Failure Analysis of a Composite Amateur Rocket Airframe

PNW AIAA Technical Symposium 2018

Risto Rushford Joseph Shields

Agenda

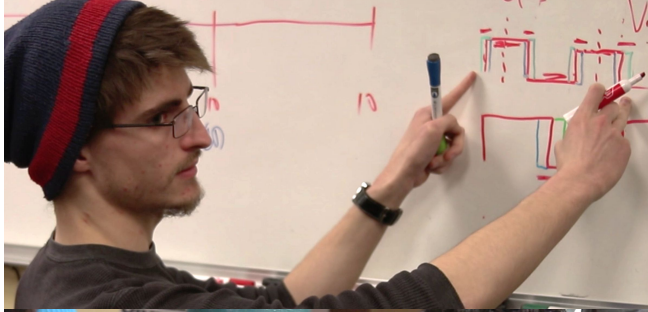
- ➔ Quick Intro to PSAS
- ➔ Strategic Projects
- ➔ Launch Vehicle 3.0
- ➔ Launch 13
- ➔ Failure Analysis
- ➔ Launch Vehicle 3.1

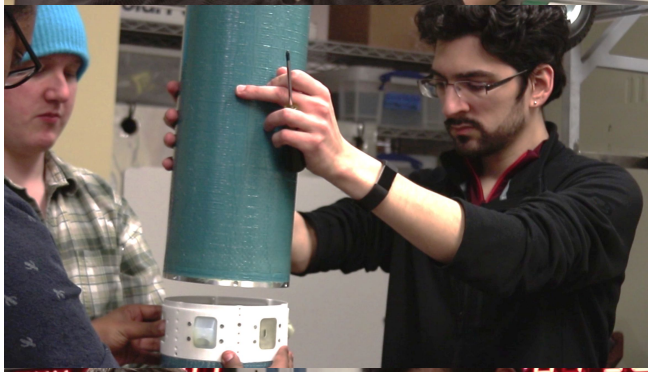
Introduction to PSAS

Portland State Aerospace Society

Rocket Science for Everyone

- ➔ *Interdisciplinary* extracurricular space program
  - ◆ Engineering, business, health, physics, film, education
- ➔ Undergraduates, Graduates and *Industry Advisors*
- ➔ Crowdfunded, and completely *Open Source*
  - ◆ GPL V2 and CERN Open Hardware



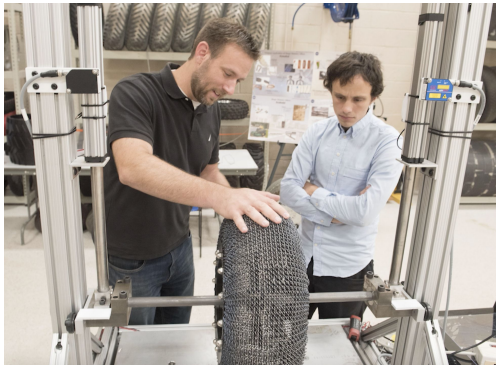


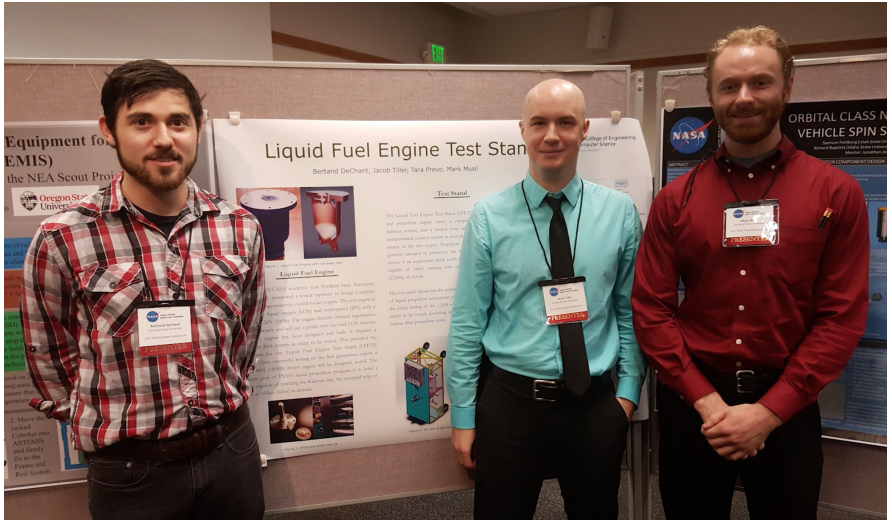
Portland State Aerospace Society

- **Vision:** Build a rocket capable of putting a 1 kg nanosatellite into low-earth orbit.
- **Mission:** We produce experienced college graduates using open source, team-based, interdisciplinary aerospace engineering projects.
- **Near-Term Goal:** Send a liquid-propelled rocket to 100 km. *Base 11 Space Challenge*

2017-2018 Student Placements

- PSAS builds rockets, satellites, and better engineering students!
- 3 internships with NASA
- 1 internship with CERN
- An increasing number of our alums are landing careers within the growing aerospace industry





