Adapting Space System Test Campaigns for High-Risk Posture Missions

Adapting Mission Assurance Conference – Nov 13, 2024

Approved for Public Release

BAE SYSTEMS

Streamlining Space System Environmental Testing for Class C and D Space Programs

- Adapting Testing Protocols for Risk-Tolerant Missions
  - No one designs their systems for Mission Failure!
  - Yet without ground testing, even the best designs are at risk of degraded mission capability or even mission failure
  - A typical space system test campaign can take upwards of 18 months to perform (and cost $$$)
  - Adopting your own proprietary, risk / return on investment test campaign is critical to minimizing infant mortality failures, and maximizing on-orbit mission availability

Note: This presentation provides examples from several publicly released papers and conference talks. Citations provided at the end.

A tremendous amount of Industry, Government, and FFRDC research and test data is available to help you tailor your test campaign for efficiency and effectiveness

Understanding Class C and D Missions in Today's Space Marketplace

- Class C and D missions are characterized by higher risk tolerance and lower resource investments
  - That doesn't mean they don't need to work!
  - "Mission Class C" – does not mean what it used to and has always meant different things to different sponsoring agencies in terms of risk tolerance.
  - "Mission Class D" – is no longer considered "experimental" according to many Customer agencies. Think: Pre-Operational.
  - The bottom line is, they want space capabilities delivered faster, and less expensive, but with PREDICTABLE on orbit availability.

	Class A	Class B	Class C	Class D
Mission risk acceptance	Lowest	Low	Moderate	Highest
National significance	Extremely critical	Critical	Not critical	Not critical
Payloads	Operational	Demonstrates operational utility, may become operational	Typically experimental	Typically experimental
Acquisition cost	Highest	High	Medium	Lowest
Development time	May take 4 or more years	May take 3 or more years	May take 2 or more years	May take 1 or more years
Mission life	Long, greater than 5 years (typically 8 to 10+ years)	Medium, up to 5 years	Short, typically less than 2 years	Short, typically less than 1 year
Launch constraints	Critical	Medium	Few	Few to None

Table 1: Mission Risk Class Characterizations (5)

The traditional risk class characterizations … not really applicable any longer!

The objective is to balance mission assurance, cost effectiveness, and delivery time frame, against the "risk" of not having a capability.

Key Challenges

- **Budget constraints:** Limited funding necessitates efficient use of resources.
- **Risk Management:** Higher acceptance of mission risks requires strategic testing approaches.
- **Testing Standards:** Traditional standards may be overly stringent for risk-tolerant missions.

