Jet Propulsion Laboratory
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Mission Assurance 2.0 - S&MA in the SmallSat Paradigm

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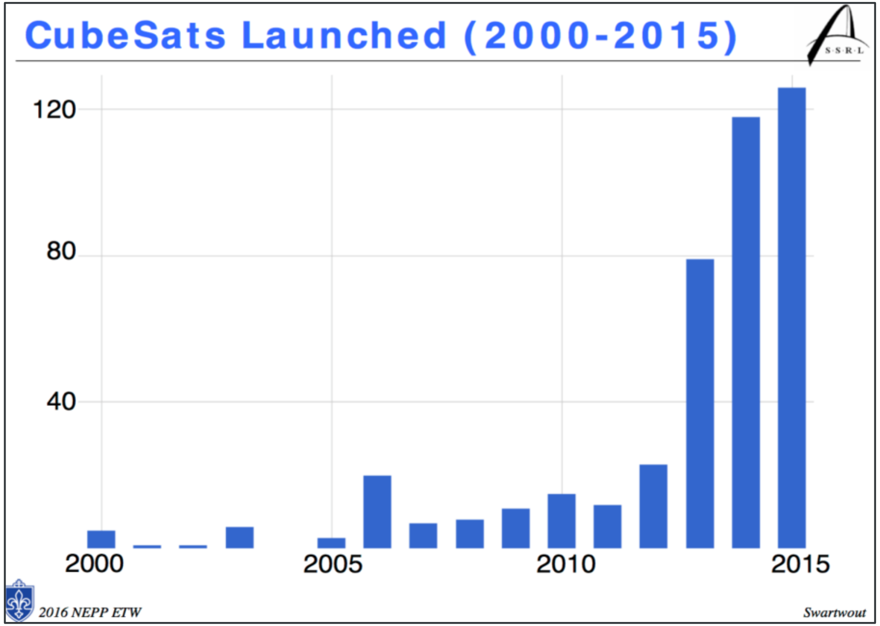
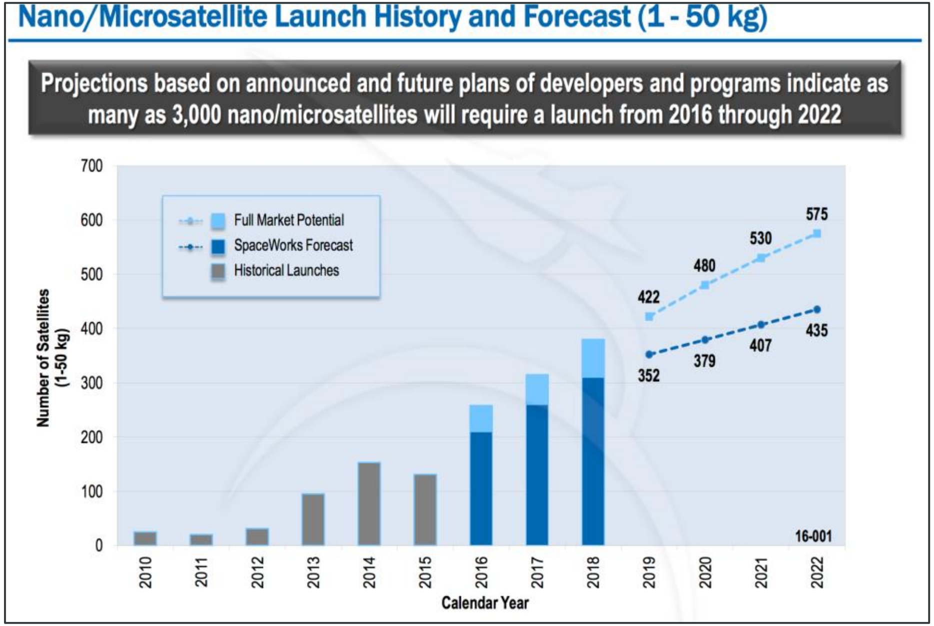
Overview

- SmallSat Market
- Quality and Reliability for Spacecraft Classes
- Mission Assurance Structure
- Comparison of Mission Assurance Across Mission Classes
- Highlights of Recent Mission Activities at JPL
    - EEE parts comparison
    - Inspection analysis
- Conclusions

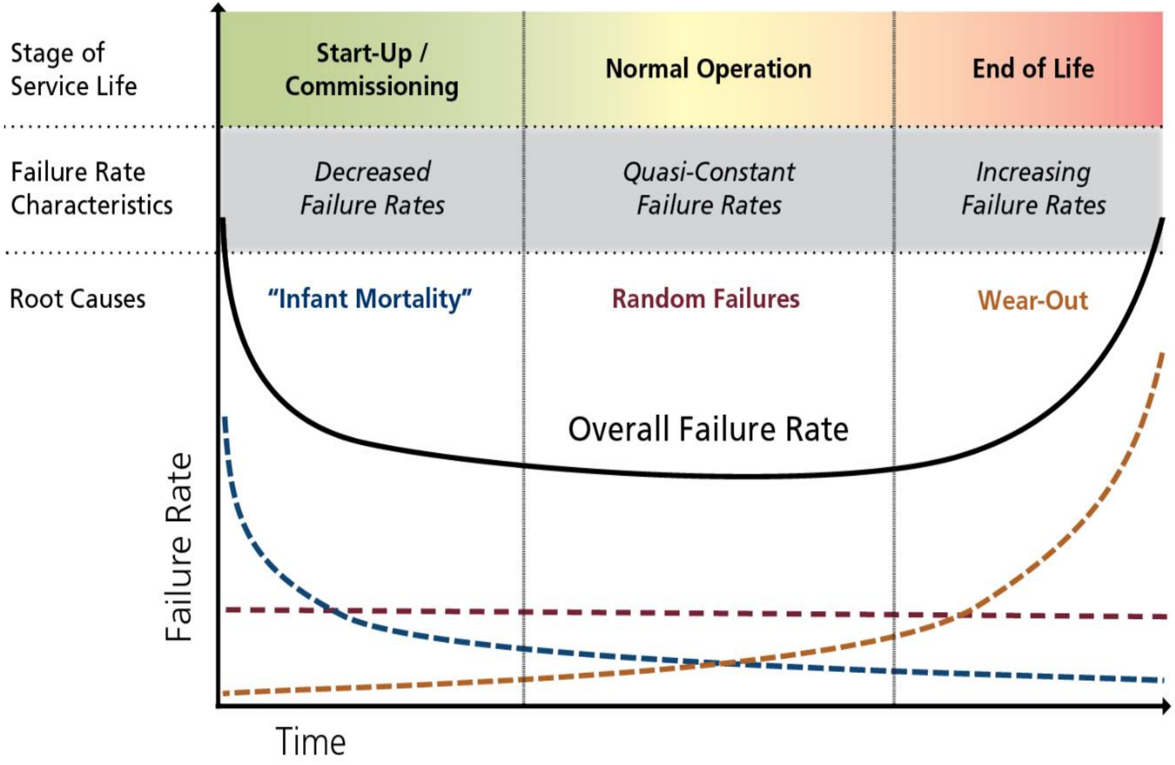
Summary of Cube/SmallSats so far…and into the future