2017-2018 Group Accomplishments

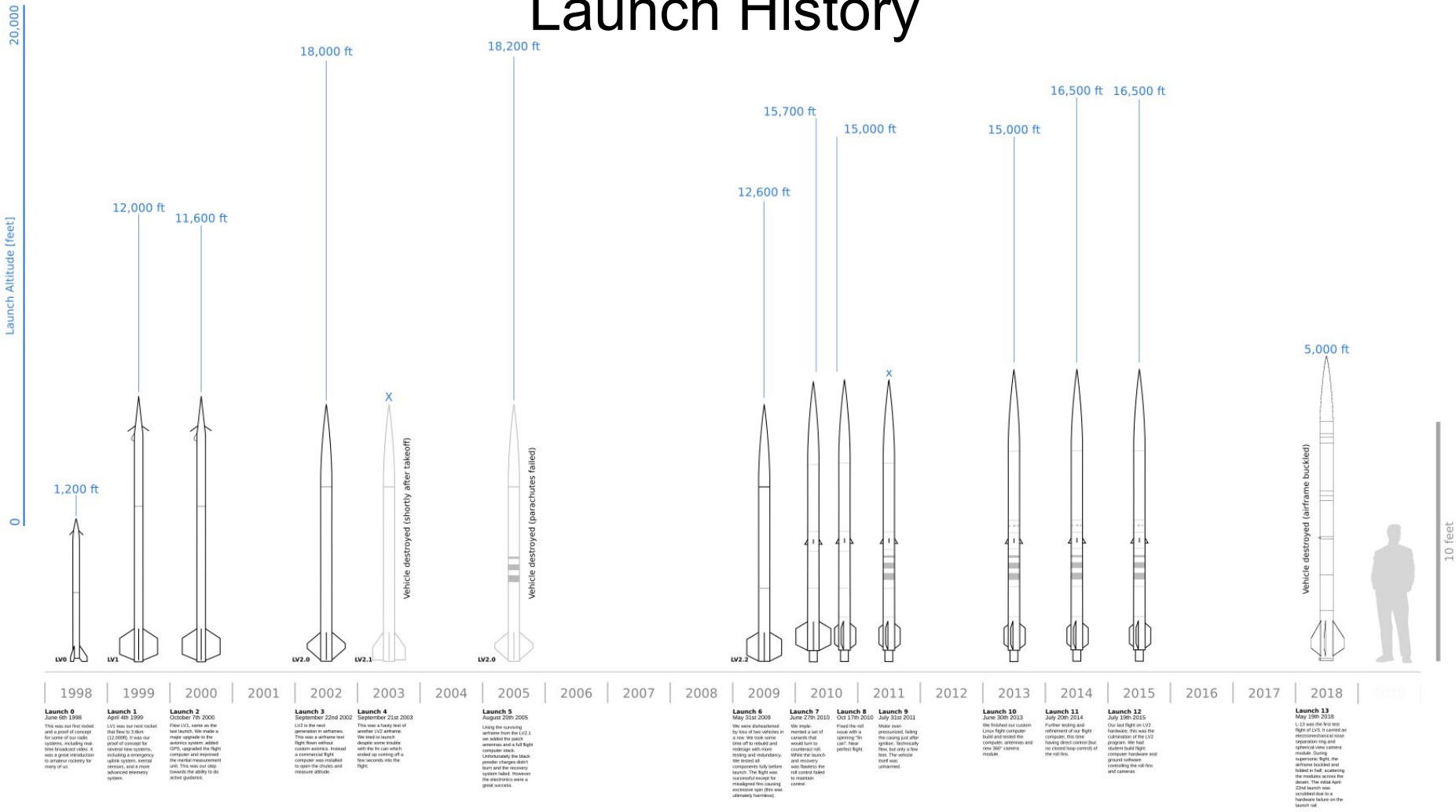
- ➔ Recognized as an official branch of AIAA
- ➔ Tabled at Daimler Days, Techfest NW
- ➔ Participated at Oregon Technology Awards
- ➔ Held successful “IPA for IPA” fundraiser ($1500 raised)

DAIMLER

TECHNOLOGY ASSOCIATION OF OREGON

TECHFESTNW

Launch History



Launch 0
June 6th 1998

This was our first rocket and a proof of concept for some of our radio systems, including real-time broadcast video. It was a great introduction to amateur rocketry for many of us.

Launch 1
April 4th 1999

LV1 was our next rocket that flew to 3.9km (12,000ft). It was our proof of concept for several new systems, including a emergency uplink system, inertial sensors, and a more advanced telemetry system.

Launch 2
October 7th 2000

Flew LV1, same as the last launch. We made a major upgrade to the avionics system: added GPS, upgraded the flight computer and improved the inertial measurement unit. This was our step towards the ability to do active guidance.

Launch 3
September 22nd 2002

LV2 is the next generation in airframes. This was a airframe test flight flown without custom avionics. Instead a commercial flight computer was installed to open the chutes and measure altitude.

Launch 4
September 21st 2003

This was a hasty test of another LV2 airframe. We tried to launch dimpple some trouble with the fin can which ended up coming off a few seconds into the flight.

Launch 5
August 20th 2005

Using the surviving airframe from the LV2.1 we added the patch antennas and a full flight computer stack. Unfortunately the black powder charges didn't burn and the recovery system failed. However the electronics were a great success.

Launch 6
May 31st 2009

We were disheartened by loss of two vehicles in a row. We took some time off to rebuild and redesign with more testing and redundancy. We tested all components fully before launch. The flight was successful except for misaligned fins causing excessive spin (fins was ultimately harmless).