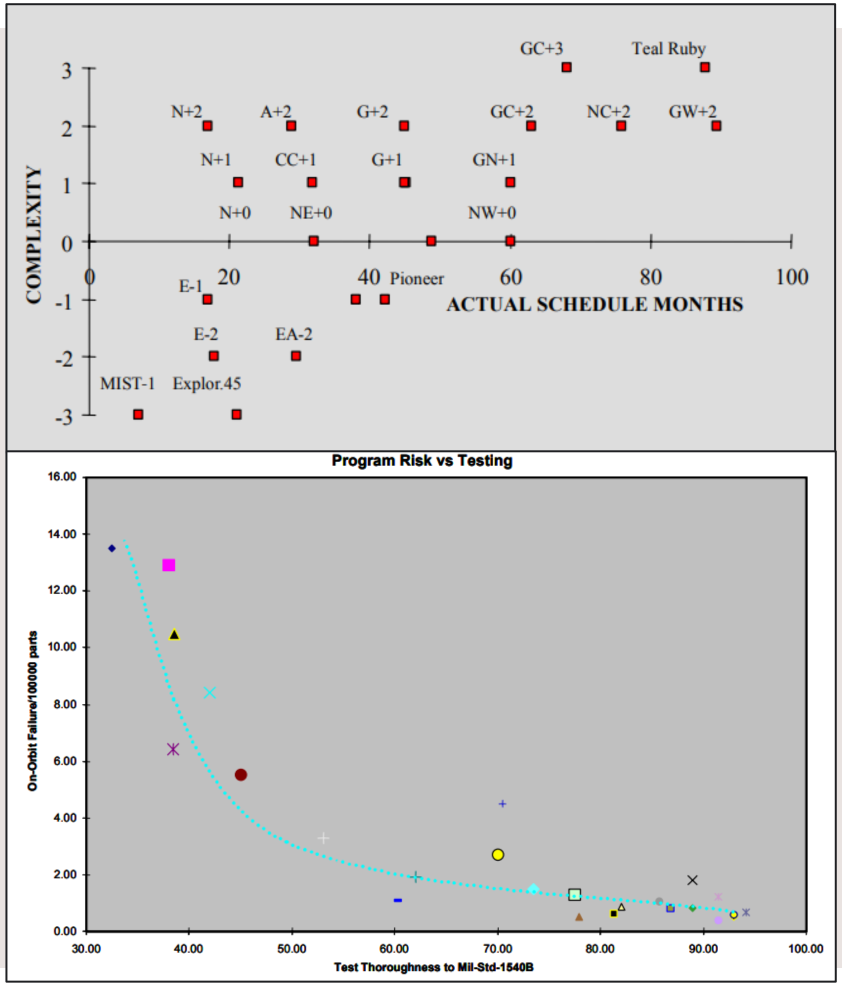

Figure 1: Mission Risk Class / Complexity = Cost in time and $$$. The problem is, time and $$$$ directly translate to potential for failure [8]

Why do we Test?

- **Qualification:** Testing that proves a new design, component, or system can meet its specific requirements in the expected mission environment.
  - Validates the design
  - Typically done once
  - Typically performed at beyond expected operational levels to prove design robustness

- **Quality:** Testing that focuses on verifying that each production unit meets the design and workmanship standards established during the qualification process.
  - Ensures consistency
  - May not be performed on every unit
  - Typically performed at operational rather than extreme conditions

Does it do what you wanted? / Did you build it good enough? Both types of testing are done to reduce the chance of failure in the field … how much one wants to reduce that risk is a function of time and $$$

Key Principals for Risk Tolerant Testing

- **Selective testing:** Focus on essential tests such as thermal cycling, vibration, and burn-in for primary mission critical components
- **Reduced Margin requirements:** Where failure impact is limited, lower test margins can suffice.
- **Cost vs. Benefit:** Prioritize cost-effective testing strategies that maximize reliability within budget / time constraints.
- **Tailored tests and parameters:** Emphasis tests that simulate operations conditions without excessive conservatism
- **Thermal Cycling and Vacuum:** Use reduced cycles for non-critical systems while maintaining full cycles for mission critical components. Adjust temperature extremes only to expected operational ranges.
- **Vibration and Shock testing:** Streamline vibration profiles to match the actual launch and orbit environment, reducing unnecessary cycles.
- **Radiation:** Implement limited total ionizing dose tests, emphasize single event effects mitigation through design instead.

Streamline Variable Quantity and Durations

- **Selective testing:** Focus on essential tests such as thermal cycling, vibration, and burn-in for primary mission critical components
- **Cost vs. Benefit:** Prioritize cost-effective testing strategies that maximize reliability within budget / time constraints.

