JPL/NASA TEST EFFECTIVENESS PROGRAM

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Acknowledgment The work described in this presentation was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration (NASA)

5/2/97
INTRODUCTION

- JPL’S ASSURANCE TECHNOLOGY PROGRAM OFFICE
- DRIVERS
- PROGRAM TE PROGRAM ORGANIZATION
- CURRENT ACTIVITIES
- TEST EFFECTIVENESS DRAFT WORKING GROUP CHARTER
JPL ASSURANCE TECHNOLOGY PROGRAM OFFICE STRUCTURE

OEMA
ASSURANCE TECHNOLOGY PROGRAM OFFICE (ATPO)
T. Gindorf (Manager)

1. Advanced Packaging and Manufacturing Assurance
   - P. Barlas (PEM)
   - S. Kayali (PEM)
   - QM
   - EEE Parts (QM)
   - AIP
   - SRM
   - Training
   - Course Development
   - Supplier Quality
   - Metrology and Calibration (QT)
   - NDE (ARC)
   - LCR - Olivas

2. Payload Reliability Assurance
   - S. Cornford (PEM)
   - EEE Parts (QM)
   - Payload Assurance
   - Spacecraft Test
   - Effectiveness (QT)
   - Mission Assurance Project Application (QT)
   - Flight Performance (QT)
   - Reliability
   - Risk Assessment (QS)
   - Process Verification & Countermeasures (QS)
   - Mechanical Parts (QS)

3. Mission Assurance
   - G. Paris (PEM)

4. Software Applications
   - J. Kelly (PEM), LCR

5. Engineering Applications
   - G. Jew (PEM)
   - Eng. Standards (M SFC)
   - ISO 9000 (QM)
   - Systems Eng. (JSC)
   - Structural Design-Test Verification (M SFC)
   - Batt & Pwr Sys. (LRC)
   - D. Stefano
   - Applied Tech (AE)

6. Engineering Applications
   - LCR - Shinbrot
   - TIJD - Lou

PEM Program Element Manager
LCR - Lead Center Representative
AM - Administrative Management

TEG: pb 3/18/97

5/2/97

MG 3
TE TASK DRIVERS

- NASA IS ASKING US TO DO MORE WITH LESS MONEY AND TO DO IT WELL

- GET NEW TECHNOLOGY INTO PRODUCTS SOONER

- PROJECT PERSONNEL ARE ASKING US TO HELP THEM IDENTIFY THE LOW VALUE ADDED ASSURANCE TASKS AND THE OVERLY REDUNDANT TASKS

- ALL WANT PROOF (I. E., METRICS) OF THE EFFECTIVENESS OF WHAT REMAINS AFTER TAILORING

- NEED A SYSTEMATIC APPROACH TO ACHIEVE THE ABOVE
RAINFALL CHART

MISSION FAILURE MODES

DEVELOPMENT

DESIGN RULES
MATERIALS SELECTION
ROBUST DESIGN

QML VENDORS
PROCESS CONTROLS

INSPECTIONS
VERIFICATIONS

RELIABILITY ANALYSES

SYSTEM TESTING
PERFORMANCE TESTING

MISSION SUCCESS?

ANALYSES

TECHNOLOGY
QUALIFICATION

LIFE TESTING
MISSION SIMULATION

ASSEMBLY TESTING
PERFORMANCE TESTING

Notes:
1) Each box is a collection of PACTs
2) Dotted lines represent "escapes" - Undetected/unprevented failure modes
3) Illustrative diagram only - nothing is "to scale" 5/2/97
TE TASK OBJECTIVES

◆ IMPROVE NASA/JPL’s OVERALL EFFECTIVENESS BY ADVANCING THE FIELD OF DEFECT DETECTION AND PREVENTION

◆ SHARE EXPERIENCES, KNOWLEDGE AND AVAILABLE DATA IN THE PACT EFFECTIVENESS ARENA

◆ LEVERAGE INDUSTRY AND OTHER GOVERNMENT AGENCIES EXPERIENCE, KNOWLEDGE AND AVAILABLE DATA

◆ DEVELOPMENT& IMPLEMENT TOOLS & METRICS FOR TECHNICAL & PROGRAMMATIC RISK MANAGEMENT

◆ DISSEMINATE RESULTS AND FINDINGS
NASA/JPL TEST EFFECTIVENESS PROGRAM

DATA SOURCES AND SYSTEMS

DATABASES
  NASA/JPL FLIGHT AND GROUND ANOMALIES AND SSED COMMERCIAL SCREENING DATA
  WORKING GROUPS, SEMINARS, SURVEYS, STANDARDS

METRICS DEVELOPMENT AND IMPLEMENTATION
  RELATIVE TEST AND COST EFFECTIVENESS VERSUS FAILURE MODES
  ROLE OF MARGINS AND INTERPLAY BETWEEN PACTS ANALYSIS VERSUS TESTING, INSPECTIONS VERSUS TESTING, TESTING COMBINATIONS, LEVEL OF ASSEMBLY, DESIGN AND FABRICATION (DESIGNING FOR AND TESTING FOR THE "ILITIES")

METHODOLOGY DEVELOPMENT AND IMPLEMENTATION
  SYNERGISTIC AND PHYSICS OF FAILURE BASED TESTING
  QUALIFICATION METHODOLOGIES FOR ADVANCED TECHNOLOGIES DEFECT DETECTION AND PREVENTION RISK IDENTIFICATION AND MITIGATION STRATEGIES MIXING AND MATCHING PACTS
Value Added Screening Effectiveness