Launch 7
June 27th 2010

We imple-mented a set of canards that would turn to counteract roll. While the launch and recovery was flawless the roll control failed to maintain control.

Launch 8
Oct 17th 2010

Fixed the roll issue with a spinning "fin can". Near perfect flight.

Launch 9
July 31st 2011

Motor over-pressurized, failing the casing just after ignition. Technically flew, but only a few feet. The vehicle itself was unharmed.

Launch 10
June 30th 2013

We finished our custom Linux flight computer build and tested the computer, antennas and new 360° camera module.

Launch 11
July 20th 2014

Further testing and refinement of our flight computer, this time having direct control (but no closed loop control) of the roll fins.

Launch 12
July 19th 2015

Our last flight on LV2 hardware, this was the culmination of the LV2 program. We had student build flight computer hardware and ground software controlling the roll fins and cameras.

Launch 13
May 19th 2018

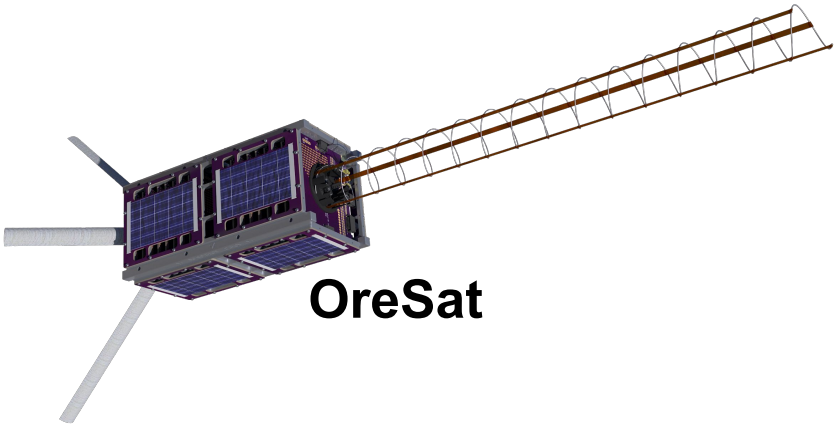
L-13 was the first test flight of LV3. It carried an electromechanical nose separation ring and spherical-view camera module. During supersonic flight, the airframe buckled and folded in half, scattering the modules across the desert. The initial April 22nd launch was scrubbed due to a hardware failure on the launch rail.

Launch History

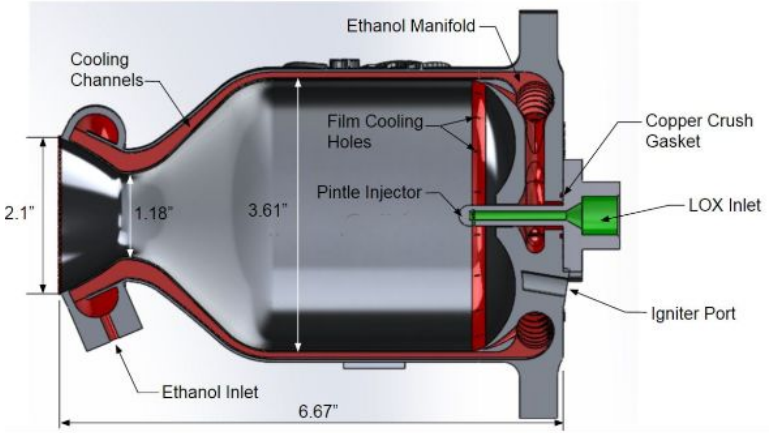
Portland State Aerospace Society on Youtube.com

