SMALLSAT RELIABILITY: ISSUES AND SOLUTION APPROACHES

Imagination is more important than knowledge.

Albert Einstein

Presented by Michael Johnson
Chief Technologist
Applied Engineering and Technology Directorate
NASA Goddard Space Flight Center

Findings derived from public-private collaboration

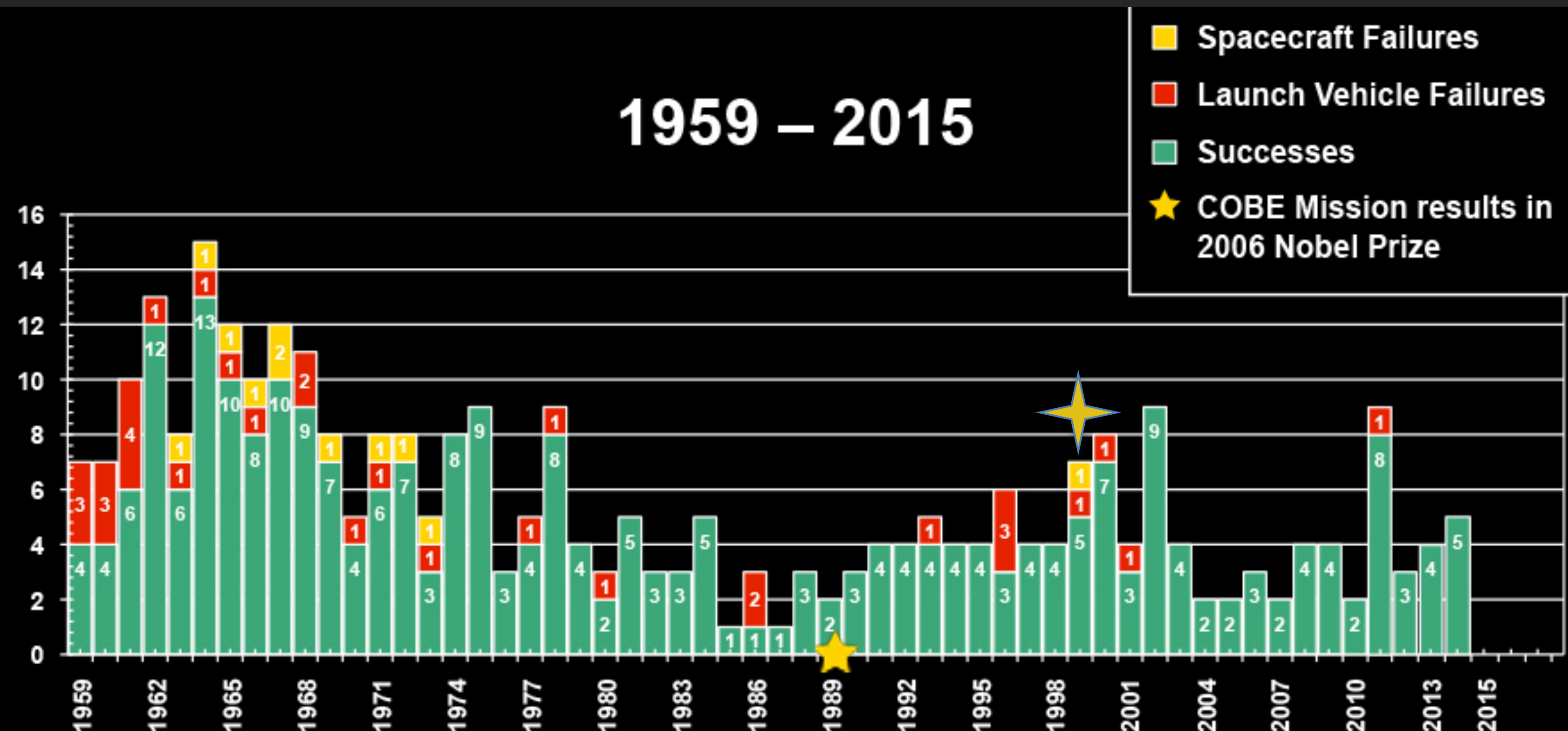
Pacific Operational Science and Technology Conference
9 March 2017

Finding:
“SmallSat” and “credible science” are consistent.