Mark Gibbel

Jet Propulsion Laboratory
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ELECTRONICS MANUFACTURING SOFTWARE CONFERENCE
MAY 4TH PORTLAND, OR
VASE OVERVIEW

VASE Concept

- RAINFALL CHART
- VASE Process
- Data Collection and Analyses
  - Level 1 Analysis (all HASS failures)
  - Level 2 Analysis (initial HASS failures)
  - HASS Data Analys's Examples
- Results
  - HASS Process
  - LESS Process
  - HASS/LESS Comparison
- Conclusions
VASE CONCEPT

Value Added Screening Effectiveness (VASE)

- NCMS ESS 2000 Project Scope: Optimize ESS process
- Process which assesses the value added by various steps in a process or all processes used in delivering a reliable product to market
  - Developed jointly between National Center for Manufacturing Sciences (NCMS) & JPL/NASA’s test effectiveness program, a derivative of JPL’s Defect Detection & Prevention (DDP) methodology
  - Captures failure mode/mechanism prevention, detection and/or precipitation data Vs. process parameter data Vs. design capabilities
  - Ranks the effectiveness of various screening stresses Vs. failure mode/mechanism categories

ENABLES OPTIMIZATION TRADE-OFFS BASED ON FAILURE ENGINEERING/PHYSICS
RAINFALL CHART

MISSION FAILURE MODES

- DESIGN RULES
- MATERIALS SELECTION
- ROBUST DESIGN

- QML VENDORS
- PROCESS CONTROLS

- INSPECTIONS
- VERIFICATIONS

- RELIABILITY ANALYSES

- ANALYSES

- TECHNOLOGY
- QUALIFICATION

- LIFE TESTING
- MISSION SIMULATION

- ASSEMBLY TESTING
- PERFORMANCE TESTING

SYSTEM TESTING
- PERFORMANCE TESTING

MISSION SUCCESS?

Notes: 1) Each box is a collection of PACTs
2) Dotted lines represent "escapes" - Undetected/unprevented failure modes
3) Illustrative diagram only - nothing is "to scale"
VASE PROCESS

Capture snapshots of data for a given set of processes:

- Failure classification (by process)
  - Failure mode/mechanism
  - Identification of responsible stress and/or combination of stresses

- Cost determination
  - Identify appropriate cost metric(s) and weighings:
    - (In this case cost per defect detected)
  - Allocate costs to each test step
    - ESS cost model (run for all three organizations specific cost conditions)

- Optimization
  - Rank the effectiveness of various stress/stress-combinations based on cost metric

USE THE SNAPSHOTS TO CREATE A “VIDEO IMAGE” OF THE EFFECTIVENESS TO CLOSE THE FEEDBACK LOOP AS PROCESSES CHANGE DUE TO NEW INFORMATION
DATA COLLECTION & ANALYSES

Collect as much data as possible in the beginning
- Typically the more detailed the data the more meaningful the conclusion
- VASE process helps avoid “getting lost in the data”
- **Use** as much detailed data as necessary but no more.

- Match level of detail for each type data collected to level of detail regarding process step
  
  E.g.
  - Screens and Workmanship
  - Vibration and Lose fastners
  - Duration and wire bond
LEVEL 1 ANALYSIS (all HASS failures)

- High Level data Analysis can be misleading
- Wrong conclusions
  - All these steps are necessary
  - May need more steps
  - Cold Vib. more effective than Hot Vib.

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LEVEL 2 ANALYSIS (initial HASS failures)

- Shows first occurrence of failures
- Different Conclusions than before:
  - Hot Vib more effective than Cold Vib.

<table>
<thead>
<tr>
<th>STEP</th>
<th>FAILURE</th>
<th>COUNT</th>
<th>TEMP (Ramp Type)</th>
<th>VIB</th>
<th>VOLT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>24</td>
<td>Ambient</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>50</td>
<td>Positive ramp</td>
<td>On</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>66</td>
<td>Hot Level</td>
<td>On</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>70</td>
<td>Hot Level/Owen</td>
<td>On</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>71</td>
<td>Hot Level/Dwell</td>
<td>On</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>17</td>
<td>Negative ramp</td>
<td>On</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>-19</td>
<td>Cold/(-ramp)</td>
<td>On</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>6</td>
<td>-21</td>
<td>Cold Owen</td>
<td>On</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>3</td>
<td>-21</td>
<td>Cold Owen</td>
<td>On</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>54</td>
<td>Hot Level</td>
<td>On</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>5</td>
<td>67</td>
<td>Hot Level/Dwell</td>
<td>On</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>0</td>
<td>70</td>
<td>Hot Level/Dwell</td>
<td>On</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>0</td>
<td>-20</td>
<td>Cold/(-ramp)</td>
<td>On</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>1</td>
<td>-21</td>
<td>Cold Level</td>
<td>On</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>0</td>
<td>-21</td>
<td>Cold Level</td>
<td>On</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>0</td>
<td>26</td>
<td>Ambient/(-ramp)</td>
<td>On</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>1</td>
<td>56</td>
<td>Hot Level/Dwell</td>
<td>On</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>0</td>
<td>66</td>
<td>Hot Level/Dwell</td>
<td>On</td>
<td></td>
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<tr>
<td>19</td>
<td>1</td>
<td>69</td>
<td>Hot Level/Owen</td>
<td>On</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>3</td>
<td>71</td>
<td>Hot Dwell</td>
<td></td>
<td>45</td>
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<tr>
<td>21</td>
<td>4</td>
<td>71</td>
<td>Hot Dwell</td>
<td></td>
<td>55</td>
</tr>
<tr>
<td>22</td>
<td>0</td>
<td>14</td>
<td>Negative ramp</td>
<td>On</td>
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</tr>
<tr>
<td>23</td>
<td>0</td>
<td>-21</td>
<td>Cold Level</td>
<td>On</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>0</td>
<td>-21</td>
<td>Cold Level</td>
<td>On</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>0</td>
<td>-21</td>
<td>Cold Dwell</td>
<td>On</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>5</td>
<td>-21</td>
<td>Cold Dwell</td>
<td>On</td>
<td>45</td>
</tr>
<tr>
<td>27</td>
<td>3</td>
<td>-20</td>
<td>Cold Dwell</td>
<td></td>
<td>55</td>
</tr>
<tr>
<td>28</td>
<td>1</td>
<td>8</td>
<td>Ambient/(-ramp)</td>
<td>On</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>0</td>
<td>24</td>
<td>Ambient</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>1</td>
<td>30</td>
<td>Ambient</td>
<td></td>
<td></td>
</tr>
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<td>31</td>
<td>0</td>
<td>30</td>
<td>Ambient</td>
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<td></td>
</tr>
<tr>
<td>32</td>
<td>0</td>
<td>30</td>
<td>Ambient</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sum</td>
<td>47</td>
<td>30</td>
<td>Ambient</td>
<td>Avg 5.8</td>
<td></td>
</tr>
</tbody>
</table>
For decisions regarding effectiveness of individual stresses must go deeper into data
### HASS PROCESS RESULTS