PSAS Strategic Projects

PSAS Strategic Projects



OreSat



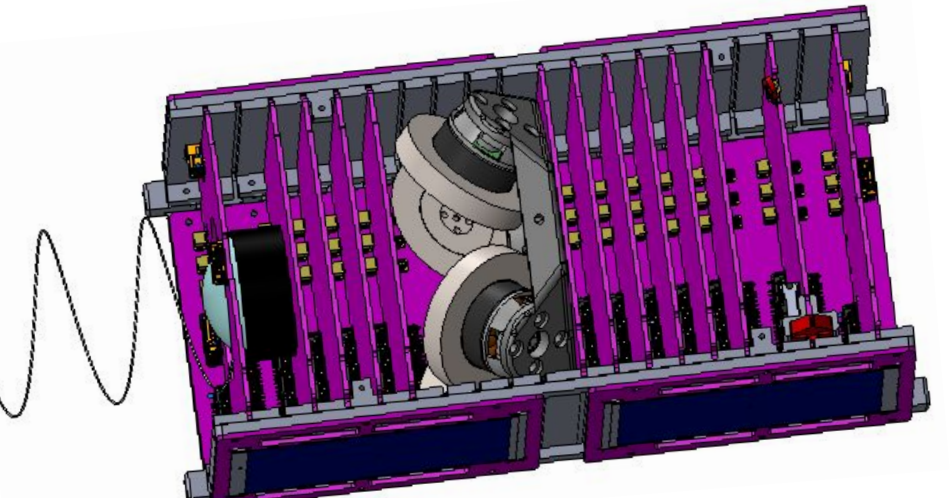
Liquid Fuel Engine

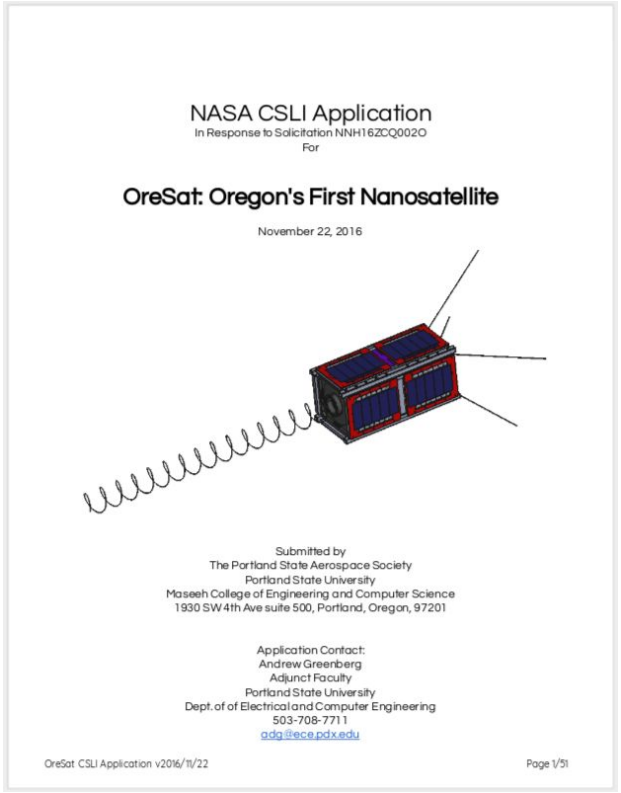
Launch Vehicle 3

PSAS Strategic Projects: OreSat

An artisanally handcrafted stellite from the State of Oregon

- ➔ Planned deployment from the ISS in 2020
- ➔ OreSat Live: STEM outreach to Oregon high school students
- ➔ Cirrus Flux Cam climate science experiment





NASA CSLI Application

In Response to Solicitation NNH16ZCQ002O

For

OreSat: Oregon's First Nanosatellite

November 22, 2016

Submitted by

The Portland State Aerospace Society

Portland State University

Maseeh College of Engineering and Computer Science

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OreSat CSLI Application v2016/11/22

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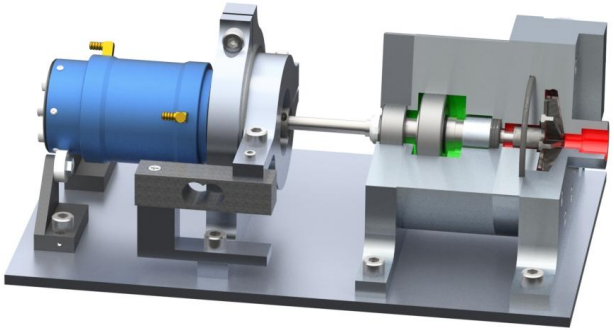
PSAS Strategic Projects: Liquid Fuel Engine

Our 100 km Rocket Technology Development Program

- ➔ Regeneratively cooled prototype engine
- ➔ LOX + Isopropyl alcohol (IPA)
- ➔ Liquid Feed System

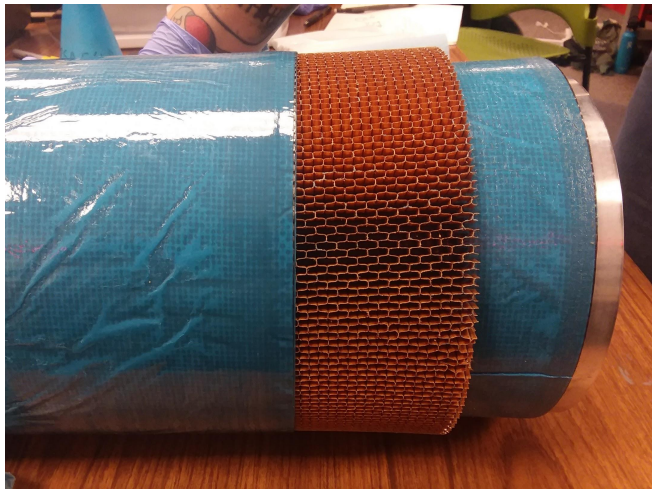


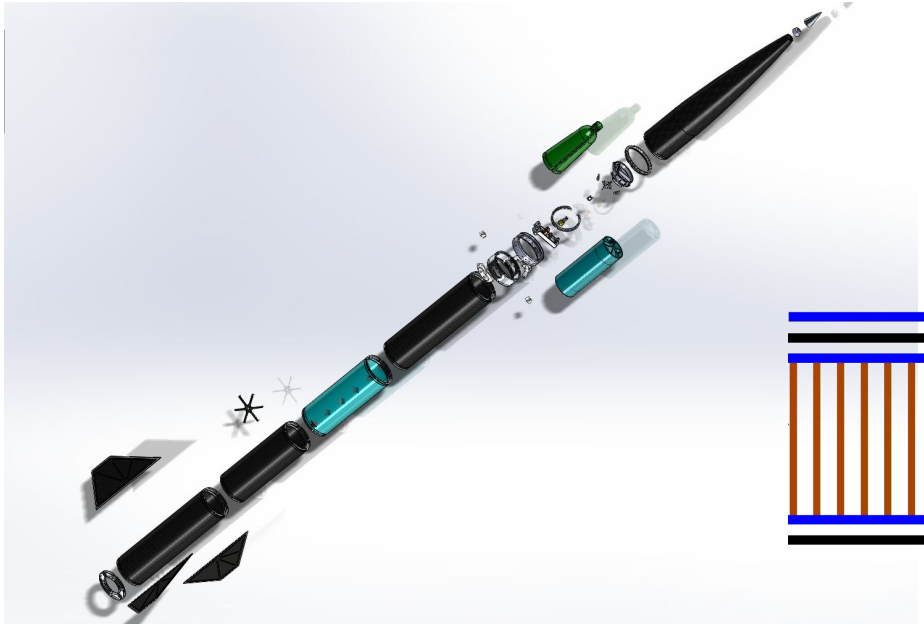
The basis for our entry into the Base 11 Space Challenge (University XPrize Competition)