However…

Expectation:
The Mission Will Succeed

Goddard's mission success performance informs our success posture
- And is inconsistent with historical CubeSat mission success



Successes = 272
Launch Vehicle Failures = 32
Spacecraft Failures = 12

Since 1974 : Successes = 163
Launch Vehicle Failures = 14
Spacecraft Failures = 1

WIRE instrument failure. GSFC bus functioned successfully.

SmallSat Missions: Reliability Challenges

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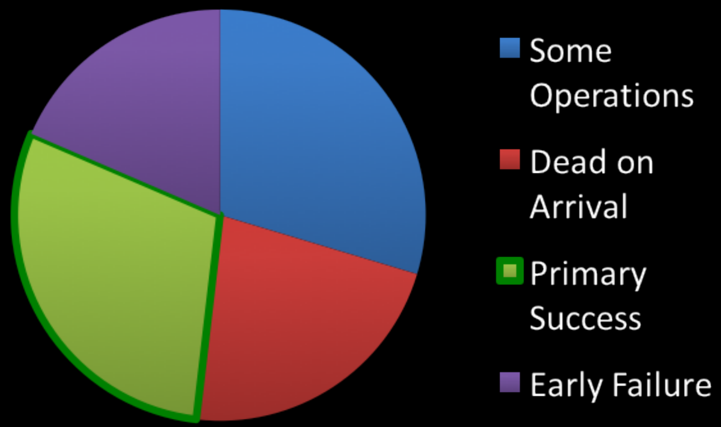
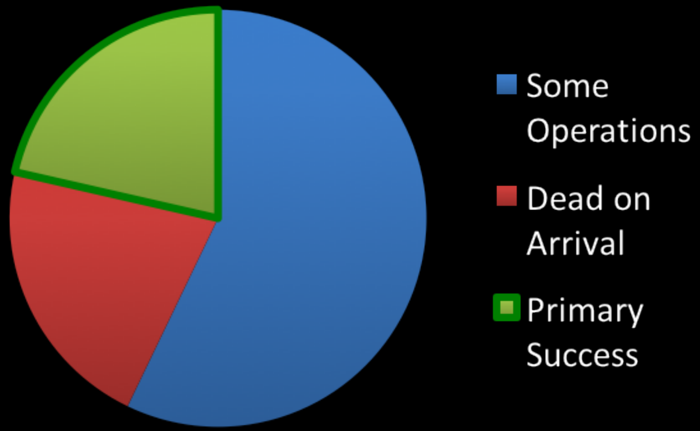
At present, CubeSat components and buses are generally not appropriate for missions where significant risk of failure, or the inability to quantify risk or confidence is unacceptable.



University Mission Status for CubeSat Spacecraft Reaching Orbit - Second Mission – (2000-2014).



Industry Mission Status for CubeSat Spacecraft Reaching Orbit - Second Mission - (2000-2014).