#### VA SE MA TRIX FOR HASS PROCESS

**HAAS STRESSES PLUS FUNCTIONAL FAILURES, I.E. Dead-On-Arrivals**

<table>
<thead>
<tr>
<th>Failure Modes/Mechanisms</th>
<th>defect Costs</th>
<th>Defect Costs</th>
<th>Relative Cost/Defects found by Screening Strategy</th>
<th>TOTAL Faults Defected by MOB</th>
<th>Relative Cost/Defects found by Screening Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FUNCTIONAL TEST (DDA)</strong></td>
<td>3</td>
<td></td>
<td></td>
<td>24</td>
<td>$17</td>
</tr>
<tr>
<td><strong>COLD LEVEL</strong></td>
<td>4</td>
<td>2</td>
<td></td>
<td>16</td>
<td>$370</td>
</tr>
<tr>
<td><strong>COLD/LOW VOLTAGE</strong></td>
<td>3</td>
<td>1</td>
<td></td>
<td>6</td>
<td>$559</td>
</tr>
<tr>
<td><strong>VIBRATION OR NOT VIBRATION</strong></td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td>$335</td>
</tr>
<tr>
<td><strong>HOT LEVEL OR RAMP RATE</strong></td>
<td>2</td>
<td></td>
<td></td>
<td>2</td>
<td>$140</td>
</tr>
<tr>
<td><strong>HOT/VOLTAGE</strong></td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td>$419</td>
</tr>
<tr>
<td><strong>HOT LEVEL</strong></td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td>$210</td>
</tr>
<tr>
<td><strong>HOT/VOLTAGE</strong></td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td>$210</td>
</tr>
<tr>
<td><strong>HOT/LOW VOLTAGE</strong></td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td>$210</td>
</tr>
<tr>
<td><strong>RAMP RATE (TH)</strong></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>$419</td>
</tr>
<tr>
<td><strong>HOT/COUNT OR NOT AFTER VIB</strong></td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td>$829</td>
</tr>
<tr>
<td><strong>MULTIPLE THERMAL CYCLES</strong></td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td>$5,032</td>
</tr>
<tr>
<td><strong>TOTAL FM'S FOUND BY ALL KNOBS</strong></td>
<td>10</td>
<td>11</td>
<td>8 3 7 4 6 5 3 1 1 2 8 7 6 4 1 1 1 1 1 1 0</td>
<td>87</td>
<td>$200</td>
</tr>
</tbody>
</table>

**Ranked HASS Stresses Vs. Cost per defect defected**

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**LESS PROCESS RESULTS**

**VALE MATRIX FOR LESS PROCESS**

<table>
<thead>
<tr>
<th>LESS S operatives &amp; Stresses plus functional failures i.e. Dead-On arrivals</th>
<th>FAILURE MODES MECHANISMS</th>
<th>TOTAL</th>
<th>DEFECT COSTS</th>
</tr>
</thead>
</table>

**FUNCTIONAL TEST DOA**

<table>
<thead>
<tr>
<th>TRANS.C<em>CL C &amp; C</em> D * RIME COLD</th>
<th></th>
<th></th>
<th>3</th>
<th>6</th>
<th>575</th>
</tr>
</thead>
</table>

**H.T LEVEL**

<table>
<thead>
<tr>
<th>TRANS.C*EL E</th>
<th></th>
<th></th>
<th>3</th>
<th>3</th>
<th>55</th>
</tr>
</thead>
</table>

**IN AIR & HIGH VOLTAGE TESTING**

<table>
<thead>
<tr>
<th>TRANS.CYCLES &amp; TRANS.CYCLES &amp; HOT AIR TIME</th>
<th></th>
<th></th>
<th>2</th>
<th>2</th>
<th>2224</th>
</tr>
</thead>
</table>