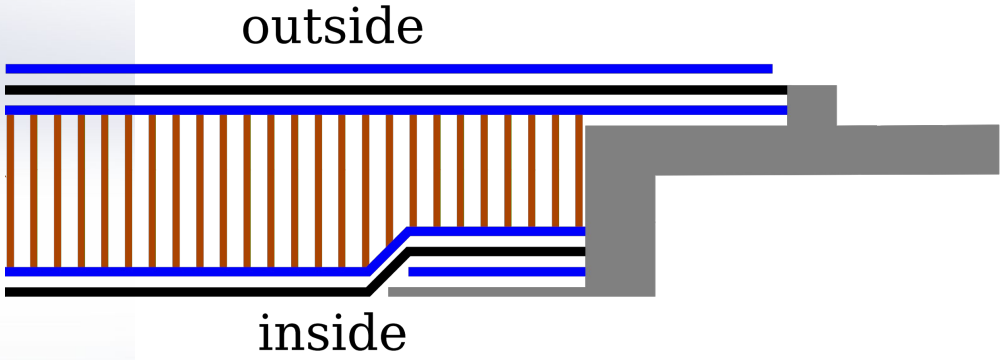
PSAS Strategic Projects: Launch Vehicle 3

Countering the Rocket Equation

- ➔ Technology demonstrator for 100 km shot
- ➔ Carbon fiber and Nomex sandwich
- ➔ Modular design

