Parts Reliability and System Reliability

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Purpose

• Parts reliability and system reliability
  – Fundamental differences between basics
  – Relationship between parts reliability and system reliability
  – Impact of parts reliability on system reliability

• Understanding the assumptions and limitations of each analysis
  – Questions:
    • Using system reliability to direct parts selection
    • Interpreting system reliability in absolute values
  – Example: flight computing architectures for common launch vehicles

• Misconceptions on parts selection strategy
Outline

• Purpose
• Flight computing architectures
• System reliability analysis
• Parts reliability impact on architecture reliability
• Parts selection
• Conclusion
Flight Computing Architectures

- Fully Cross-Strapped Switched Triplex Voter (FCSSTV)
- Partially Cross-Strapped Switched Triplex Voter (PCSSTV)
- Channelized Bussed Triplex Voter (CBTV)
- Fully Cross-Strapped Switched Self-Checking (FCSSC)
- Fully Cross-Strapped Bussed Self-Checking (FCSBSC)
- Channelized Bussed Self-Checking (CBSC)

3 Voter, 3 Self-Checking
3 Switched, 3 Bussed
Highly Channelized, Partially & Fully Cross-Strapped Architectures
Example of Architectures

Instruments/Sensors

- DAU₁
- DAU₂
- INU₁
- INU₂
- INU₃

- RGA₁
- RGA₂
- RGA₃
- MPS₁
- MPS₂
- HCU₁
- HCU₂
- RCS₁
- RCS₂
- PIC₁
- PIC₂

Effectors/Actuators

- FC₁
- FC₂
- FC₃

- Switch₁
- Switch₂
- Switch₃
Assumptions

• Fault tolerance
  – One fault tolerance by design for all function element groups

• Failure modes
  – Only hard or non-recoverable failures considered
  – *No common failure mode included*

• Failure rate and failure criteria
  – Same for each type of sensors and effectors
### Architecture Reliability Table

<table>
<thead>
<tr>
<th>Architecture</th>
<th>R (24 hrs)</th>
<th>R (9 months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCSSTV</td>
<td>0.999993</td>
<td>0.666999</td>
</tr>
<tr>
<td>PCSSTV</td>
<td>0.999991</td>
<td>0.613596</td>
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<tr>
<td>CBTV</td>
<td>0.999979</td>
<td>0.464581</td>
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<tr>
<td>FCSSC</td>
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<td>FCSBSC</td>
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<tr>
<td>CBSC</td>
<td>0.999960</td>
<td>0.357675</td>
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</tbody>
</table>

Parts reliability does not matter for short missions??

This is system reliability; it is **system** reliability which does not show much difference, **NOT parts**!!

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Exponential for System Reliability

• Exponential $MTTF_{\text{exponential}} = 1/\lambda$

Assumption: random defects; no infant mortality

• Workmanship and proper build and assembly issues are not considered
• Results misleading if one or some of the parts not properly screened or used under certain bias condition when different failure modes may occur
Weibull for System Reliability

- **Weibull**
  \[ MTTF_{\text{Weibull}} = \alpha \Gamma \left( \frac{1}{\beta} + 1 \right) \]
  - Failure modes for \( \beta < 1, =1, >1 \)

- **Weibull to replace Exponential in system reliability analysis**
  \[ MTTF_{\text{Weibull}} = MTTF_{\text{Exponential}} \]
  
  Explore impact of parts operating in 3 regions by changing \( \beta \)

  Assume the same parts lifetime

  Impact of \( \beta \) only: impact of parts reliability in terms of operating regimes, not lifetime, on system reliability
System Un-reliability Distribution

FC is the biggest contributor
Assume different $\beta$ while keeping the same MTTF

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Smaller $\beta$ yields lower reliability, even with same MTTF. The workmanship and effectiveness of screening have an impact on system reliability.
When Beta Changes

Beta = 0.5

Reliability (%) vs. Time (Hrs)

- FCSSTV
- PCSSTV
- CBTV
- CBSC
- FCSSC
- FCSBSC

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When Beta Changes

Beta = 0.8

Reliability (%) vs. Time (Hrs)

- FCSSTV
- PCSSTV
- CBTV
- FCSSC
- FCSBSC
- CBSC

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When Beta Changes

![Graph showing reliability (%) over time (Hrs) with different beta values.]

Beta = 1.0

Reliability (%) vs Time (Hrs)

- FCSSTV
- PCSSTV
- CBTV
- FCSSC
- FCSBSC
- CBSC
When Beta Changes

The workmanship and effectiveness of screening are the most influential differentiator for system reliability and architecture selection.

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System Un-reliability Distribution

Unreliability Contribution (%)

Components

- BUS
- CDDL
- DAU
- ECU
- FC
- HCU
- INU
- MPS
- PIC
- RCS
- RGA
- Switch
- TVC
- C&C

FCSSTV  PCSSTV  CBTV  FCSSC  FCSBSC  CBSC

System reliability: should not focus on the absolute numbers, but on how to improve overall reliability

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When Beta Changes

The change of one part’s operation regime may impact system reliability improvement paths.

- FCSSV Beta 0.5
- FCSSTV Beta 0.8
- FCSSTV Beta 1.0
- FCSSTV Beta 2.0

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Misconception I

• Misconception: Less Stringent Component Selection Plan for Shorter Missions
  – Depends on the actual architecture
  – May yield a less stringent up-screening procedure
  – May suggest “lower grade parts” and “upgrading”
  • NASA NEPP cost model indicates more costly.

<table>
<thead>
<tr>
<th>Beta</th>
<th>FCSSTV</th>
<th>PCSSTV</th>
<th>CBTV</th>
<th>FCSSC</th>
<th>FCSBSC</th>
<th>CBSC</th>
</tr>
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<tr>
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<td>0.999979</td>
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<tr>
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<td>0.999985</td>
<td>0.999981</td>
<td>0.999994</td>
<td>0.999981</td>
</tr>
</tbody>
</table>
Misconception II

- System Reliability Analysis and System Level Testing are Sufficient for Component Selection and Component Level Testing
  - Roles and limitations of system reliability – early failures
  - Testing at system does not give full access to parts characteristics – translation
  - Impact of parts reliability on system reliability – depends
Conclusions

• Parts reliability, not only lifetime, but also the operation regimes, has direct impact on system reliability.
  – Workmanship and effectiveness of screening has greater impact on system reliability.

• Critical for space missions to evaluate the risk, risk mitigations and impacts of the parts selection plan
  – Not technically justified:
    • a “less stringent” parts plan for shorter missions
    • an attempt to use system reliability analysis and testing for component selection or reliability
  – Both system reliability analysis and parts reliability analysis must be fully understood and fully implemented to ensure mission success.
    • Screening is the key!!