**HOT & LOW VOLTAGE**

<table>
<thead>
<tr>
<th>TRANS.CYCLES &amp; TRANS.CYCLES &amp; HOT AIR TIME</th>
<th></th>
<th></th>
<th>1</th>
<th>1</th>
<th>114</th>
</tr>
</thead>
</table>

**TOTAL FM FOUND BY ALL KMBS**

| 4 | 4 | 3 | 1 | 2 | 7 | 1 | 1 | 7 | 31 |

Ranked LESS Stresses Vs. Cost per defect defected

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# HASS/LESS COMPARISON

Comparison VASE Matrix for HASS AND LESS PROCESSES
(BY Tall Pole FAILURE MODES)

<table>
<thead>
<tr>
<th>CONFIDENCE LEVEL ESTIMATE</th>
<th>TIMING</th>
<th>FUNCTIONAL FAILURE/WRONG OUTPUT</th>
<th>SHORT</th>
<th>STUCK BIT (Cracked Die)</th>
<th>SOLDER DEFECTS (REFLOW + COLLECT INSUFFICIENT SOLDER + WETING)</th>
<th>FAILURE NOT REPRODUCIBLE OR UNKNOWN (2)</th>
<th>PARAMETER DRIFT</th>
<th>OPEN TRACE INSIDE BOARD</th>
<th>WIRE SHORTED</th>
<th>OVERALL INCLUDING NO DEFECT FOUND &amp; UNKNOWN</th>
<th>OVERALL EXCLUDING NO DEFECT FOUND &amp; UNKNOWN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ho = HASS is equal or better than LESS</td>
<td>90%</td>
<td>84%</td>
<td>82%</td>
<td>82%</td>
<td>74%</td>
<td>74%</td>
<td>74%</td>
<td>32%</td>
<td>82%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ho = LESS is equal or better than HASS</td>
<td></td>
<td></td>
<td>90%</td>
<td>96%</td>
<td>96%</td>
<td>96%</td>
<td>96%</td>
<td>62%</td>
<td>10%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Which Process is Best?
- Depends on your "Corporate Culture"
- What defects are slipping through previous process steps

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CONCLUSIONS

VASE process snapshots are most effective where product technologies are mostly evolutionary rather than revolutionary.

- Use DDP & HALT process to handle the evolutionary technology pieces.
- VASE tool was demonstrated to be an effective tool for process optimization.

Extension of VASE process to other processes (Software Development, ICT, system test, field failures) is straightforward and could result in significant cost savings by increasing scope to beyond just optimizing ESS Steps.

- Utilize existing SPC data
- Provide guidance for V&V
DEFECT DETECTION AND PREVENTION (DDP) IMPLEMENTATION

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MAY 4TH PORTLAND, OR

* From a JPL presentation originally presented by Steve Cornford on Risk Management
INTRODUCTION

● ACHIEVING THE FBC PARADIGM:

FASTER AND CHEAPER CAN BE EDICTED, BUT HOW TO GET BETTER? BE SMARTER. DO IT BETTER OR DO IT DIFFERENTLY.

- CONSIDER RISK AS A RESOURCE
- CONSIDER ALL “ASSURANCE” ACTIVITIES ON EQUAL FOOTING (COUNT EVERYTHING WHICH HELPS ACHIEVE SUCCESS)

- THINK ABOUT THE “VALUE-ADDED” OF EACH ACTIVITY

- UTILIZE METHODOLOGY TO MANAGE “RISK AS A RESOURCE”, FILL HOLES AND REMOVE REDUNDANT ACTIVITIES
  - IMPLEMENTED AS PART OF DESIGN PROCESS
  - FOCUS PROJECT EFFORTS ON MEETING REQUIREMENTS
  - UTILIZES LATEST FINDINGS, DATA AND HELPS FOCUS RESEARCH EFFORTS
  - REFINED AS PROJECT MATURES, AS NECESSARY
  - SERVES AS A “KNOWLEDGE BASE” FOR SUBSEQUENT PROJECTS
DEFINITIONS

• PACTS - Are everything that could be done
  (toolbox of prevention/detection options)
  - Preventions (Redundancy, Design Rules, Materials Selection, Software Architecture, etc.)
  - Analyses (Reliability (Fault Tree Analyses, Failure Mode and Effects Criticality Analysis (FMECA), Worst Case Analysis), Fatigue, Structural, Performance, Electrical SPICE models, etc.)
  - process Controls (Inspections, Materials purity, QML vendors, Documentation, etc.)
  - Tests (Environmental, Life, Simulations, Performance, etc.)

• FAILURE MODES (FMs)/DEFECTS
  - “Hard” - Cracks, Explosions, Open Circuits, etc.
  - “SoEt” - Resets, Performance Degradations, etc.
  - I am using the word failure in its broadest sense: Failure to meet goals/requirements
RAINFALL CHART

Notes: 1) Each box is a collection of PACTS
2) Dotted lines represent "escapes" - Undetected/unprevented failure modes
3) Illustrative diagram only - nothing is "to scale"
DDP UTILIZES ACEQ "ENGINE"

ACEQ = ACCURATE, COST EFFECTIVE QUALIFICATION
Developed by Steve Cornford and Phillip Barela

- REQUIREMENTS MATRIX
  - WEIGHT FM$s AGAINST REQUIREMENTS
    - REQUIREMENTS WEIGHTED PER PROJECT
    - SUMMATION YIELDS IMPACT COEFFICIENTS
    - IDENTIFIES "DRIVERS" (FM$s AND REQUIREMENTS)