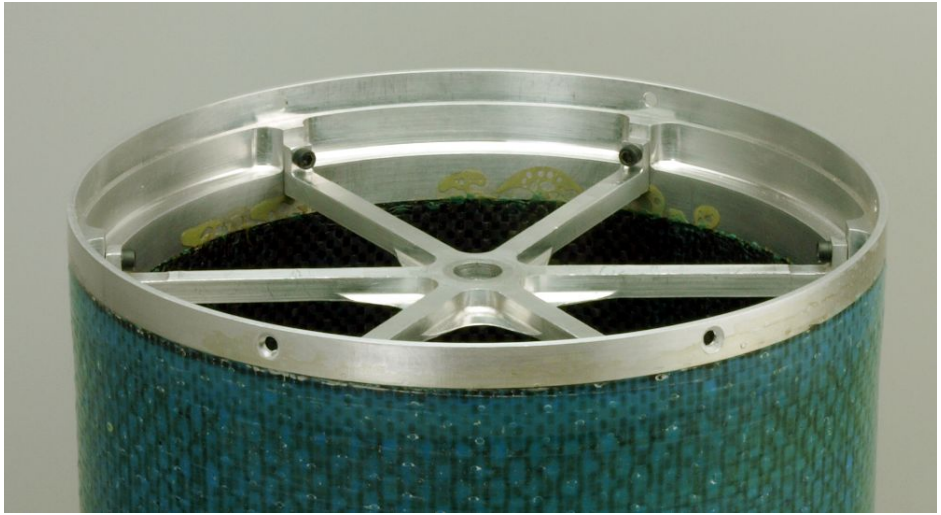


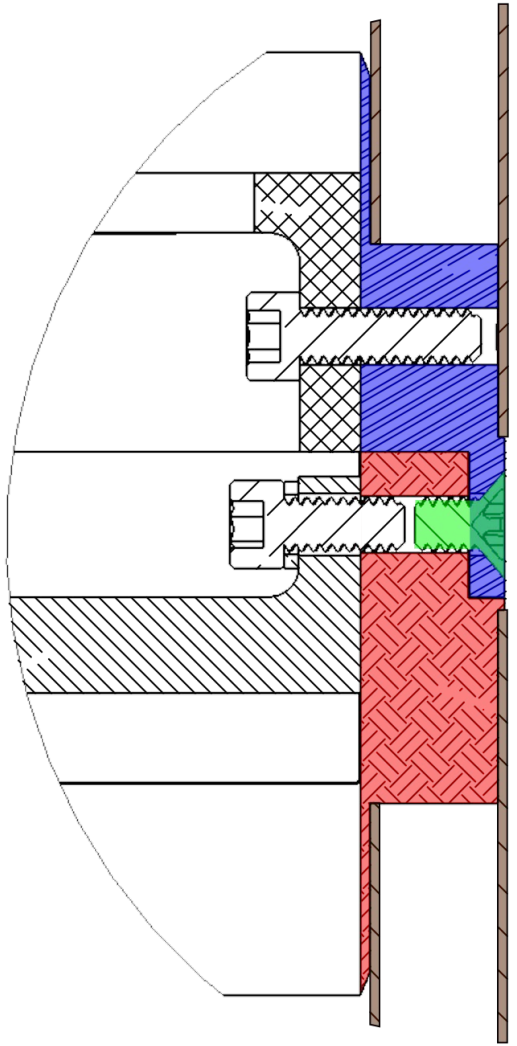




LV3 Coupling Rings

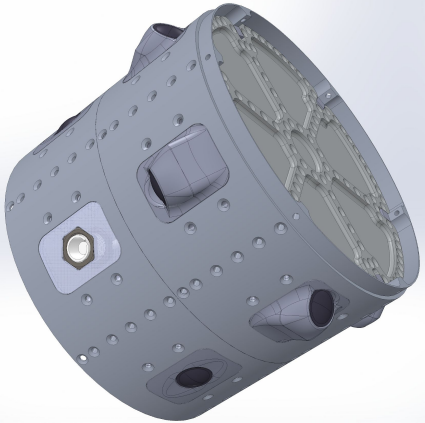
- ➔ Inner/outer sleeve
- ➔ Radial screws
- ➔ Designed for axial compression

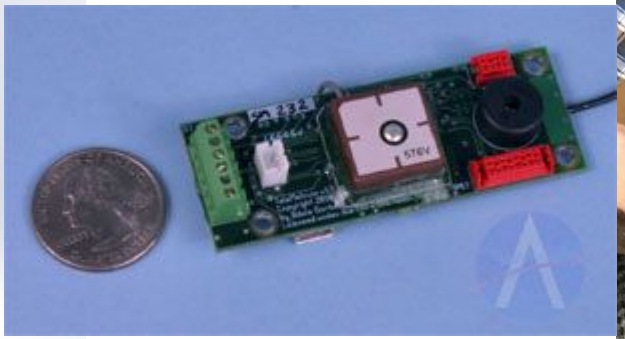




Launch 13

- ➔ LV3 airframe demonstrator
- ➔ O-class solid motor (21 kNs)
- ➔ Altus Telemetrum flight computer
- ➔ 360° camera module
- ➔ Electromechanical recovery system





May 2018:
Launch 13.1 of LV3.0

- ➔ Motor “chugged” just before take-off
- ➔ Rocket reached ~ Mach 1.5
- ➔ Flew to ~ 1.5 km before "Rapid Unscheduled Disassembly"