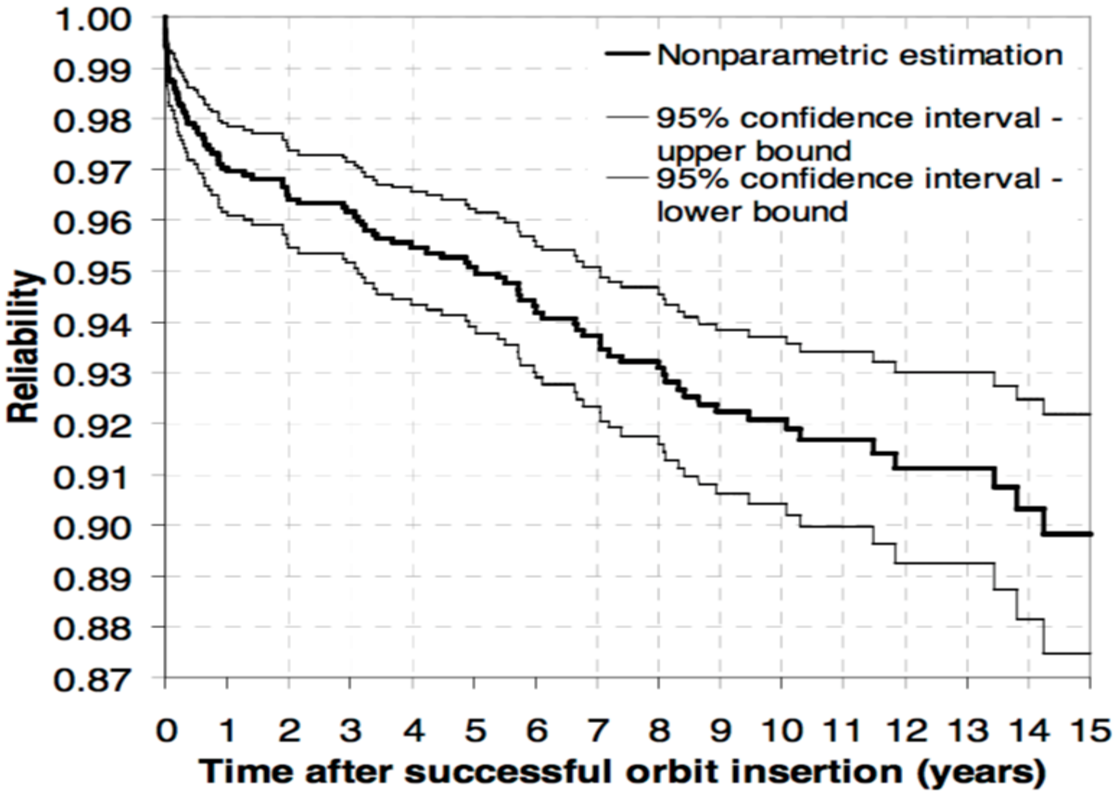
- Significant growth in number of launches expected through end of decade
- Smallsat trend is away from technology demonstration towards commercial remote sensing using constellations
- Large financial investments means higher expectations of performance and reliability

Quality vs. Reliability



- Quality issues (defects) are the root cause for infant mortality region
  - Manufacturing variation
  - Incoming material
  - Poor design margin to variation
  - Early sensitivity to application of voltage/temperature/current
- Reliability issues (wear-out) drive end of life region
  - Physics of failure related
    - Dielectric breakdown
    - Electromigration
    - Etc..

Reliability of “heritage” satellites > 100kg



- Total sample size = 1584
- >99% operational at time of launch
  - (<1% DOA / Early Fails)
- Continued decreasing reliability as time increases

Jean-Francois Castet and Joseph H. Saleh. "Satellite Reliability: Statistical Data Analysis and Modeling", Journal of Spacecraft and Rockets, Vol. 46, No. 5 (2009), pp. 1065-1

What about CubeSat reliability…?