- EFFECTIVENESS MATRIX
  - WEIGHT PACTS AGAINST FM$s
    - SUMMATION YIELDS EFFECTIVENESS COEFFICIENTS
    - IDENTIFIES HOLES AND UNKNOWNS
      - LOOK TO "ROOT CAUSE" OR FAILURE PHYSICS

- WEIGHTED SUM
  - PROVIDES RELATIVE EFFECTIVENESS
    - "MIX AND MATCH" PACTs AND ASSOCIATED COSTS
    - OPTIMIZATION PROBLEM WITH COST AND SCHEDULE CONSTRAINTS
• IN OUR "ONESY" ENVIRONMENT (COMMERCIAL INDUSTRY CALL US "ULTRA-LOW VOLUME") THE ABILITY TO USE DETAILED KNOWLEDGE (TECHNOLOGY, RISK ELEMENTS, ETC.) IS CONSTRAINED
  - NEED TO "PHASE-LOCK" WITH PROJECT DEVELOPMENT
  - USE ITERATIVE PROCESS, REFINED VIA KNOWLEDGE AND DECISIONS IN PROJECT LIFE CYCLE

• RELATED LESSONS LEARNED (LL):
  - BUILD PROTOTYPES/EM’s TO GET EARLY INFORMATION
  - GET INTO TEST AS EARLY AS POSSIBLE, LONG ENOUGH TEST SCHEDULE TO BE ABLE TO USE ANSWERS TO TAILOR/TARGET SUBSEQUENT TESTING
  - PERFORM SEPARATE TECHNOLOGY QUALIFICATION
DDP ON DS 1 PROCESS FLOW

Process repeats to lower levels of assembly/requirements

“Nets” refers to not meeting lower level requirements as a failure mode

System Requirements

Project Weighting

Subsystem Requirements

Other Information

Subsystem Impact Matrix

"Nets"

Assembly Requirements

System Failure Modes

"Nets"

Assembly Failure Modes

Level 2 PACTS

Level 2 Effectiveness Matrix

Prioritize failure modes by impact on Level 2 requirements. Results in a Failure Mode pareto/Sig Risk List:

Results in Level 2 Verification and Validation matrix. Example: "IEM Supports autonomy" is to be verified during system testing and during thermal vacuum testing.

Level 3 PACTS

Level 3 Effectiveness Matrix

Prioritize failure modes by impact on Level 3 requirements. Results in a Failure Mode pareto/Sig Risk List:

Results in Level 3 Verification and Validation matrix. Example: "IEM has 8 Hz interrupt" will be verified via a specific aspect of the functional testing. Could also be verified, to some degree, via software testing, circuit analysis, IEM benchtop testing.

Failure Modes

Weighted Failure Modes

Failure Modes

Weighted Risk Reduction

M Gibbel-7
EMSC 5/4/97
Partial Information from DS 1
Partial List, Not Project Reviewed

--- Note that at higher levels it's tough to develop discriminators

- As move to lower levels and assign likelihoods, start to see separation of risk values
- At any given time, some subsystems may have more (or less) information available - Use all you got!

<table>
<thead>
<tr>
<th>Weight</th>
<th>Requirements</th>
<th>Navigation Failure</th>
<th>Power Failure</th>
<th>MICAS Failure</th>
<th>Other Modes</th>
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<tbody>
<tr>
<td>0.5</td>
<td>Deliver to Cape</td>
<td>3</td>
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<td>0.3</td>
<td>Demo New Technology</td>
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<td>0.2</td>
<td>Asteroid/Comet Science</td>
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<td>1</td>
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<td>Requirement Impact</td>
<td></td>
<td>4.2</td>
<td>4.2</td>
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<td><strong>PACTs</strong></td>
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<tr>
<td>Mission Assurance Plan</td>
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<td>Design Approach</td>
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<td>Total Effectiveness</td>
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<td><strong>Risk Balance</strong></td>
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<td>2.1</td>
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<table>
<thead>
<tr>
<th>Weight</th>
<th>Sub-requirements</th>
<th>IEM not support autonomy</th>
<th>Autonomy fails function</th>
<th>HV converter degrades</th>
<th>HV converter fails to distribute</th>
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<tr>
<td>0.06</td>
<td>Optical Star Imaging</td>
<td>9</td>
<td>9</td>
<td>1</td>
<td>2</td>
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<tr>
<td>0.1</td>
<td>Ion Engine Operation</td>
<td>9</td>
<td>9</td>
<td>1</td>
<td>2</td>
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<tr>
<td>0.04</td>
<td>Ion Engine Control</td>
<td>9</td>
<td>9</td>
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<td>2</td>
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<tr>
<td>0.06</td>
<td>Autonomy</td>
<td>9</td>
<td>9</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Likelihood</td>
<td></td>
<td>0.4</td>
<td>0.7</td>
<td>0.6</td>
<td>0.9</td>
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<td>Requirement Impact</td>
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<td>1.30</td>
<td>2.27</td>
<td>0.22</td>
<td>2.92</td>
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<td><strong>PACTs</strong></td>
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<tr>
<td>Functional Test</td>
<td></td>
<td>9</td>
<td>3</td>
<td>1</td>
<td>3</td>
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<tr>
<td>S/W Test Bed</td>
<td></td>
<td>3</td>
<td>9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Technology Qualification</td>
<td></td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Converter Inspection</td>
<td></td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
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<tr>
<td>Total Effectiveness</td>
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<td>13</td>
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<td>10.0</td>
<td>5.7</td>
<td>23.1</td>
<td>3.1</td>
</tr>
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</table>
DDP IN THE RISK MANAGEMENT PROCESS

