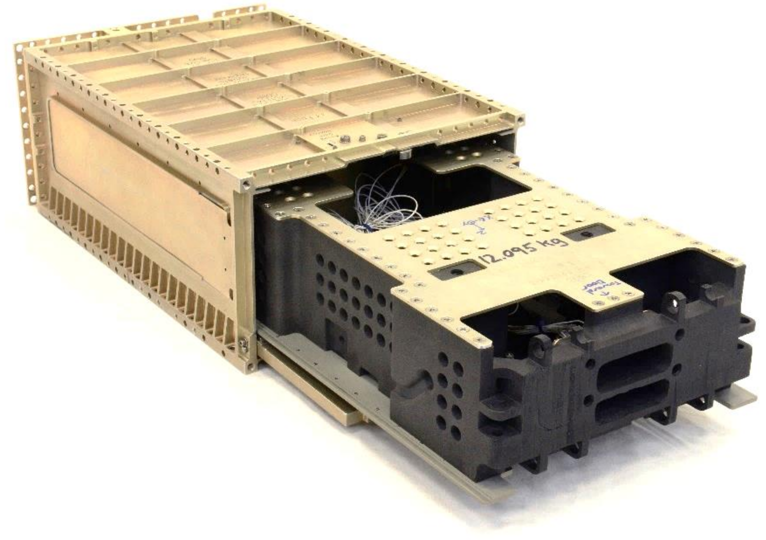
Design and Test Methods to Increase Mechanism Reliability in CubeSats

- Walter Holemans and Ryan Williams
  - We make mechanisms that separate satellites from launch vehicles

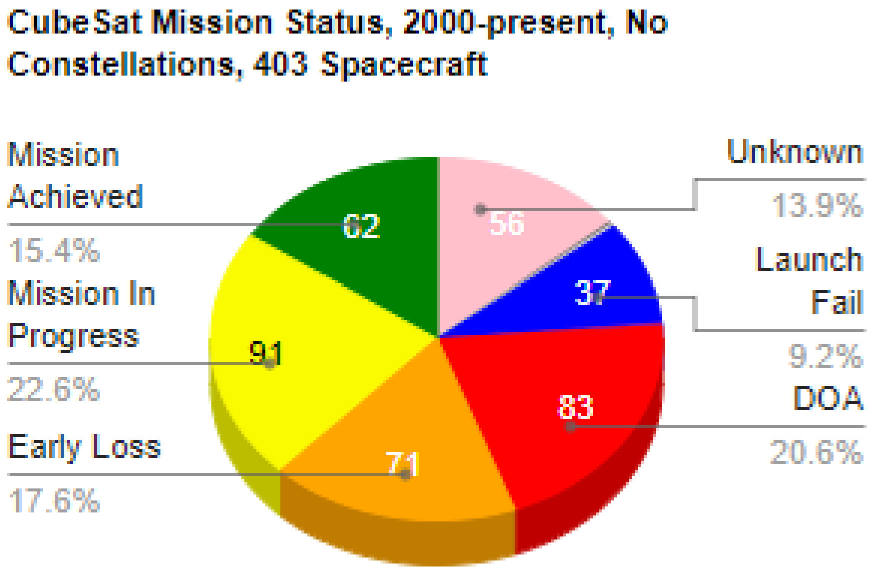


Canisterized Satellite Dispensers (CSD)

Advanced Lightband (ALB)

The Reliability Problem

- 61 years after the beginning of the space age, the reliability of space systems remains five orders of magnitude below aircraft systems
- It may be getting worse--in the past year:
  - – Launch services
    - Dispensed satellites into the wrong orbit
    - Launch to the wrong orbit
    - Inadvertently de-orbit their payloads
    - Fail to dispense their payloads
  - – In one constellation, all the spacecraft failed
  - – Unlicensed spacecraft
  - – Lost spacecraft
- Failed CubeSats are space debris that tax future missions



CubeSats fail more often than they succeed

(Ref 1)

Why might space systems be unreliable?

