is the center of the database
  - Dbase differentiates SFP required vs. FDD generated monitors but it is all in the same table
### Monitor Mining Database Benefits

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IV&V Fault Protection Analysis

Step 1: Perform Monitor Mining to attain a FP baseline. Must be performed first.

Steps 2, 3, 4: Ensure
a) Monitors have underlying fault analysis
b) Handoffs to SFP occur correctly
c) Implementation in code is correct
Can be performed in parallel
Step 1: FDD Monitor Mining

Criteria:
- Each monitor needs to have an associated Requirement that includes Fault Scenario, Local Response (if applicable) and System Response (if applicable)
- Monitor requirement and design must be consistent
Monitor Mining Best Practices, Lessons Learned

• Monitor mining was the trickiest part – this defined the baseline for the rest of the analysis
  – We heard that the FP domain lead kept a copy of the IVV monitor list with her since we had integrated the architecture
  – MSL project didn’t use consistent lexicon or organization – announce vs. declare fault .. No mnemonics .. Ancillary worksheets, commands, separate sections, pdf pictures

• The good
  – The monitor mining required a detailed eye. Analysts were selected with this skill.
  – Having a good understanding of the fault protection architecture enabled us to correctly set this analysis up – we asked the project if they had a single list of all the monitors and they acknowledged this weakness (due to distributed nature of FP implementation)
  – Peer reviews were essential to gain understanding of the fault protection schema. A strong systems engineer in the peer review was beneficial

• Lessons Learned
  – We tried to use different reviewers this ended up being inefficient and ultimately we had to redo the reviews with the same people
  – We ended up having to do this a couple times on the launch monitors – in the end, it might have been useful to run the fault protection monitors with subsystem owners to make sure we got it right
  – Reuse of fault protection is tricky since it is a system activity. MSL used MER FP for cruise and had criticality of cruise been higher, we would have done a separate task here.
Step 2: Fault Analysis

Criteria:
-The subsystem fault analysis needs to be consistent with the FP monitors and associated responses described in FDDs and implemented in code

Methods
- Two way trace between monitors and CDR charts

Thoughts
- Skill set requires sufficient SE skills to understand the Fault analysis and correlation to FDD. This is to filter false positives when discrepancies identified
Step 3: Monitor Compare with SFP—Engineering Approach

• Work Instructions
  1. Extract monitors from IV&V monitor mining that were conditions 2 or 3 (send to SFP)
  2. Compare to SFP Annex which showed monitors expected for SFP operation
  3. Criteria: handoff must occur – looked for orphans on both sides. If subsystem FDD had anticipated SFP response (vs. SFP handoff only) ensured that response was correct
  4. Peer Review and Write TIMs

• Analysis Facilitation
  – Wrote a script to extract full compares of monitors (required mnemonic) – only 4 exact matches
  – SFP used Mnemonics, FDDs often didn’t. SFP used specific cases of monitors, FDDs often used general cases (resulting in many to one relationships)
  – Manual matches became difficult because of narrative nature of the monitor descriptions, we didn’t want to inadvertently pass something.
  – Spreadsheet was “messy”
SFP Compares: Best Practices and Lessons Learned

• In general, we’ve received feedback that IVV analysis associated with interactions between subsystems yields high value – biggest concern from SFP folks was that they might have missed an intended fault requiring a system response

• Best practice
  – SFP FDDs had lists of monitor names using mnemonics with system fault responses. That facilitated our analysis greatly and we liked this
  – We did about 4 iterations of this analysis until everything lined up – results written up in group TIMs
  – Automation and database facilitated analysis – matches between same monitor instantiated as “local monitor” in FDD and “system monitor” in SFP vol2

• Lessons Learned
  – One-many matches (e.g. thermal too-hot zones was a single monitor in Thermal FDD but had dozens of counterparts in system FP). Subsystem FDDs often didn’t have mneumonics to match
Step 4: Code Analysis