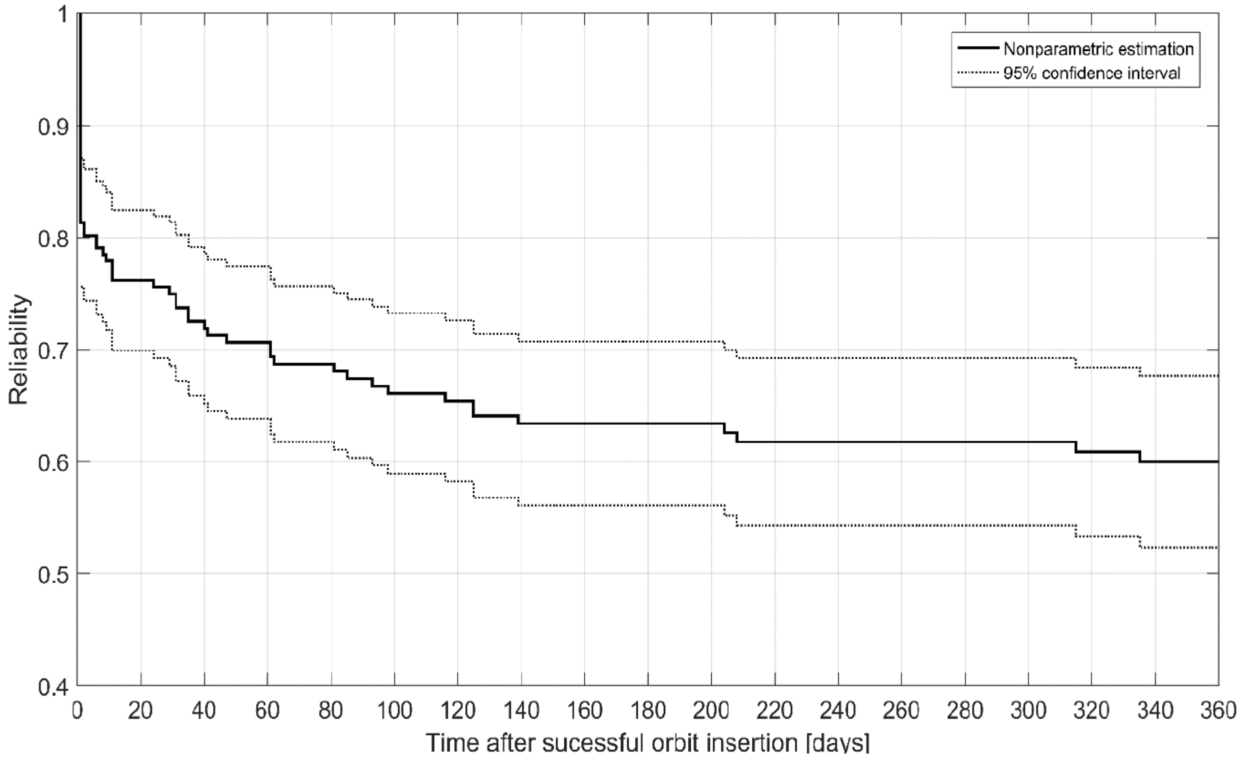
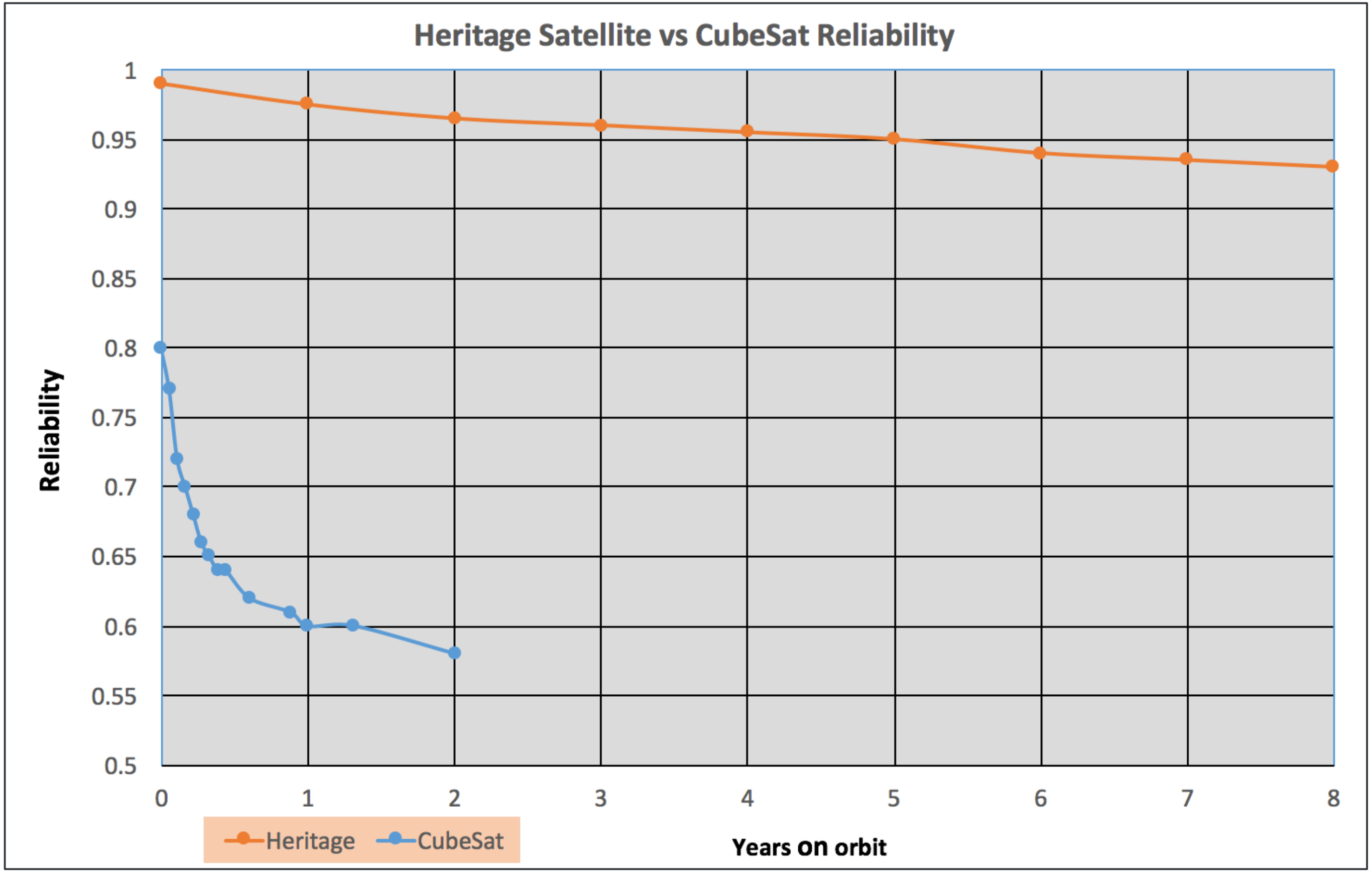