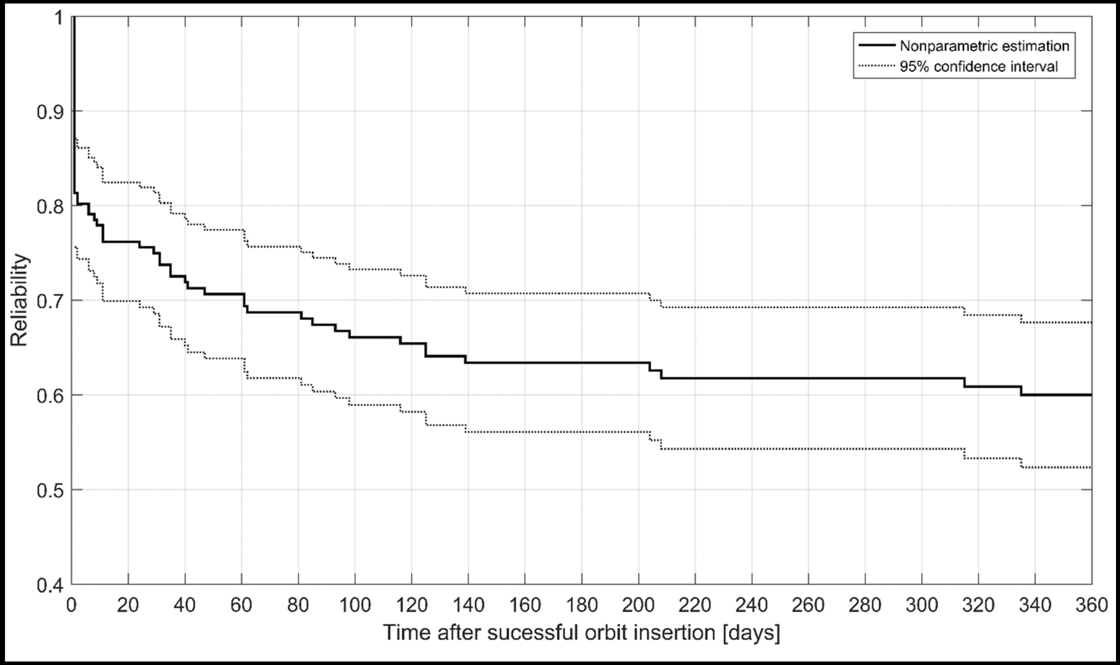
Ref. M. Swartwout

Mission success likelihood is not consistent with most science mission

SmallSat Missions: Reliability Challenges

A statistical analysis of CubeSat on-orbit failure rate derived from

- Non-parametric estimation
- Parametric models
- Developer intuition



Results of a nonparametric reliability estimation with 95% confidence intervals for 1 year in orbit.

Important note: Database is largely populated by single platform mission.

Ref: Martin Langer, Institute of Astronautics, Technical University of Munich, *Reliability of CubeSats – Statistical Data, Developers' Beliefs and the Way Forward*, 2016

SmallSat Missions: Reliability Challenges

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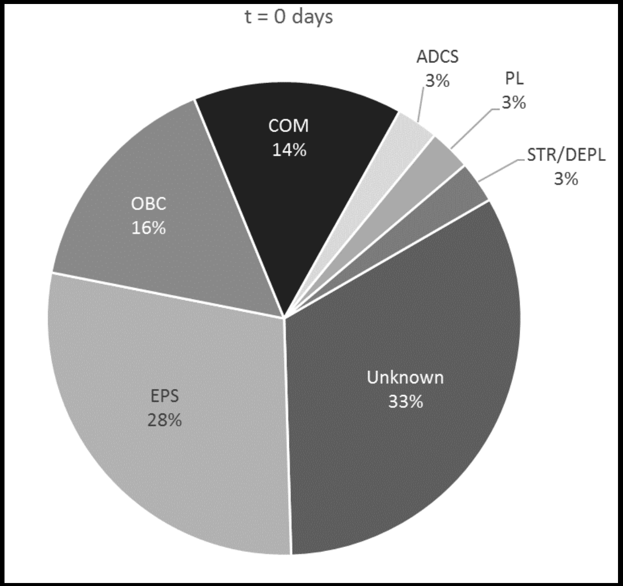

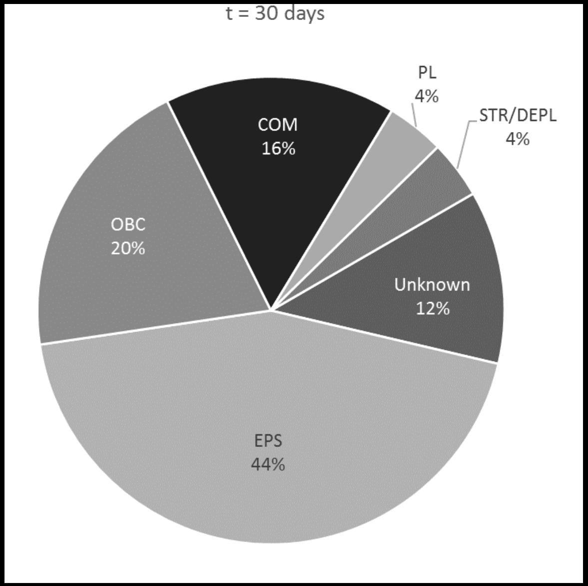

Subsystem contributions to CubeSat failure after ejection (incl. DOA), and 30 days