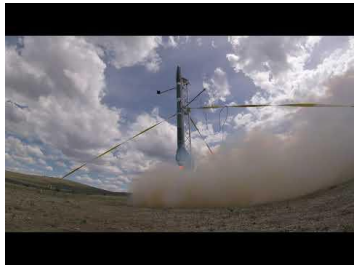


Photo credit: Gary Goncher

Failure Analysis Using Lean Thinking

Failure Analysis Using Lean Thinking

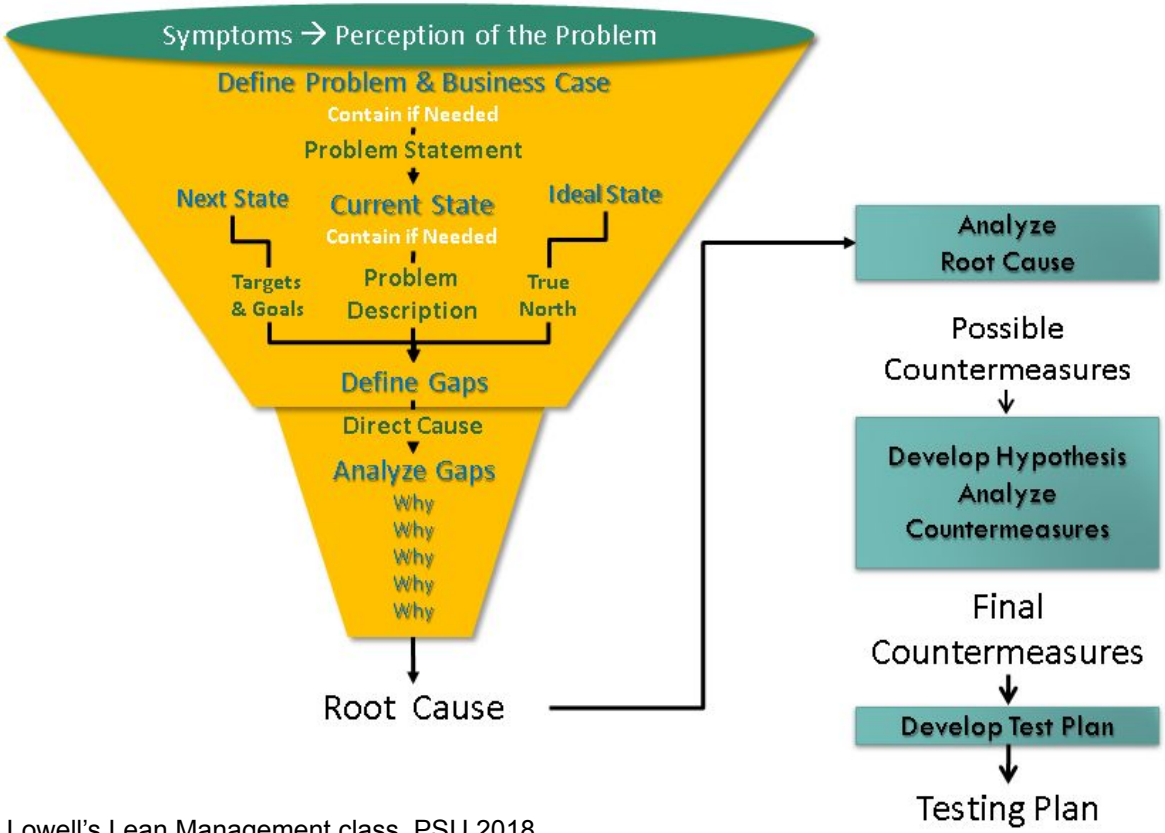


Image Credit: Heather Lowell's Lean Management class, PSU 2018

Failure Analysis - Define the Problem

- **Problem Statement:**
  - The rocket was destroyed in flight.
- **What must be fixed?**
  - Airframe must withstand flight dynamics.
- **Why is it important?**
  - Duh.

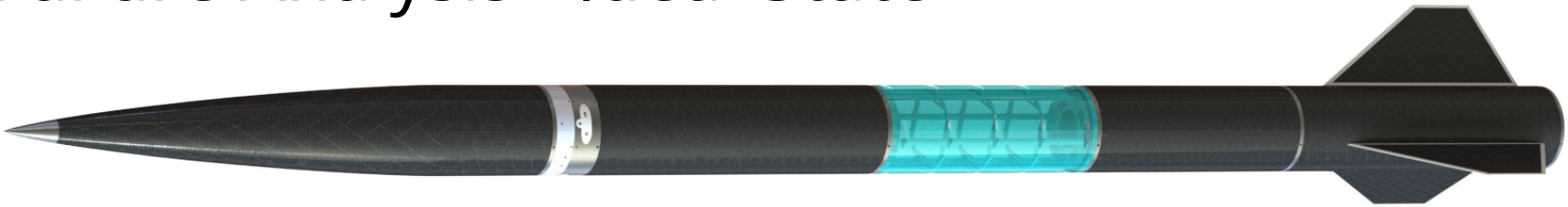
Failure Analysis - Current State

- ➔ Coupling rings tore away from each other
- ➔ Fins ripped off
- ➔ One module destroyed

What Wasn’t a Problem?

- ➔ Composite modules were intact
  - ◆ Damage was clearly due to lithobraking
- ➔ Fins didn't tear off until after breakup
  - ◆ Evidence: onboard video, and stills from ground
- ➔ Nose cone didn't come off until after airframe buckling
  - ◆ From sequenced ground images

Failure Analysis - Ideal State



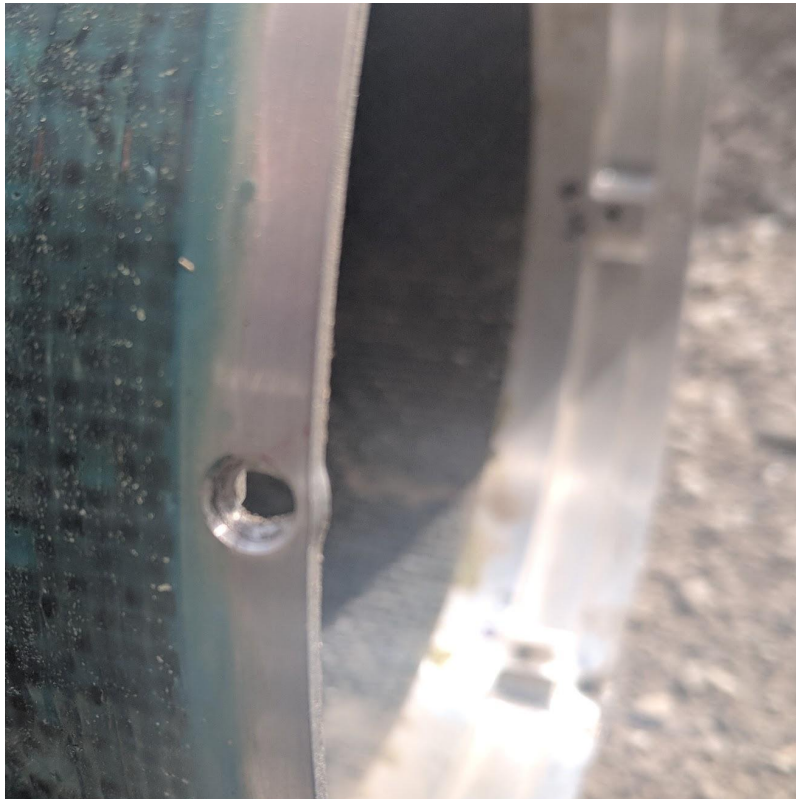
A lightweight rocket airframe which can be scaled up to use on our 100 km rocket.

Failure Analysis - Root Cause

1. Why? *Rapid Unscheduled Disassembly*
2. Why?
3. Why?
4. Why?
5. Why?

Failure Analysis - Root Cause

1. Why? *Rapid Unscheduled Disassembly*
2. Why? *Ring had 5/6 fasteners sheared and 1/6 pulled through Aluminum rings*
3. Why?
4. Why?
5. Why?