Figure 1: CubeSat reliability with 95% confidence interval – first year in orbit

Reliability of CubeSats – Statistical Data, Developers' Beliefs and the Way Forward, Martin Langer, SSC16-X-2 2016

- 178 CubeSats launched through mid-2014.
- Very steep initial drop in reliability => large number of deployment/DOA failures
- Reliability continues to decrease with increasing time

Heritage and CubeSat Reliability Plotted on Same Curve



- Both CubeSat and Heritage show *decreasing* reliability with *increasing* time
- Failure Rate, $\lambda(t)$, for both Heritage and CubeSat *also* decreases with increasing time
- Implies both types of missions in a failure regime dominated by *defects* in design, materials, and variation
- Increasing failure rate with time (ageing/wear out) is not seen
- ***Importance of mission assurance to address defects and quality related issues***

$$\lambda(t) = \frac{f(t)}{R(t)}$$

Mission Assurance Flight Project Practice (FPP) Structure

				FPP				
Section	Title	Total		Policy	Requirements	Standard	Procedures	Guidance
7.1	Mission Assurance Management	5					MA approach and budget, MA Program implementation, Assure Delivery Review	HW Review and Certification, QA for HW/SW Review, MAM Handbook
7.2	Reliablity Engineering	10			Reliability Assurance			Reliability Analyses for FHW, System Fault Tree, Fault Tree Handbook, PRA Procedures
7.3	Quality Assurance	9					Plan Project QA, Handling etc. of Criical flight HW, HW Inspection, QA responsibility for ATLO, QA Contractors	
7.4	*Deleted*							
7.5	Electronic Parts	8			IPPR	PETS		Derating, PEMS
7.6	Problem Reporting	16				Anomaly Resolution		
7.7	Mission Operations	3						MAM Handbook
7.8	Systems Safety	6		System Safety	JPL Standard for System Safety		System Safety Surveys, Safety Complaince data package, System Safety Plan	Lab Laser Safety, Systems Safety Survey
	Total	57						

- FPPs are the framework requirements that form the structure of all missions
  - *Over 600 total*
- Mission Assurance discipline FPPs are organized into 7 main topic areas:
  - *MA Management*
  - *Reliability*
  - *Quality Assurance*
  - *EEE parts*
  - *Problem Report*
  - *Mission Operations*
  - *Systems Safety*
- Codified in a variety of different types of documents
  - *Different amounts of technical detail, waiver requirements, etc.*
- ***Smallsat missions require intelligent subset of FPP's for risk and cost management***
- ***Emphasis on QA and EEE parts disciplines (and Safety)***

Class D/Tech Advisor Board (DTAB)

Define three types of projects:

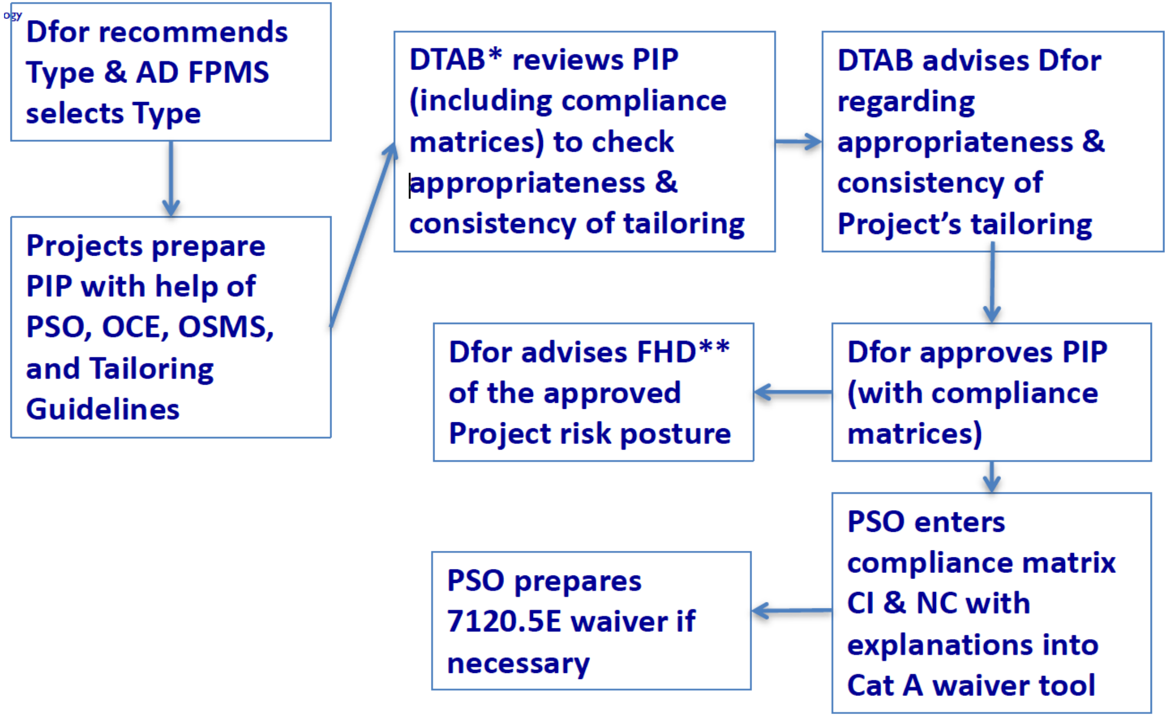
- Type I: Primarily contains *space flight* projects with NPR 8705.4 risk classifications A, B, & C.
- Type II: Primarily contains risk class D *space flight* projects, or other *space flight* projects that do not get risk classified (e.g. NPR 7120.8)
- Type III: Primarily contains projects that do not go into space (i.e., sounding rockets, balloons, aircraft payloads, and ground based projects)