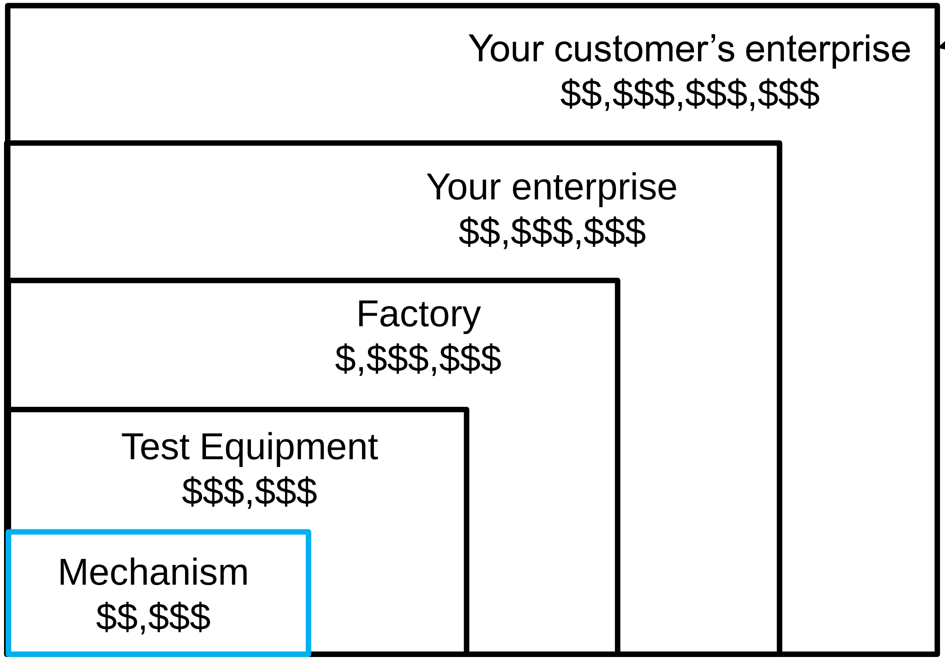
- Failure is normalized
  - “Spaceflight is the reliability test”
  - “Our products fail because space is tough”
  - “At best, the satellite will last a week on orbit”
  - “In past launches the foam impacts on the orbiter did not cause issues”
  - “I’m glad the rocket failed, because the satellite wasn’t going to work”
- Cash flow pressures starve developers of time and money
  - Managers gamble with unverified hardware to avoid cancellation
- Developers overestimate the utility of “new ideas” and minimize contrary results from the past
  - “Everything NASA does is wrong”
  - “Jiggling spacecraft is a feature, not a problem”
- A development success is scaled to “operational” systems
  - Scaling it before nailing it
- Failure is hidden
  - preventing others from learning how to avoid a repeat
- Reliability specification is absent

Solutions

- Take responsibility
- Learn from the past
- Specify Reliability
- Minimize the design
- Emulate flight boundary conditions
- Thermal vacuum chambers
- Airborne Tests
- Design for ground testing

Take responsibility

- If you want to do great things in space, first you must master mechanism design and test



Your customer’s enterprise
$$,$$$,$$$,$$$

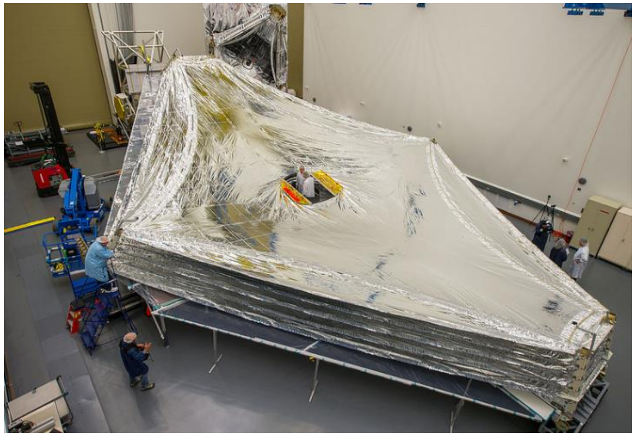
Your enterprise
$$,$$$,$$$

Factory
$,$$$,$$$

Test Equipment
$$$,$$$

Mechanism
$$,$$$

“The James Webb Space Telescope will be a giant leap forward in our quest to understand the Universe and our origins.“
(Ref 6)



Do the engineers know if the mechanism reliability will enable the objective?