DOA- dead on arrival

Data derived from CubeSat Failure Database and developer interviews

NASA Goddard Space Flight Center

Ref: Martin Langer, Institute of Astronautics, Technical University of Munich, *Reliability of CubeSats – Statistical Data, Developers' Beliefs and the Way Forward*, 2016

SmallSat Missions: Reliability Challenges

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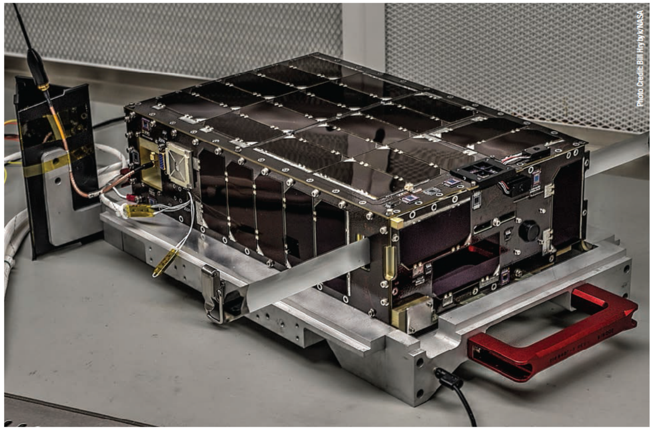
Personal experiences tie it all together:

- Dellingr 6U development highlighted
  - Numerous "out of the box" subsystem deficiencies
  - Numerous potential development pitfalls

Volume 13 • Issue 2 • WINTER 2017

Raising the Curve

Goddard Team Advances SmallSat Reliability



Dellingr's exterior is lined with solar panels. Slightly larger than a cereal box, Dellingr is a 6U CubeSat — indicating that its volume is about six liters.

When a tiger team set out to design, build, integrate, and test a large shoebox-sized satellite capable of executing NASA-class science, the group didn't completely appreciate the challenges it would face. It knows now. And because of the experience, Goddard currently is spearheading initiatives to dramatically improve the reliability of small satellite-based systems and missions.

Although the six-unit, or 6U, Dellingr spacecraft is nearly finished and awaiting launch to the International Space Station in June 2017, it took double the time and more funds than budgeted to build a robust CubeSat mission capable of achieving NASA-quality science (CuttingEdge, Fall 2014, Page 4).

No one, however, is calling the project a failure.

Underscoring a Hard Truth

The experience underscored a hard truth, said Michael Johnson, the chief technologist of Goddard's Applied Engineering and Technology Directorate, who championed the Dellingr pilot project.

"In many cases, our desired level of performance wasn't there," he said, referring to many small satellite-related components and subsystems offered by commercial vendors. "The Dellingr team encountered more than a handful of technical challenges with components right out of the box that affected the project's cost and schedule. This wasn't a theoretical activity. Some of the systems simply did not meet our expectations."

Created in 1999 by the California Polytechnic State University primarily as a learning tool, the CubeSat platform has grown in popularity among organizations worldwide mainly because they offer less-expensive access to space. Many CubeSats, however, are notoriously unreliable. They are analogous to the early days of the rocket program, with a mission-failure rate exceeding 40 percent, Johnson explained.

Continued on page 8

cuttingedge • goddard's emerging technologies

Cutting Edge, Winter 2017, https://gsfctechnology.gsfc.nasa.gov/Current.pdf

Our strength is our weakness.