• RISK PLANNING
  - IMPLEMENTS SYSTEMATIC REQUIREMENT DEVELOPMENT PROCESS
  - PROCESS FOR DOCUMENTING RISK AND RISK MITIGATION (RATIONALE AND DECISIONS)
  - TOOL FOR IMPLEMENTING THE ALLOCATION PROCESS (RESOURCES, RESERVES, ETC)
  - OBVIOUS LESSON LEARNED TO DATE: THE EARLIER THE TOOL IS IMPLEMENTED, THE MORE USEFUL/COST BENEFICIAL IT IS

• RISK IDENTIFICATION AND ASSESSMENT
  - AS PROJECT REQUIREMENTS, AND PACT SELECTIONS EVOLVE, RISKS ARE IDENTIFIED IN MORE DETAIL
  - RISKS ARE IDENTIFIED AS EARLY AS POSSIBLE
  - IMPACT OF VARIOUS RISK ELEMENTS CORRELATED TO SPECIFIC PROJECT IMPLEMENTATION DECISION’S
  - WEIGHTED BASED ON PROJECT/MISSION PRIORITIES
  - PROVIDES QUANTITATIVE EVALUATION OF RELATIVE RISK
  - OBVIOUS LESSON LEARNED TO DATE: VALUE DEPENDS ON INFORMATION AVAILABLE

• RISK DECISION MAKING
  - ENABLES PROJECT MANAGERS/PERSONNEL TO MAKE INFORMED DECISIONS
  - DECISION RATIONALE CAPTURED AS PART OF PROCESS
    - USES ALL AVAILABLE INFORMATION
    - IDENTIFIES “TALL POLES”
    - IDENTIFIES “BANG FOR BUCK” OPPORTUNITIES

• RISK TRACKING (ITERATION WITH PROJECT EVOLUTION/CLOSING THE LOOP)
  - CAN EASILY SEE IMPACTS OF DESIGN TRADEOFFS AND CHANGES, CONSTRAINTS
  - EARLIER DECISION AND RATIONALE NOT LOST, NOR NEED TO BE “REMEMBERED”
DDP IMPLEMENTATION NEEDS

- Requires “CRITICAL MASS” of expertise and skills
  - Concurrent engineering
  - Project support is imperative

- Requires effectiveness information
  - Information sources, metrics, teaming

Iterative process
  - Start with generic FM/CPCTs
  - Refined as project matures: generic becomes specific
  - Knowledge base updated and applied to next project
DDP SUMMARY

- ADDITIONAL RESOURCE FOR NEW PROJECT PROPOSALS, RISK MANAGEMENT PLANNING
- UTILIZES A PHYSICS OF FAILURE OR “ROOT CAUSE” APPROACH
  - TRANSLATABLE FROM HARDWARE TO HARDWARE
  - CORRELATES TO OBSERVED ANOMALIES
  - REDUCES TO A SMALLER “CORE” SET OF FM's
- ISA TOOL BOX FOR PACTS
  - RELATIVE EFFECTIVENESS VERSUS FM's
  - COST VERSUS PACT PARAMETERS
- ISA TOOL BOX FOR FM's
  - ANOMALY DATABASE
  - CORRELATED WITH HARDWARE, LEVEL OF ASSY, ETC.
- CONCURRENT, TAILORED APPROACH
  - REQUIREMENTS, FM's AND PACT's ARE DEVELOPED AND TAILORED CONCURRENTLY WITH THE PROJECT LIFE CYCLE
- PROVIDES MEANS OF CAPTURING CORPORATE KNOWLEDGE IN TIMES OF “SKUNK WORKS”
- DDP IS A SYSTEM LEVEL APPROACH TO RISK MANAGEMENT, RISK PLANNING, RISK IDENTIFICATION AND ASSESSMENT, RISK DECISIONS, AND RISK TRACKING
BACK-UP VIEWGRAPHS
DDP FLOW CHART

IDENTIFY APPROPRIATE REQUIREMENTS

AVAILABLE TECHNOLOGIES AND IMPLEMENTATION OPTIONS

PROJECT IMPLEMENTATION DECISION

FAILURE MODES (FMs) FROM FAULT MATRIX

FMIs are weighted by their impact on requirements

IDENTIFY RELEVANT FMs FOR PROJECT

Pareto FM Impacts

AVAILABLE PREVENTIONS, ANALYSES, CONTROLS AND TESTS

PLOT FMs VS. AVAILABLE PACTS

EFFECTIVENESS MATRIX

Determine which FMs can be prevented/detected with what effectiveness and with what resources

PLOT FMs VS. MISSION REQUIREMENTS (REQUIREMENTS MATRIX)

Identify PACT

Efficiency

EFFECTIVE TRADEOFF

PRIORITIZE RISK REDUCTION ACTIVITIES

Acceptable RISK AND FUNDING?

YES

CHANGES IN BASELINE REQUIREMENTS OR IMPLEMENTATION?

NO

PERFORM RISK REDUCTION ACTIVITIES BASED UPON ESTABLISHED PRIORITIES.