DTAB process and FPP

	Type I	Type II	Type III
FPP/DP compliance attached to PIP	➢ Document on compliance matrices ➢ Cat A waiver required for non-compliances	➢ Document on compliance matrices ➢ Projects expected to comply with the intent (CI) of applicable requirements ➢ No waiver required for non-compliance, however, the matrices are archived in the Waiver A tool by the PSO	➢ N/A except for human safety
PIP signature	Programmatic Director For advised by - JPL CE - Dir For OSMS - Dir For ESD - Manager PSO	Programmatic Director For advised by - PEMC delegates (DTAB)	N/A
Subsequent FPP/ DP non-compliance	Cat A waiver*	Cat A waiver*	N/A except for human safety

* Cat A waivers process is defined separately (internal JPL document)

Type II Implementation



- Tailoring is the key concept
- Each mission has unique requirements, constraints, and risks
- Careful and disciplined approach to tailoring decisions and requirements is fundamental to successful Smallsat Mission Assurance program

* DTAB = Class-D/Technology Advisory Board, consisting of PEMC delegates

** FHD = JPL CE, Dir For OSMS, Dir For ESD, Dfor

JPL Directorate Staff

Mission Assurance Across different Class Missions

Cassini Mission to Saturn

Mission Attribute	MA Implementation
Mission Class	Class A
Architecture	Dual string, cross-strapped architecture, few Single Point Failures Graceful degradation Multiple combinations of instruments to meet mission success
Lifetime	11-year prime mission, 9-year extended mission Class S parts, extensive parts qualification program Thorough reliability analyses and review
Environments	Outer planet, high radiation (~100 krad TID) Increased margins testing (thermal, lifetime) Tests at assembly, subsystem and system-level
Inheritance	Little inheritance Extensive HQA presence at JPL and vendors, extensive MIPS program

Mars Science Laboratory - Mars Surface Rover Mission

Mission Attribute	MA Implementation
Mission Class	Class A/B
Architecture	Dual string, Block-redundant, limited cross-strapped architecture, few Single Point Failures Multiple combinations of instruments to meet mission success
Lifetime	23 month prime mission, 3+ year extended mission Class B+ parts, full lifetime and environmental parts assessment Thorough reliability analyses and review
Environments	Daily deep thermal cycles Significant component thermal cycle testing (thermal lifetime) Tests at assembly, subsystem and system-level Low TID radiation (<10 krad)
Inheritance	Little-no inheritance Extensive HQA presence at JPL and vendors, extensive MIPS program

Soil Moisture Active Passive Earth Orbiter

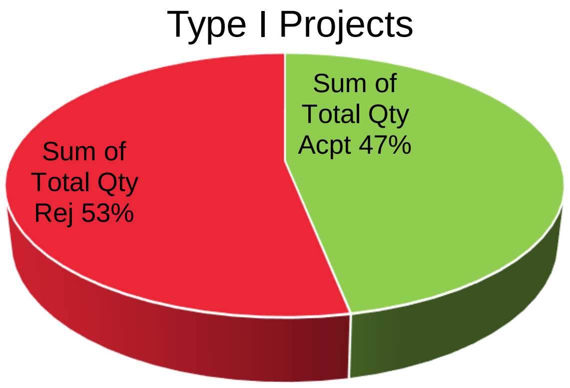
Mission Attribute	MA Implementation
Mission Class	Class C
Architecture	Single string with selected block redundancy Two instruments share key single string elements; both required to meet mission success
Lifetime	3 year prime science mission Class B parts Selected reliability analyses and review
Environments	Earth orbital shallow thermal cycling Limited component thermal cycle testing Tests at assembly (limited), subsystem and system-level Low TID radiation (<10 krad) South Atlantic Anomaly
Inheritance	Significant inheritance on Engineering hardware and software Moderate HQA presence at JPL and vendors, reduced MIPS program

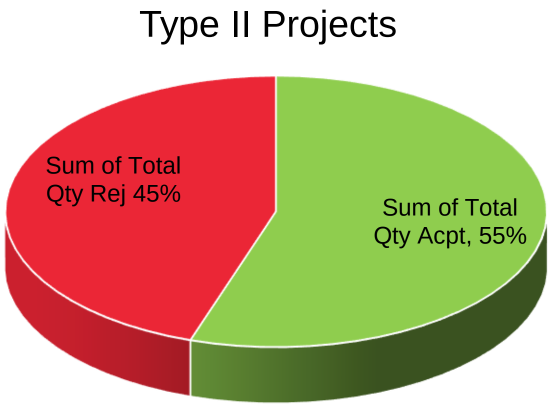
Lunar Flashlight Cubesat Technology Demonstration Mission

Mission Attribute	MA Implementation
Mission Class	Class D, Technology Demonstration
Architecture	Single string cubesat
Lifetime	8 month prime deep space mission Mix of screened COTS and formal Rad tolerant parts Destructive SEE parts assessment & TID analysis and measurement No reliability analyses and review
Environments	Deep space thermal cycling Workmanship test at system-level Board/system level TID assessment Low TID radiation (<10 krad)
Inheritance	Some cubesat components inherited Very limited HQA presence at JPL, vendors have some heritage, no MIPS program