SmallSat Missions: Reliability Challenges

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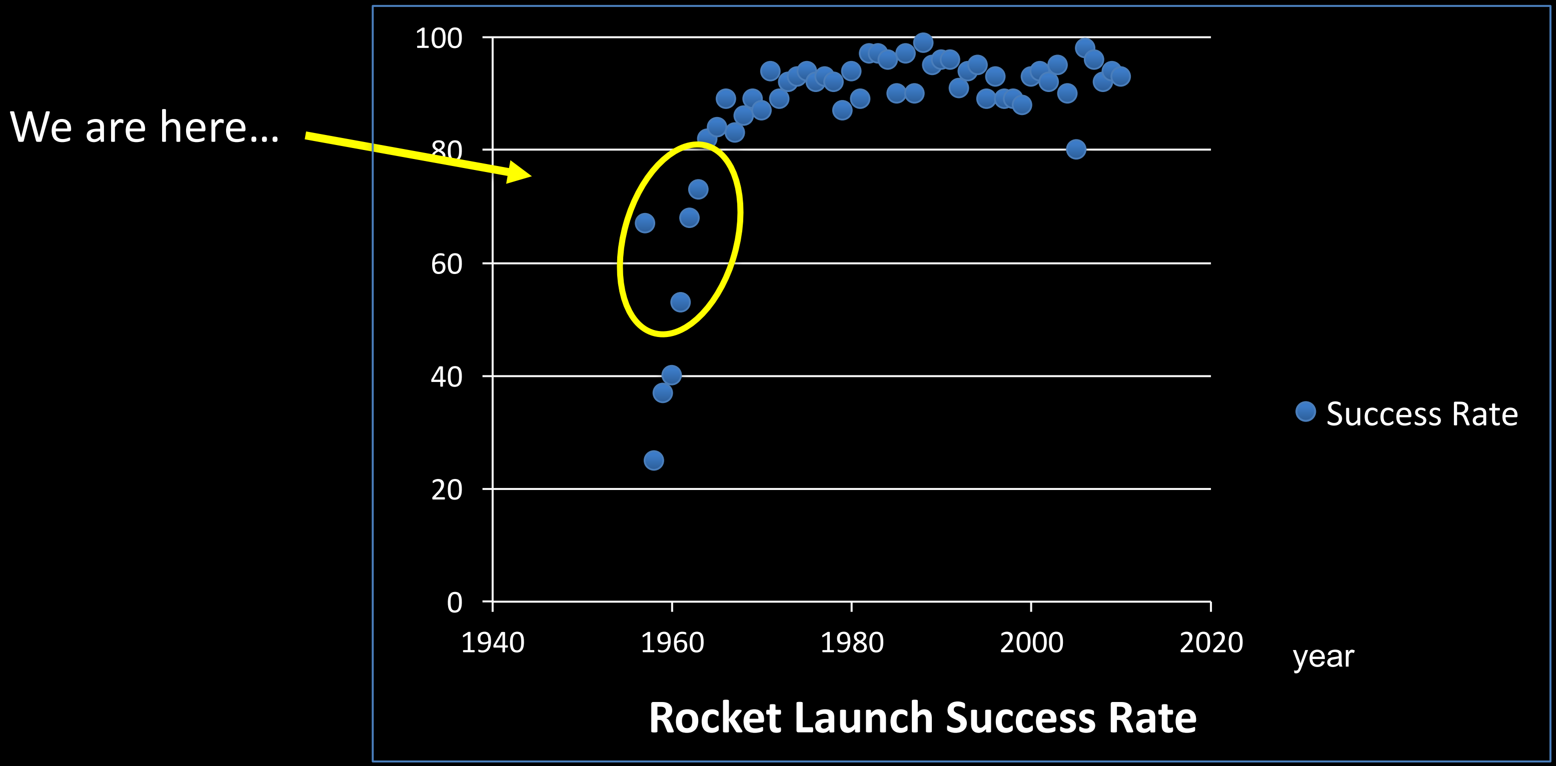
CubeSats are in the 1960s
Statistically, overall robustness is analogous to the early days of space flight.