Learn from the past

- Read the voluminous public documentation of past success and failure
  - They exist to inform you
  - Reading is more cost effective than mission failure
- European Space Mechanisms and Tribology Symposium (EMATS) and Aerospace Mechanism Symposia (AMS) are examples

Specify reliability

- Choose the number of no-fail tests based on your reliability and confidence requirements
- We recommend > 0.999
  - though > 0.9 would be an advancement for the CubeSat industry

Number of no-fail tests =
log(1-confidence level) / log (reliability)
(ref 2)

	Confidence level (the likelihood the reliability is greater)	
Reliability	**0.5**	**0.95**
0.999999	693,147	2,995,731
0.99999	69,314	299,572
0.9999	6,931	29,956
0.999	693	2,994
0.99	69	298
0.98	34	148
0.97	23	98
0.95	14	58
0.9	7	28
0.8	3	13
0.7	1.9	8
0.6	1.4	6
0.5	1.0	4

Landing gear

Soyuz-FG →

Current Launch vehicles
(ref 5)

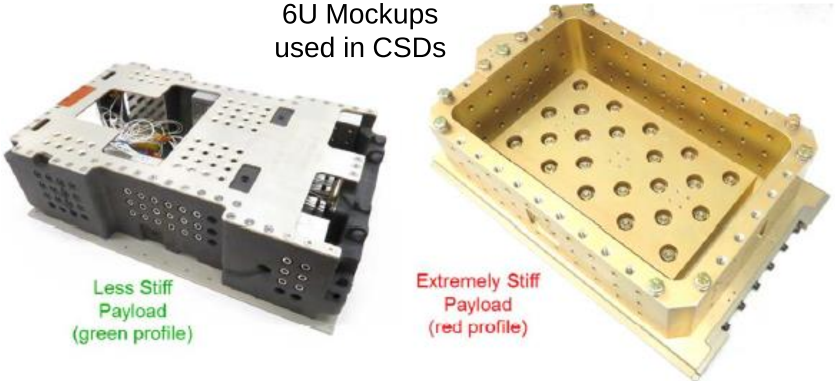
A mechanism that meets specification on its first attempt has a reliability of 0.5, and you are somewhat confident it is at least that. In other words: it can work.

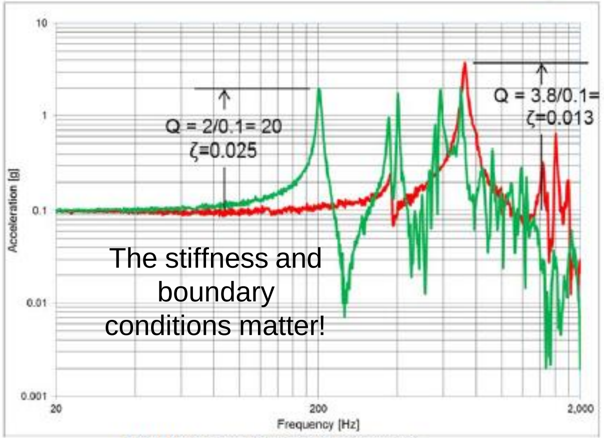
Minimize the design

- Eliminate or minimize your design
  - Often it is less costly to have a larger fixed solar panel than to deploy or articulate a panel
- Will redundancy be worth the added cost?
  - Redundancy increases cost and decreases reliability knowledge
    - If you have budgeted for 100 tests and have a single string design, all your results will be applicable to a computation of reliability
      - With a redundant system you must additionally verify that the failed primary will not inhibit the successful back-up. That can double or triple the number of test to attain the same reliability knowledge
  - Automobiles, which are orders of magnitude more reliable than spacecraft and are ‘Man rated’ don’t have redundancy!
    - But they are exquisitely fault tolerant