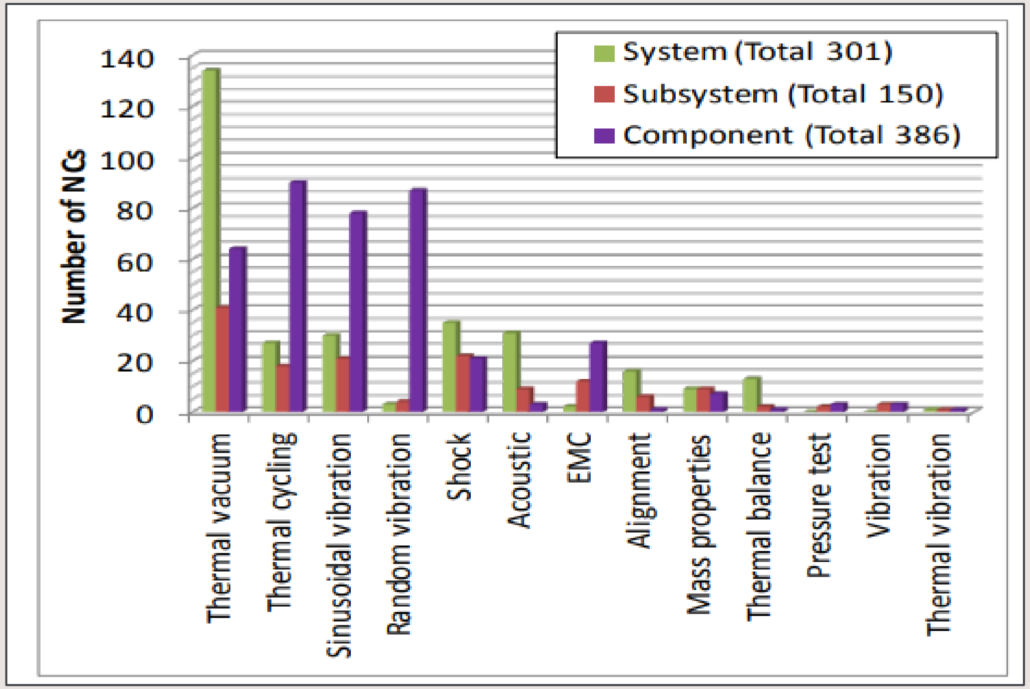

Figure 2: Total number of NCs (except for functional tests and visual inspections) in descending order of occurrence probability for system, subsystem and component tests for three Space Vehicle test campaign [9]

BAE SYSTEMS

Reduce Environmental Extremes

- **Tailored tests and parameters:** Emphasis tests that simulate operations conditions without excessive conservatism
- **Reduced Margin requirements:** Where failure impact is limited, lower test margins can suffice.

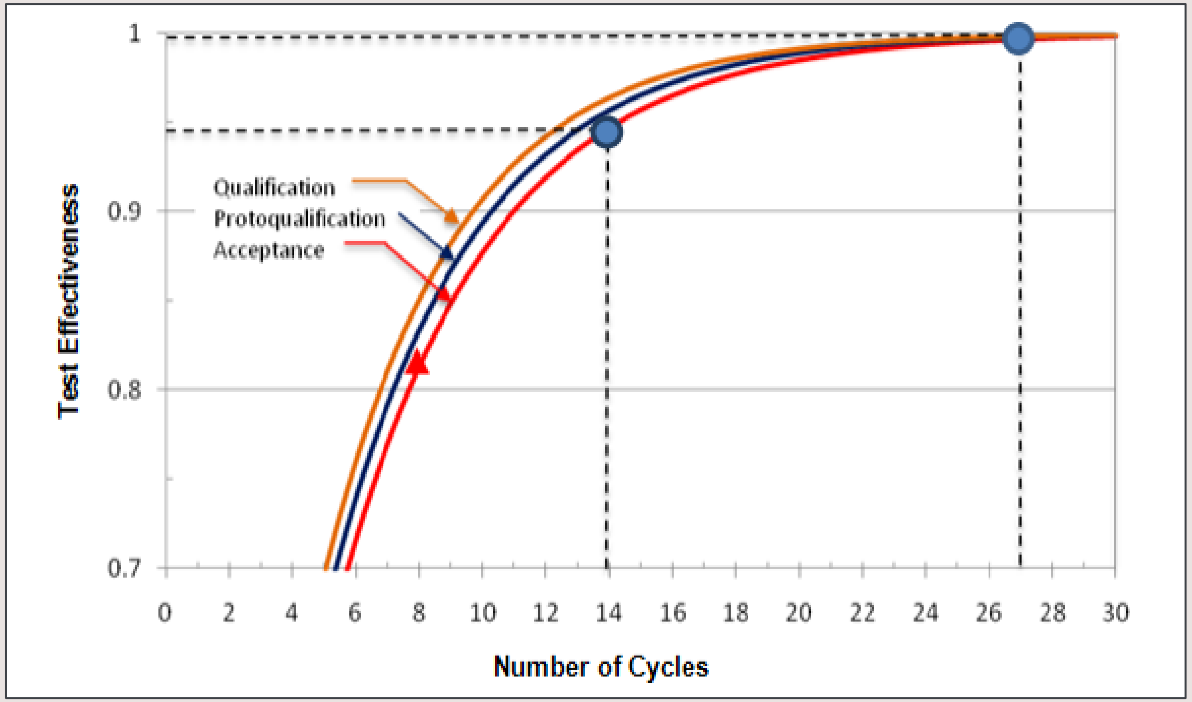

Figure 3: Curves show test effectiveness versus the number of ΔT=85°C thermal cycles. Obviously, the more you test the more you find, yet improvement in effectiveness becomes negligible for large numbers of cycles. Furthermore, the delta effectiveness for environmental extremes in length and temperature could be considered nominal (11)

Thermal Cycle, Thermal Vacuum, and Burn-in

- **Thermal Cycling and Vacuum:** Use reduced cycles for non-critical systems while maintaining full cycles for mission critical components. Adjust temperature extremes only to expected operational ranges.