Case Study – Type I vs Type II - HQA In-Process/Testing Inspections

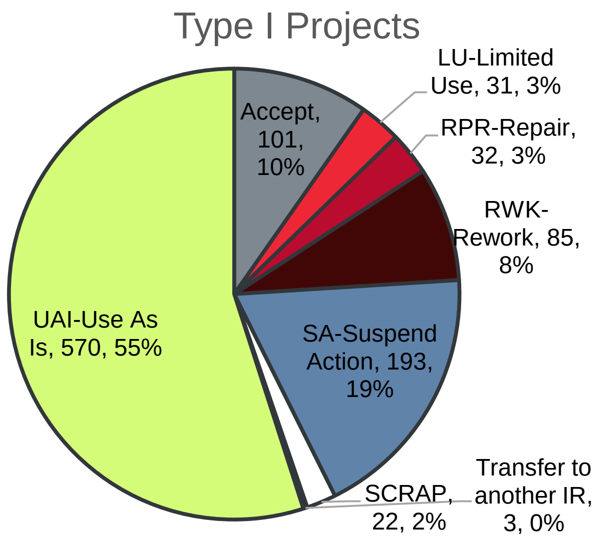
Part Quantity Rejected/Accepted

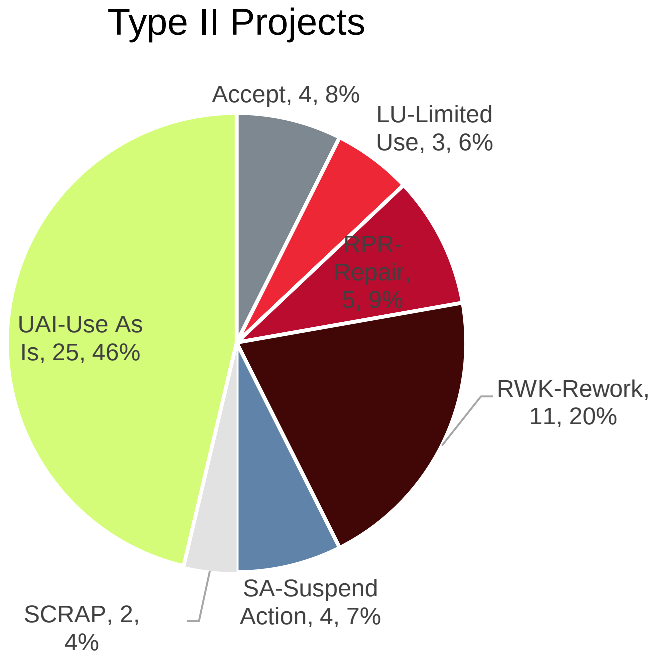




- Percentage rejection rate higher for Type I => additional requirements
- However Type II rejection rate is still significant
- HW used by Type II projects is **not** significantly lower quality (higher defectively)

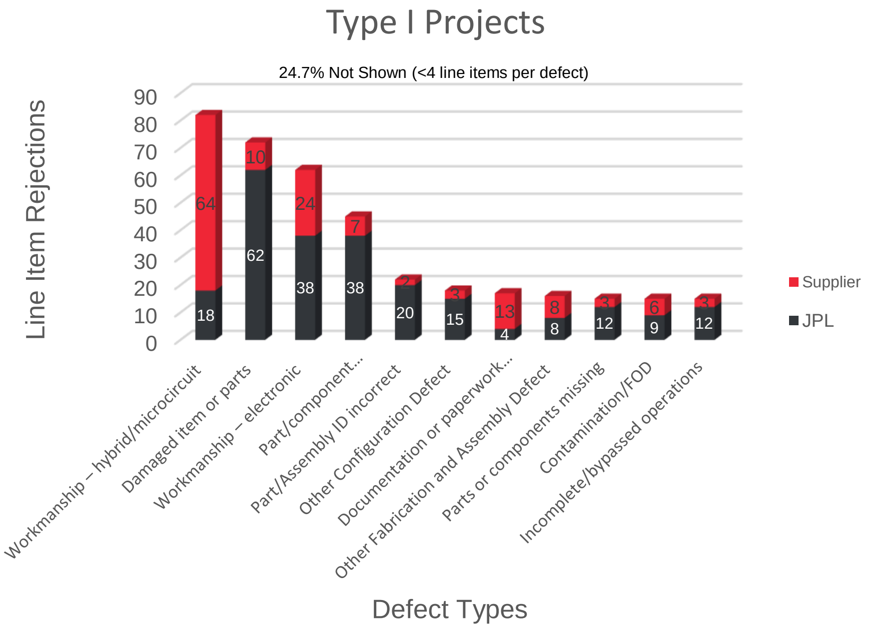
HQA In-Process/Testing Inspections
Dispositions of Rejected Line Items