YES

M Gibbel 13
EMSC 5/4/97
### KITE EXAMPLE

#### Req Impact

<table>
<thead>
<tr>
<th>Req Impact</th>
<th>PACT Effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>9= significant loss</td>
<td>always prevents/detects</td>
</tr>
<tr>
<td>3= moderate loss</td>
<td>a few scenarios it may not</td>
</tr>
<tr>
<td>1= minimal loss</td>
<td>a few scenarios it may not</td>
</tr>
<tr>
<td>0= no impact</td>
<td>will not detect/prevent</td>
</tr>
<tr>
<td></td>
<td>options</td>
</tr>
</tbody>
</table>

#### PACT Effectiveness

<table>
<thead>
<tr>
<th>Opt</th>
<th>P2+P3+P4+T2+T3</th>
<th>Opt 2</th>
<th>P2+P3+P4+T1+T2+T3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20 KS</td>
<td>25 KS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>21,18,18,12</td>
<td>21,21,21,12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Effec w/o weight)</td>
<td>(Effec w/o weight)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.9, 1.9,60, 1.5</td>
<td>0.9, 2.3,70, 1.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Risk Reduction Balance)</td>
<td>(Risk Reduction Balance)</td>
<td></td>
</tr>
</tbody>
</table>

- **Opt 1:** P2+P3+P4+T1+T2 | 9 KS |
- **Opt 2:** P2+P3+P4+T1+T2+T3 | 25 KS |
- **Opt 3:** P1+P3+P4+T2 | 9 KS |
- **Opt 4:** P1+P3+P4+T4 | 4 KS |

#### PACT Effectiveness

<table>
<thead>
<tr>
<th>Opt 1</th>
<th>Opt 2</th>
<th>Opt 3</th>
<th>Opt 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.0</td>
<td>25.0</td>
<td>19.0</td>
<td>19.0</td>
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<tr>
<td>12.0</td>
<td>12.0</td>
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</tr>
<tr>
<td>9.0</td>
<td>9.0</td>
<td>9.0</td>
<td>9.0</td>
</tr>
</tbody>
</table>

#### PACT Effectiveness

<table>
<thead>
<tr>
<th>Opt 1</th>
<th>Opt 2</th>
<th>Opt 3</th>
<th>Opt 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
<td>0.8</td>
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<tr>
<td>1.9</td>
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</tr>
<tr>
<td>0.6</td>
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</tr>
<tr>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
</tr>
</tbody>
</table>

#### PACT Effectiveness

<table>
<thead>
<tr>
<th>Opt 1</th>
<th>Opt 2</th>
<th>Opt 3</th>
<th>Opt 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>1.1</td>
<td>1.1</td>
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<td>1.1</td>
</tr>
<tr>
<td>1.1</td>
<td>1.1</td>
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<td>1.1</td>
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<tr>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
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</table>

### PACT Effectiveness

<table>
<thead>
<tr>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>C1</th>
<th>A1</th>
<th>A2</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>P1</strong></td>
<td>Choose &quot;normal string&quot;</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>9</td>
<td>9</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>P2</strong></td>
<td>Choose &quot;super string&quot;</td>
<td>3</td>
<td>9</td>
<td>9</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>P3</strong></td>
<td>Human not grounded</td>
<td>9</td>
<td>9</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>P4</strong></td>
<td>Avoid flying if looks like rain</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>6</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>C1</strong></td>
<td>Examine length of string</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td><strong>A1</strong></td>
<td>String strength estimation</td>
<td>6</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>A2</strong></td>
<td>String weight estimation</td>
<td>6</td>
<td>6</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>T1</strong></td>
<td>Weigh string</td>
<td>9</td>
<td>9</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>T2</strong></td>
<td>String &quot;copy&quot; pull test - qual</td>
<td>9</td>
<td>9</td>
<td>18</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>T3</strong></td>
<td>String &quot;copy&quot; pull test - acc</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>T4</strong></td>
<td>String &quot;similar&quot; pull test - qual</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
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### PACT Effectiveness

<table>
<thead>
<tr>
<th>Opt 1</th>
<th>Opt 2</th>
<th>Opt 3</th>
<th>Opt 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.0</td>
<td>21.0</td>
<td>19.0</td>
<td>19.0</td>
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<tr>
<td>18.0</td>
<td>21.0</td>
<td>12.0</td>
<td>12.0</td>
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<tr>
<td>12.0</td>
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<tr>
<td>9.0</td>
<td>9.0</td>
<td>19.0</td>
<td>19.0</td>
</tr>
</tbody>
</table>

### PACT Effectiveness

| Risk Balance (Opt 1) | 0.9 |
| Risk Balance (Opt 2) | 0.9 |
| Risk Balance (Opt 3) | 0.8 |
| Risk Balance (Opt 4) | 0.8 |

### PACT Effectiveness

- **Judgement call which is best!**
  - Depends on resources and risk posture

When include likelihood there is a feedback loop after selection of some PACTS (i.e. super string never breaks means likelihood gets very small).

This means that the "tall pole" failure mode ranking may change.

Similarly, if new requirement is imposed (e.g. don't fly if raining)

---

EMSC 5/4/97
DDP IMPLEMENTATION STATUS

● ACEQ ORIGINALLY DEVELOPED FOR QUALIFICATION OF ADVANCED TECHNOLOGIES
  - NASA, DoD, INDUSTRY QUALIFYING MCMs IN RELTECH PROGRAM
  - USUAL STANDARDS HAVE UNKNOWN RELEVANCE
  - GO TO ROOT CAUSE OR PHYSICS OF FAILURE