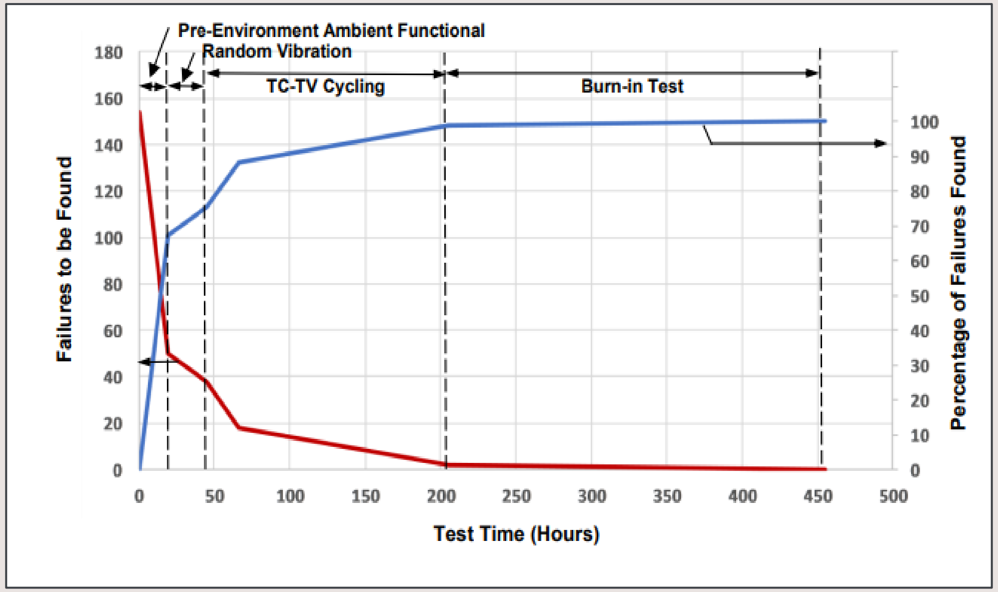

Figure 4: Shows the percentage of failures detected for totality of component level burn-in, including Thermal Cycle and TVA, majority of NCs found in first 50hrs, including first two Thermal Cycles. [5]

Conclusion

- Streamlining a test campaign allows for agile mission timelines.
- Focused testing mitigates high costs, while providing the maximum value for investment of time, facilities, and $$$$.
- Tailoring preserves essential reliability without over-engineering for non-critical parameters.