Emulate space-flight boundary conditions

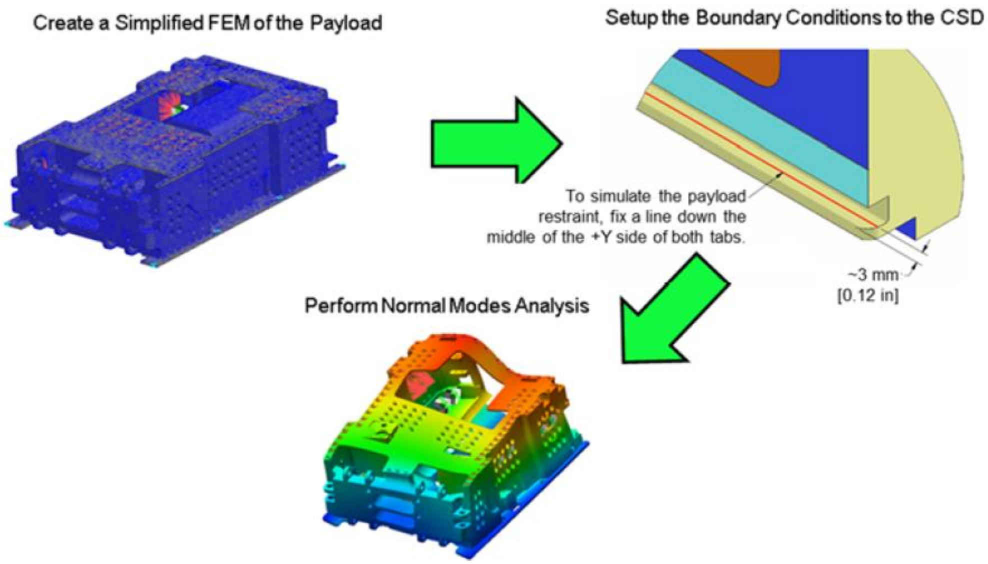
- Mass mockups that respond like the flight vehicle may be faithful enough to expose probable failure modes
  - So whenever you can, employ a spacecraft engineering development unit (EDU)
- Big blocks of aluminum, while inexpensive, have lower damping than real spacecraft and fewer modes
  - Cheap mass mockups can create unrealistic and destructive loading


6U Mockups used in CSDs



The stiffness and boundary conditions matter!

Figure 10-1: Comparison of payload responses

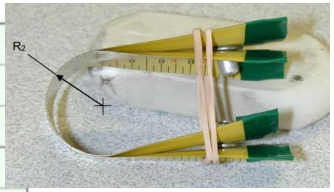


Accurately emulating boundary conditions is a substantial and valuable task

- Deploying in air is relatively inexpensive, but made useless by air damping and pumping
  - If no vacuum test was done, would the engineers know about a collision hazard from 90 degrees of over-travel?

Deployable, hinged solar sail

Figure 12. Original Deployment Fixture (In air)



A tape measure hinge is inexpensive. Measuring its reliability is a substantial task