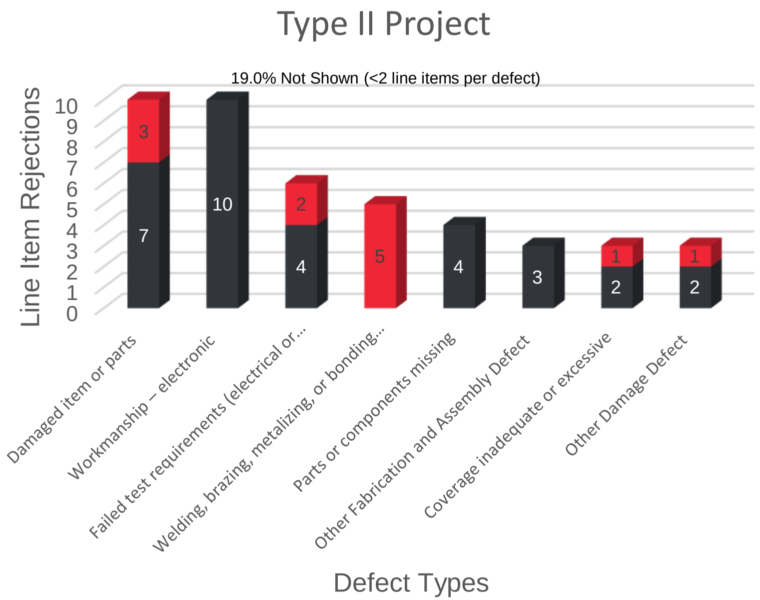




- Type II projects tend to scrap and/or rework more than Type I

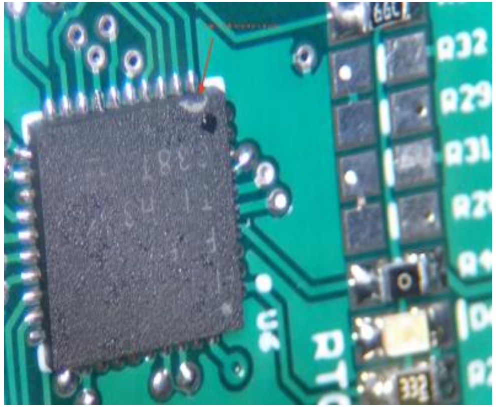
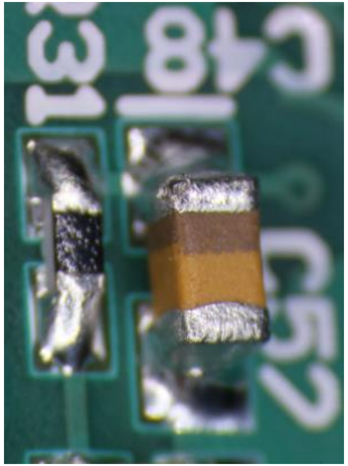
High-Impact HQA In-Process/Testing Defects
with LU/RTV/RPR/RWK/SCRAP Dispositions





- Defects are dominated by workmanship and damage
- Formal defect reduction plans and overall process capability improvement (both internal and external) required

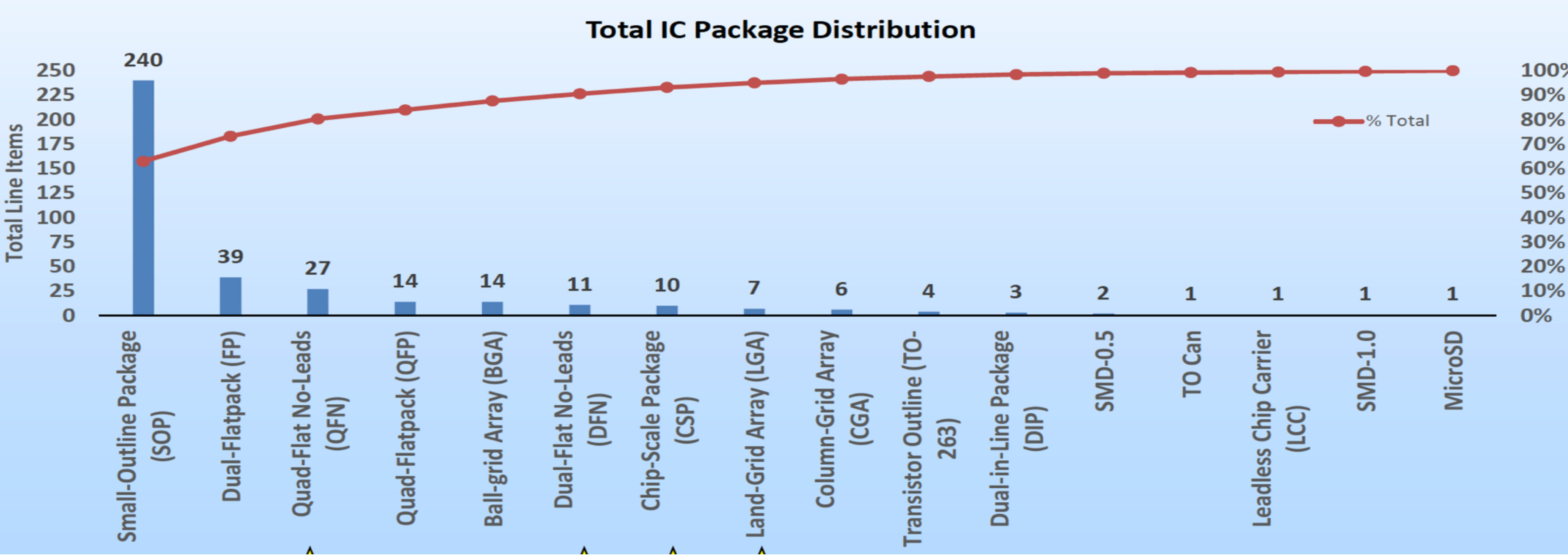
Examples of Type II Defects

Type of Defect	Use-As-Is Disposition Pulled from QARS	Rework Disposition Pulled from QARS
Damage	Damage found on microcircuit. Damage is contained within the package and does not appear to start a crack in the package but more like a chip-out 	C52 has a gouge out of the end cap. Remove and replace C52 with a new part. 

NASA NEPP CubeSat Parts Data Base

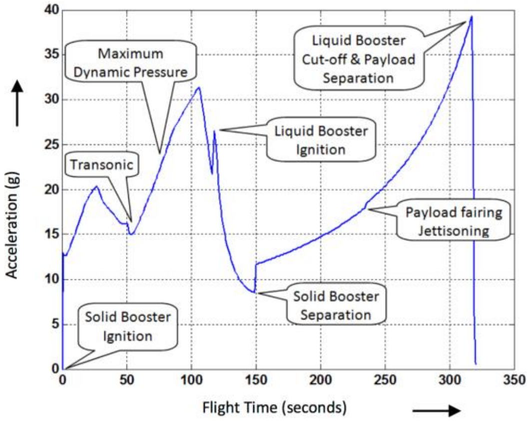
- > 2200 individual lines of data
  - Line = Part and corresponding part number
- Consistent trends
  - 33% of total parts are common to at least two or more board designs
  - ~98% of parts are rated for industrial (-40C to 85C) or more temperature
- Almost all passives are SMD 0402 or larger
  - Only 25 parts are listed as SMD 0201, nothing smaller
- Approximately 33% of passives are qualified for automotive use (AEC-Q200)
  - 30% of passives are manufactured by non-QML vendors
  - Polymer tantalum capacitors are 33% of all tantalum capacitors
    - (Special attention required due to moisture sensitivity)