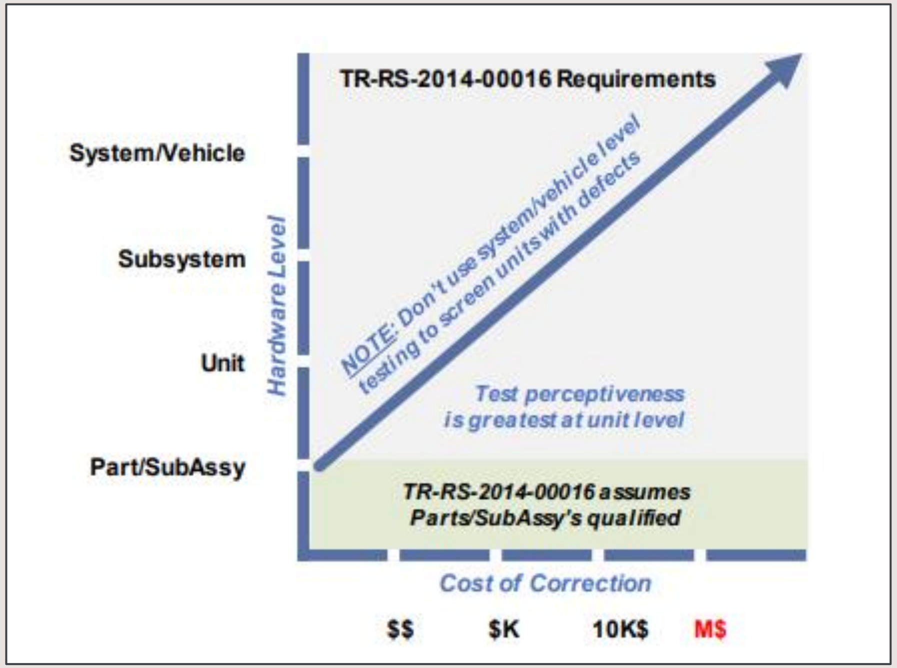

Figure 7: It is taken as an axiom that cost of correcting failures goes up as NCs are identified at the component, system, and vehicle level. Furthermore, environmental testing is considered most perceptive at lower levels. Test campaigns should be designed to prove quality at lowest levels, while qualifying at highest levels. (16)

The number one reason missions fail is money!

Delayed launch results in a reliability of zero for the length of the delay!

Sources

1. Arnheim, B., Lessons Learned from Space Vehicle Test Trends, Proceedings of the 26th Aerospace Testing Seminar, October 2006, PP1-11.
2. Military Handbook: Design, Construction and Testing Requirements for One-of-a-Kind Space Equipment, DoD MIL-HDBK-343 (USAF), 1 February 1986.
3. Johnson-Roth, G. A., J. B. Juranek, J. Perry, and B. E. Shaw, Mission Risk Posture Assessment Process Description, Aerospace Report Number ATR-2015-03151, The Aerospace Corporation, El Segundo, CA (29 September 2015).
4. Johnson-Roth, G. A. and W. F. Tosney, Mission Risk Planning and Acquisition Tailoring Guidelines for National Security Space Vehicles, Aerospace Report Number TOR-2011(8591)-5, The Aerospace Corporation, El Segundo, CA (13 September 2010).
5. TR-2021-00283 - Thermal Test Tailoring Guidelines for Class C and D Space Programs TOR-2021-00283, The Aerospace Corporation, El Segundo, CA (15 February, 2021).
6. Test Requirements for Launch, Upper-Stage and Space Vehicles, Air Force Space Command, Space and Missiles Center (SMC) Standard, DoD SMC-S-016, 5 September 2014.
7. Perl, E., A. J. Peterson, J. M. Snyder, C. P. Wright, and J. W. Welch, Test Requirements for Launch, Upper-Stage, and Space Vehicles, Aerospace Report Number TR-RS-2014-00016, The Aerospace Corporation, El Segundo, CA (25 June 2014).
8. Jurnek, J.B., et.all., The Mission Assurance Technical Baseline and Environmental Test Thoroughness Assessment Process, Proceedings of the 21st Aerospace Testing Seminar, October 2015, 1-29.
9. Quinzhong, S., et.all., Introduction of Test Standard Update and Activities on the Test Effectiveness Reflected By Ground Environmental Test Anomalies, 27th Aerospace Testing Seminar, October 2012.
10. Welch, J. W., Investigation of the Relative Importance of Thermal Test Parameters as Specified in MIL-HDBK-344, 25th Aerospace Testing Seminar, October 2009.
11. Wright, C. P., Test Effectiveness of SMC-S-016 Unit Acceptance Thermal Testing, 26th Aerospace Testing Seminar, March 2011.
12. Environmental Stress Screening (ESS) of Electronic Equipment, DoD MIL-HDBK-343A, 16 August 1993.
13. Smith, D. A, Acceptance Test Effectiveness including "High Temperature Acoustic Testing, Proceedings of the Institute of Environmental Sciences, 1988, pp. 120–130.
14. Welch, J. W., General Approach for Specifying Thermal Environmental Test Requirements for Spacecraft Units, 29th Aerospace Testing Seminar, October 2015.
15. Welch, J. W., Thermal Testing of Small, Class C Space Vehicles: A Case Study, AIAA-91-1302, AIAA 26th Thermo-physics Conference, June 1991.
16. Wendler, B.H., Establishing Minimum Environmental Test Standards for Space Vehicles, Proceedings of the 21st Aerospace Testing Seminar, October 2003, PP1-27-35.