Source: Ref 3

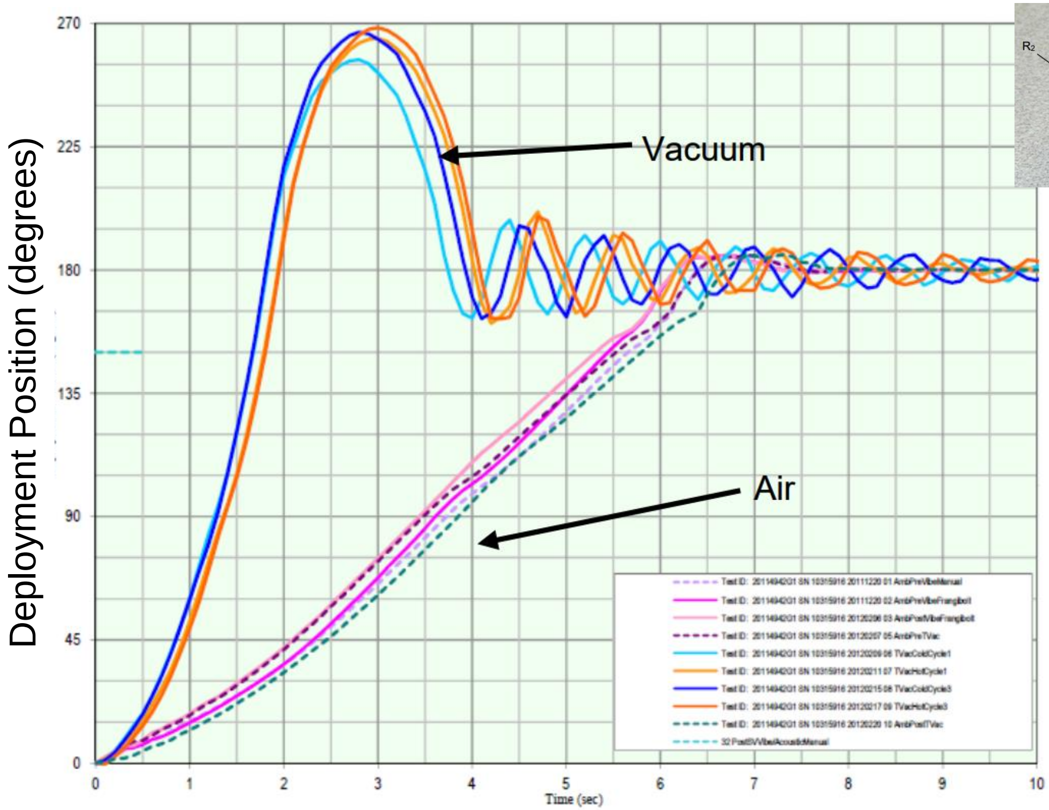


Figure 15. Mechanism Deployment in Vacuum and Air

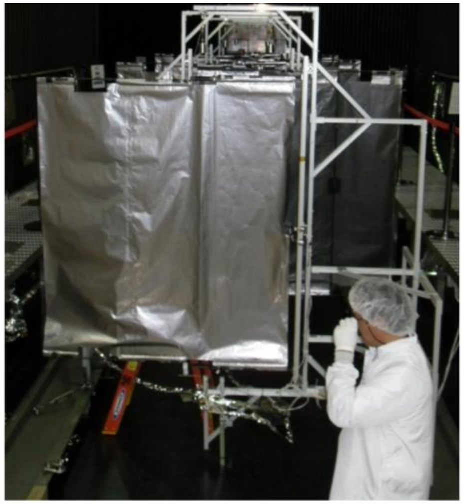


Figure 13. Deployed Hinges in Large Thermal Vacuum Chamber

Thermal Vacuum chambers are the most valuable verification tool

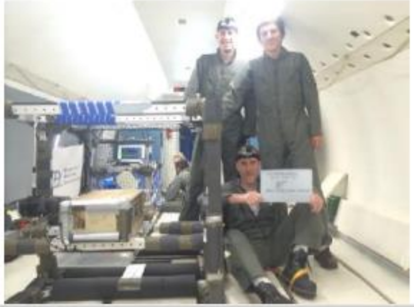
- Thermal vacuum chambers accurately emulate the space atmosphere and temperatures
- Because air is a coolant, a lubricant, a damper and has inertia it prevents credible verification tests
- Temperature induces expansion changes interface fit and pre-load which can cause force margins to become negative
- Temperature changes lubricant viscosity and force margins
- Gravity loads must be minimized, typically with off-loading structures
- To create many statistically useful results, mechanism reset cost must be minimized