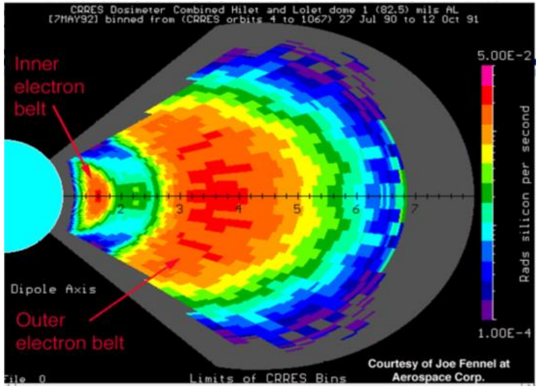
Types of IC Packages used in NASA NEPP CubeSat database

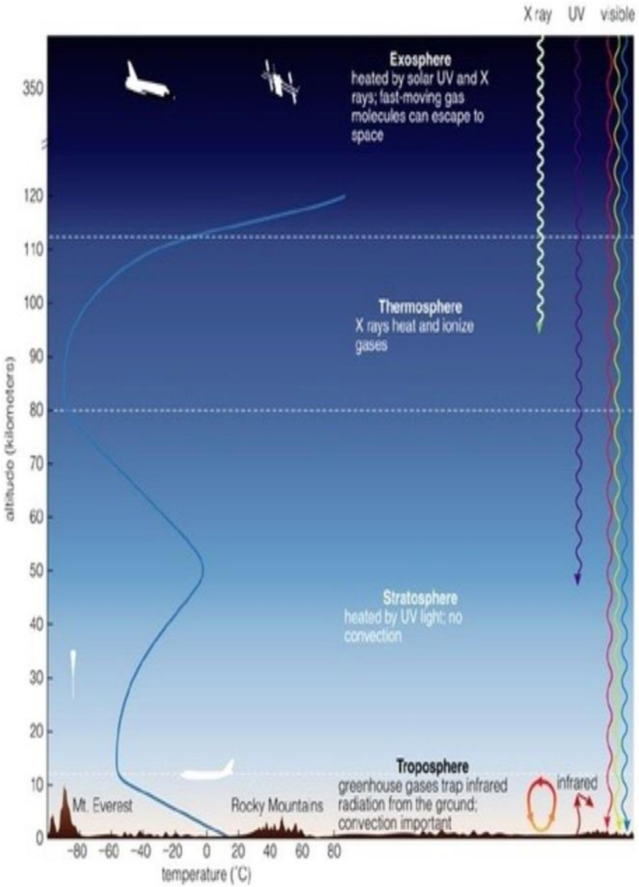


- SOP package types completely dominate
- Being able to handle and process these types of packages will substantially improved quality

Spacecraft Environment Stress



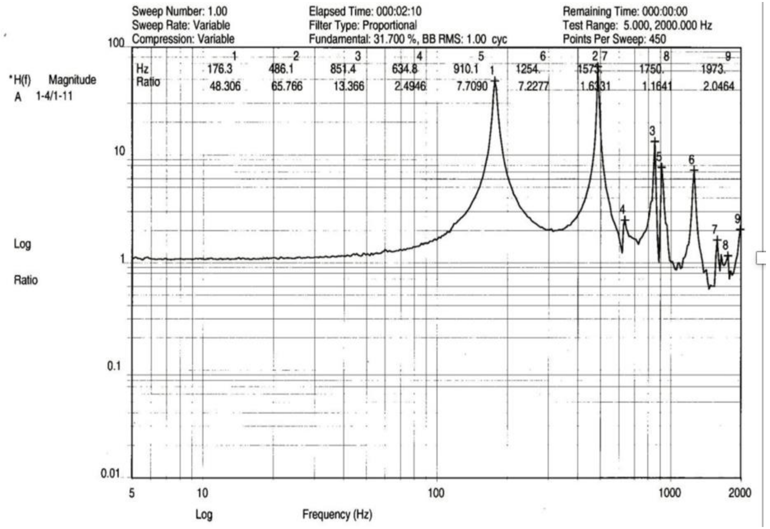


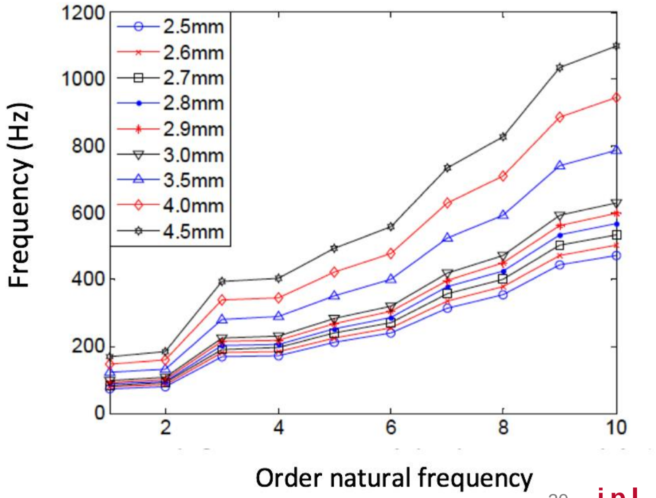


- Mechanical, temperature and radiation effects will stress entire system and magnify weakness associated with defects
- CubeSats design practices and assembly operations must take these into account.
- Cannot be ignored simply to save cost

Designing in Quality

- While inspection and verification remain at the heart of identifying and reducing defects, the initial design effort is the key to identifying sensitivity and building in margin to defects
- Mission Assurance evolving to more part of early phase design decisions
  - Example – simulation of PCB mechanical vibration frequency modes
    - Use of thinner/smaller scale COTS can provide significant increase in margin to mechanical vibration





Summary

- Small/CubeSats face many of the same defect based quality issues that larger heritage missions face
- **This results in significant decrease in satellite reliability as mission time increases**
- Small/CubeSats still require a formal FPP based design methodology
  - Tailoring FPP to Small/CubeSat is key contribution/collaboration of S&MA
- **Emphasis on defect identification and elimination throughout entire assembly and manufacturing processes (internal and external) is where S&MA discipline can be best leveraged to maximize risk mitigation effect for Small/CubeSats**
- Developing and supporting the use various types of sensitivity analysis early in the design phase are areas for future evolution of S&MA discipline

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