Finding: Reliability must be addressed if SmallSats are to achieve their full potential.
SmallSat attribute advantages <u>must</u> be preserved.

Interagency *SmallSat Reliability Initiative* launched July 2016

Technical Interchange Meeting convened 14-15 February 2017- One component of a public-private national initiative

Historically, it was understood and accepted that "high risk" and "CubeSat" were largely synonymous; expectations were set accordingly.

Their growing potential utility is driving an interagency effort to improve and quantify CubeSat reliability, and more generally, small satellite mission risk.

Goals-

- Secure industry inputs on initial government thoughts on SmallSat mission classifications and mission assurance approaches
- Establish next steps

SmallSat Reliability Technology Interchange Meeting

February 14th-15th, 2017
Avery Library, Caltech Campus- Bldg 99, Pasadena, CA 91125
Event is free of charge
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Background

CubeSat-SmallSat components and buses are generally not appropriate for missions where significant risk of failure, or the inability to quantify risk or confidence is unacceptable. This precludes their use where their attributes could otherwise enable or enhance mission objectives or provide other meaningful benefits—e.g. lower cost, increased coverage (spatial, temporal, spectral), agility, resiliency, etc. Historically, this has not been an issue since it was understood and accepted that "high risk" and "CubeSat" were largely synonymous; expectations were set accordingly. But their growing potential utility is driving an interagency effort to improve and quantify SmallSat mission risk.

Workshop Goal

This forum will foster a collaborative public-private engagement with presentations from the broad community. The ensuing brainstorming sessions seek to build a compendium of mission assurance approaches, novel test approaches and mitigation techniques associated with SmallSat mission risk classifications while maintaining to the extent practical, cost efficiencies associated with small satellite missions. These mission risk postures span "do no harm", to those whose failure would result in loss or delay of key national objectives. A prioritized list of development tasks will build the foundation of a future investment roadmap for reliability assurance techniques.

Topic Areas

Mission and System Level Reliability: Assessment and Mitigation
SmallSat risk can be addressed at various architectural levels. This topic area targets risk assessment and mitigation approaches that are applied at higher or overarching levels—the mission or the spacecraft system. We solicit thought and discussion on assessment approaches that are efficient and effective, and mitigation strategies that facilitate resiliency to mission or system component anomalies. These approaches may be proven and leverage traditional methodologies, may leverage physics of failure or model based design, or perhaps migrate new and innovative systems and processes employed in other domains to the aerospace sector.

Component/ Subsystem Reliability
Typically, reliability and quality is assessed at the component level by thorough screening, lifetime and/or radiation tests. In this topic area, unconventional and innovative means of assessing the component or small subsystem performance are solicited. Additionally, mitigation of residual risks is a rich area of research at the component, circuit and subsystem level. Effective and proven mitigation approaches are also solicited.

Caltech

Attendees: GSFC, JPL, ARC, NASA HQ, NOAA, Los Alamos, Aerospace Corp, Air Force Research Lab, US Special Ops Command, Innoflight, VAACO, Tyvac, Pericle Communications, Spaceflight Industries, Phase Four, Vulcan Wireless, Univ Michigan, Space Dynamics Lab, Blue Canyon, AAC Microtec, Maryland Aerospace, GeoOptics, others