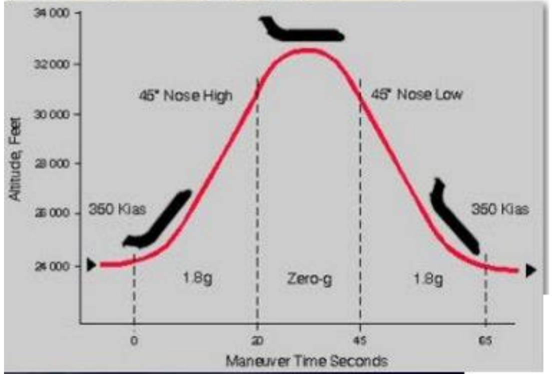
At PSC we can qualification test four test items simultaneously and autonomously in a custom made thermal-vacuum chamber

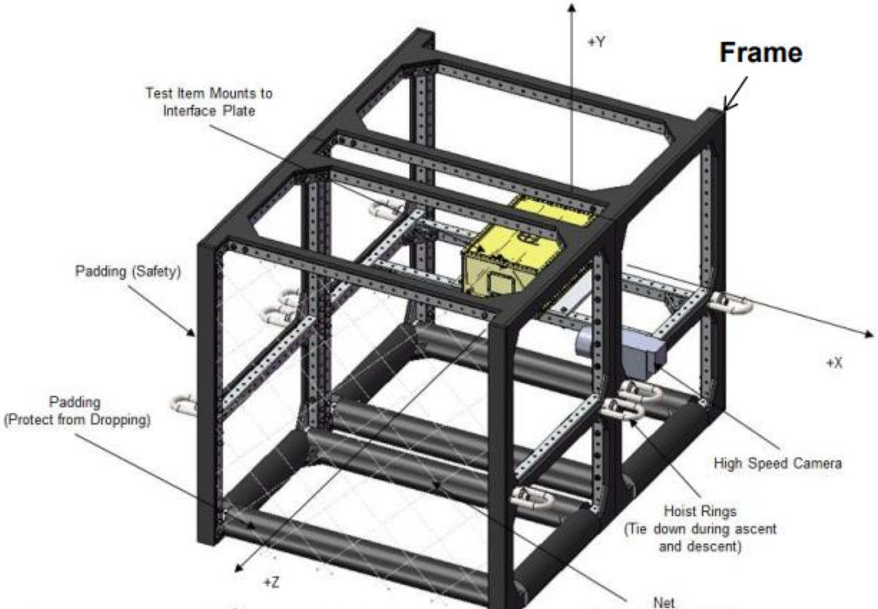
Figure 10-7: Thermal vacuum testing four CSDs in PSC's chamber. Conveyor rails allow complete payload dispensing.

Airborne tests

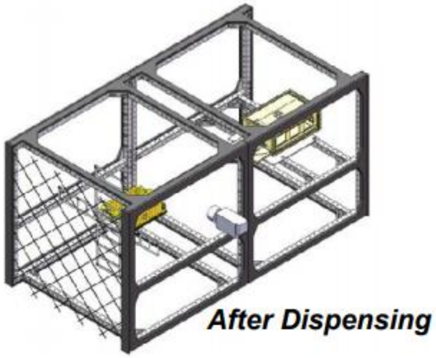
- A wonderfully informative experience for mechanisms engineers
- Removes the need for gravity nullifying fixtures
- Atmosphere is still present as a damper
- Initial rotation rates are about 6 degrees/second (aircraft pitch)

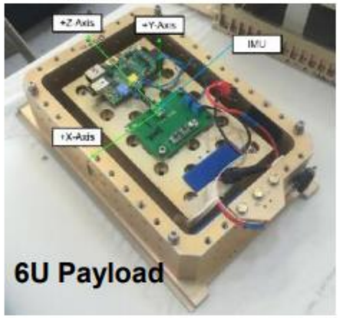






About $400K for 136 tests
(Ref 7)





Design for ground tests

- Design test fixtures and all procedures concurrently with the test item to avoid any ‘gotchas’
  - Like your Tvac chamber is too small
  - Or an accelerometer that is just too large
  - Or mechanism reset will take 100x longer
- Design your mechanism to be a cost effective reliability data generator
  - For example, you might add a rotary transducer to a hinge line so you can compute margin inexpensively
- Design-in accepting features for accelerometers, temperature sensors, gravity nullifying fixtures and robotic interfaces

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