Criteria:
- Code should match requirement, if it exists.
- Requirements should match design.
- Requirements should agree. (often monitor had multiple associated requirements)
- If there's no requirement, code must match design.
• In Oct 2010, MSL project updated their SFP handoff from a “push” (function call) to a “pull” (polling) strategy. The code needed to be retroactively updated (~1200 monitors)
• All monitor code is supposed to implement the color pattern shown on the right
  • Black – initial state
  • Yellow – error persistence exceeded
  • Red – fault persistence exceeded
  • Green – nominal
• Along with monitor colors, a standard code pattern was implemented
Fault Monitor Code Analysis Overview

- Used monitor mining and MSL code pattern (on right) as a basis for our code analysis.
- Compared code to requirements, design and implementation of code pattern
  - "monitor-centric" analysis (reqts + design), vs. reqt only
  - Used IV&V Monitor Database
- Grabbed additional metadata location that wasn’t always available in the requirements/design
  - Enables
  - Persistence

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## Code Analysis Worksheets (p1 of 2)

### Associated Monitor Mining Data
- Monitor name from SFP FDD
- Monitor name from Subsystem FDD
- Which subsystem FDD
- Requirement ID and text
- Fault Scenario
- System Response
- Local Response

<table>
<thead>
<tr>
<th>SFP Monitor</th>
<th>FP Monitor</th>
<th>Document</th>
<th>Requirement</th>
<th>Requirement</th>
<th>Cond_Fail</th>
<th>System Response</th>
<th>DD Local Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>MON_REL_ALC_MONOTONIC_TRUE</td>
<td>MON_REL_ALC_MONOTONIC_TRUE</td>
<td>REQ_A</td>
<td>Y</td>
<td>Abnormal</td>
<td>REP_SAFER_OCI_SAFER</td>
<td>Loss (Immediate)</td>
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### Code Mining Tracking Sheet part 2 of 2

**IV&V Assessment Fields**

- Monitor Implementation
- Response Implementation
- Req consistent with each other? (TIM)
- Req/Design consistent with code? (TIM)
- Issue description (TIM)
- Recommended Severity (TIM)
- Req fully verified? (Y/N/Partial) (Randall)
- Assigned to

**Associated code color patterns captured during code analysis**

<table>
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<tr>
<th>Row</th>
<th>Monitor Implementation</th>
<th>Response Implementation</th>
<th>Req consistent with each other? (TIM)</th>
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<tr>
<td>1</td>
<td>For each FIV</td>
<td>RSP Safe ENC_0106 ENC_0106 ENC</td>
<td>The monitors are</td>
<td>in active mode</td>
<td>Due to the</td>
<td>error</td>
<td>Due to the</td>
<td>error</td>
</tr>
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<td>2</td>
<td>For each FIV</td>
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<td>3</td>
<td>For each FIV</td>
<td>RSP Safe ENC_0106 ENC_0106 ENC</td>
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Code Analysis Challenges, Best Practices

• System Response: Look for color pattern first
  – Great for finding everything about monitor.
  – If there’s no pattern, use similar keywords as monitor mining, or monitor name if applicable (e.g. fault, monitor, trip, announce)
• Local Responses harder to find, since the pattern wasn’t required for implementation.
  – We used EVRs to identify potential faults
• Does a local deadend qualify as a local response? ← we never quite converged and just called it orange in the end 😊
Other FP design/code analysis tasks performed by MSL IV&V team

- Understand SFP Fault Protection engine and trace to code
- Monitor response collisions – system to system; system to local and local to local
  - Make sure that if you were doing one response, that another one didn’t come in and mess the system up
- System response implementation in code
- “Fatal” EVRs
- EDL Second Chance
Monitor Database – Pulling it all together

- **Objective:** Detangle distributed nature of monitors and responses – project and IV&V activities (to date and anticipated). Additions to IV&V analysis will be easier in database

- **Approach:** Access Database, with philosophy to “Keep it Simple”. Database tables include
  - FP Monitor
  - Requirements
  - FDD
  - SFP FDD
  - Monitor Category
  - Code Implementation

- **Database Facilitation**
  - With many to many relationships, it was useful to incrementally dump data from each of the spreadsheets to refine actual organization
  - Needed queries straightforward since we had been using mining data frequently

- **Database successfully used in launch build fault protection analysis. Portions of the dbase migrating to the SQL dbase for MSL surface analysis**
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