A Public-Private Initiative
TIM Findings

Finding: Focus on Mission Confidence Levels

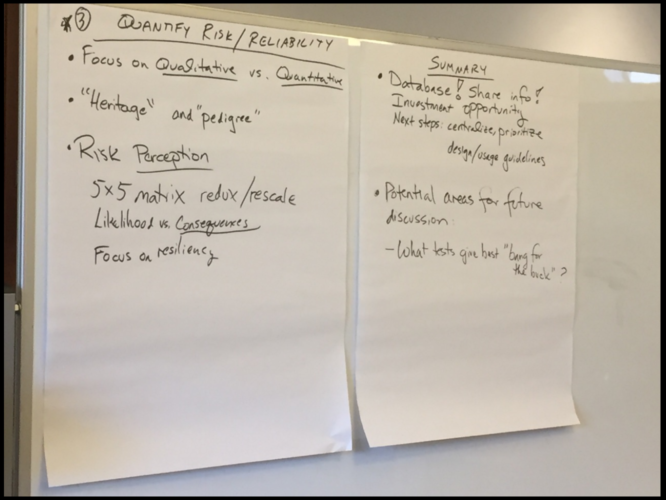
High Confidence

- You want a system and execution approach that generates HIGH CONFIDENCE when:
  - It is a single vehicle that has got to work (no opportunity to refly)
  - It is a multi-vehicle system that needs every vehicle to work (no vehicle redundancy, no opportunity for a second launch)
- You can achieve HIGH CONFIDENCE through various combinations of:
  - Part, component, and vehicle redundancy
  - EEE parts selection
  - Design practices and margins
  - Previous flight and system experience; heritage
  - Testing (HW and SW) and requirements verification
  - Spares policy
  - Design iterations (e.g. breadboards, engineering models, Qual units, flight units)

TIIM Findings, cont.

Finding: Focus on Mission Confidence Levels, cont.

Low Confidence

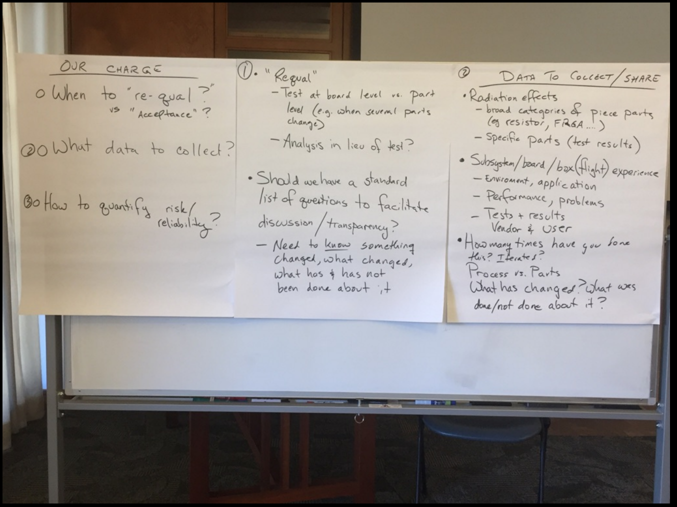


- You could say you have a system and execution approach in which there may be LOW CONFIDENCE when:
  - It is a completely new item (system, component, application, environment….) (aka low TRL)
  - It has not been analyzed or tested
  - Operational environment is unknown (e.g. launch vibe, radiation) or unproven (e.g. first flight of launch vehicle)
- Proceeding with a LOW CONFIDENCE approach or component can be acceptable when:
  - It is a demonstration or prototype
  - It is "inexpensive" and another can be made
  - Re-flight is readily available (fly-fail-fix-fly again)
  - Time scales are "fast"

TIM Recommendations

Recommendations

- Reliability Subcommittee should:
  - Capture characteristics of missions / systems for which HIGH CONFIDENCE is expected
  - Capture characteristics of missions systems for which LOW or MEDIUM CONFIDENCE is acceptable
  - Outline priorities for increasing the confidence level of a component, system, or approach



- Proposed output (Guideline Document):
  - Decision criteria for when to use Guidelines as opposed to NASA and other Standards (7120, INST-002…)
    - Some missions, especially NASA deep space, may use CubeSats / SmallSats but effectively still be "Class D" or above (?)
  - Focus on RAPID SPACE
    - Fast, cheap, "failure is acceptable" missions

Take Homes

“SmallSat” and “credible science” are consistent.

However… CubeSat reliability is a barrier to achieving full SmallSat potential.

- The public-private Reliabilty Initiative targets this challenge
  - Must fix it without diminshing SmallSat advantages
  - Novel approaches are waiting to be discovered or employed
- CubeSat advancement will impact SmallSats
  - SmallSats could be developed using CubeSat components and subsystems, but will not have the CubeSat form factor
- SmallSat advancement will impact large satellites

Disruption is ongoing

Thank you.

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