● DDP METHODOLOGY
  - RESOURCES OF ONGOING R&D/STUDY EFFORTS FOCUSED ON PROVIDING USEFUL DATA
  - ESTABLISHING A SOFTWARE/DATABASE TOOL (WILL LINK WITH PDC)
  - INFRASTRUCTURE FUNDS TO ESTABLISH BETTER COST NUMBERS
  - BEING APPLIED TO:
    • NMP DS2: NEW MISSION ASSURANCE APPROACH
    • QuIC: QUALIFICATION/RISK REDUCTION OF BRASSBOARD INTERFEROMETRY COMPONENTS
    • PLUTO EXPRESS: IN PROCESS FOR FLIGHT COMPUTER

● CONTACT STEVE CORNFORD (818) 354-1701) FOR MORE INFORMATION
End of Life Simulation

Mark Gibbel/ Michael A. Gross

Jet Propulsion Laboratory
California Institute of Technology

ELECTRONICS MANUFACTURING SOFTWARE CONFERENCE
MAY 4TH PORTLAND, OR
EOL Simulation Objectives

- Develop and validate an approach to combining testing and analysis which:
  - Demonstrates functional performance throughout the mission life cycle at the beginning of the circuits life
  - Results in an Enhanced Stress Screen

- Analyze VTFMT **effectiveness** versus circuit block type and mission characteristics

- Develop **EOL** Simulation Guidelines
Driving Force & Benefits

- Quantitative Verification of Design Performance and Robustness
- More Reliable, Faster, Better and Cheaper
  - Labor Intensive Analysis Traded for Relatively Benign Costs of Testing
- Concurrent Process
  - **Ties the** Design and Verification process together
- Can be used to Enhanced Product Screen
The “mission” is equivalent to the “desired field life”

The Initial Parameter value may move due to initial part “bum-in” variations, but the biggest effect is typically the initial part parameter tolerance

Radiation will not be as critical for terrestrial applications
Electrical Parameter Variation

Required Delta T’s For Worst Case EOM Simulation

<table>
<thead>
<tr>
<th>Delta T’s &lt;30</th>
<th>Delta T’s &gt;50</th>
</tr>
</thead>
<tbody>
<tr>
<td>all DIODES</td>
<td>some Capacitors</td>
</tr>
<tr>
<td>$I_{cc}$ of DIGITAL IC’s</td>
<td>$T_{HL}$ of DIGITAL IC’s</td>
</tr>
<tr>
<td>A/D CONVERTERS</td>
<td>most OPAMP’S</td>
</tr>
<tr>
<td>VOLTAGE REGULATORS</td>
<td>D/A CONVERTERS</td>
</tr>
<tr>
<td>12 of 16 TRANSISTOR TYPES</td>
<td>1 of 16 TRANSISTOR TYPES</td>
</tr>
<tr>
<td>1 of 6 FET TYPES (linear)</td>
<td>2 of 6 FET TYPES (linear)</td>
</tr>
<tr>
<td>4 of 6 FET TYPES (switch)</td>
<td>REFERENCE ZENER DIODES</td>
</tr>
<tr>
<td>some RESISTORS</td>
<td>some RESISTORS</td>
</tr>
<tr>
<td>some VOLTAGE REGULATORS</td>
<td>some RESISTORS</td>
</tr>
</tbody>
</table>

USE Voltage and Clock Frequency Margining where Delta T’s >50C

All of the Worst Case Analysis For This Database Assumed 17 Year Life and 100 krad @~100 rad/s Which Could Yield Extremely Pessimistic Results, Depending on Individual Device Annealing Rates. Thus, All Delta T’s Required For EOM Simulation Are Upper Bounds.
Current Funded Products of EOL

- Part Parameter Variation Databook (PPVD) (User Interactive)
- Implementation Guidelines
  - Defining Critical Parameters/Paths
  - Key Parameters of Individual Parts (Op Amps, Diodes, etc.)
  - Identification of Means for Stimulating Part Parameters (Initial Value, Aging, Radiation)
- Catalog of Typical Circuits
  - Encompass a Wide Range of “Typical” Circuits Used in NASA and JPL App.
    - Schematics,
    - Characteristic Equations,
    - Critical Parameters of Each Circuit,
    - and the Fundamental Test/Monitoring Points Associated with Each Circuit.
Phase 1: Establish Feasibility

- Study Interactions of Voltage and Temperature on Simple, Easily Analyzed Circuits on Perf.
- Study the Means by Which VTMT Can be Used to Simulate Life Environments of Radiation, % EOL Degradation and Temperature
  - Use Critical Path/Critical Parameter technique
  - Other Techniques?
- Other collaborative efforts (with parts people)
  - Class S vs. Commercial grade parts
  - FPGAs
  - Others?
- Establish Link Between Expected Rad Effects and Real Rad Effects on these Test Circuits (Joint w/Parts Radiation RTOP)
  - Establish Whether Superposition is a Reality
  - Study Fast & Slow Dose Rate and Annealing Time Effects
Phase 2: EOL Simulation Study

- Will Focus on More Advanced Circuits with Mixed Technologies Which Will Stretch Our Ability To Simulate End Of Life Of These Test Vehicles.
  - Will Look at Galileo Telemetry Data on Certain System Circuits (Start in FY97)
    - Compare WCA of these Circuits with Telemetry Data
    - Using Similar (if not exact copies of these circuits) test what VTF Combinations will bring to Various States of the Galileo Mission.
- From The Results of The FY97 and FY98 Validation Results, End of Life Simulation Guidelines Will Be Produced. These Guidelines Will Include The Following:
  1. Steps For Establishing VTFMT For The Circuit Under Test
    - Either Critical Path/Critical Parameter Technique
    - Inherited/Similar Hardware Technique
    - Other Techniques?
  2. How and Where to Find the Critical Parameters to be Used