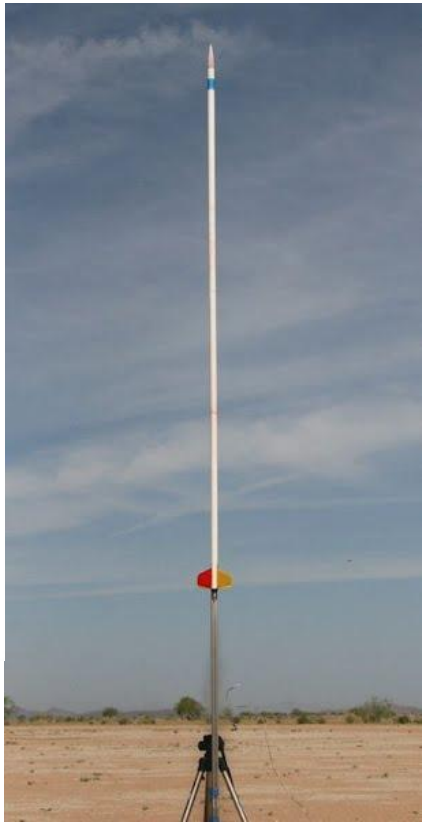


Failure Analysis - Root Cause

1. Why? *Rapid Unscheduled Disassembly*
2. Why? *Ring had 5/6 fasteners sheared and 1/6 pulled through Aluminum rings*
3. Why? *Unexpected buckling*
4. Why?
5. Why?

Failure Analysis - Root Cause

1. Why? *Rapid Unscheduled Disassembly*
2. Why? *Ring had 5/6 fasteners sheared and 1/6 pulled through Aluminum rings*
3. Why? *Unexpected buckling*
4. Why? *Aeroelastic effects*
5. Why?



Failure Analysis - Root Cause

1. Why? *Rapid Unscheduled Disassembly*
2. Why? *Ring had 5/6 fasteners sheared and 1/6 pulled through Aluminum rings*
3. Why? *Unexpected buckling*
4. Why? *Aeroelastic effects*
5. Why? *Non-rigid couplings and high aspect-ratio*

Next State

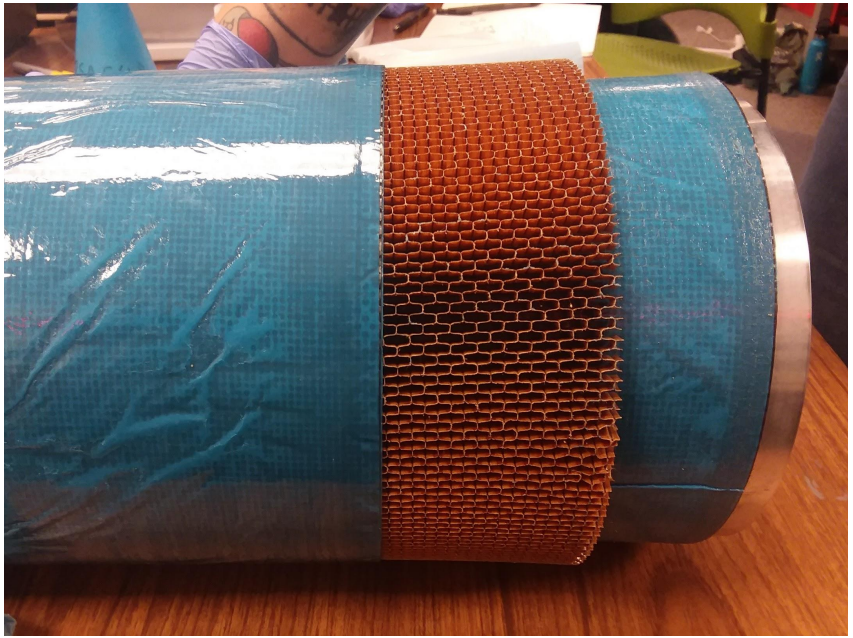
Failure Analysis - Next State

- ➔ Couplings that resist tension.
- ➔ More rigid airframe

Next State: LV 3.1

➔ Reducing risks of Rapid Unscheduled Disassembly

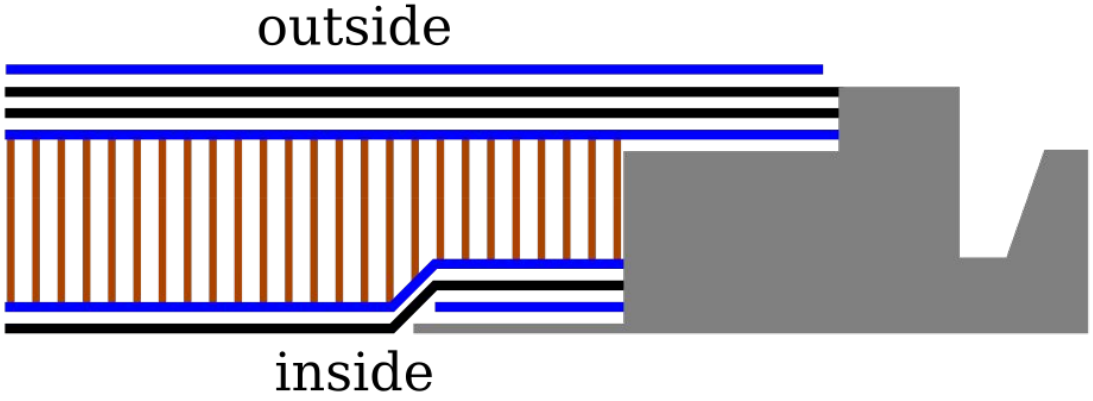
Newly designed coupling system

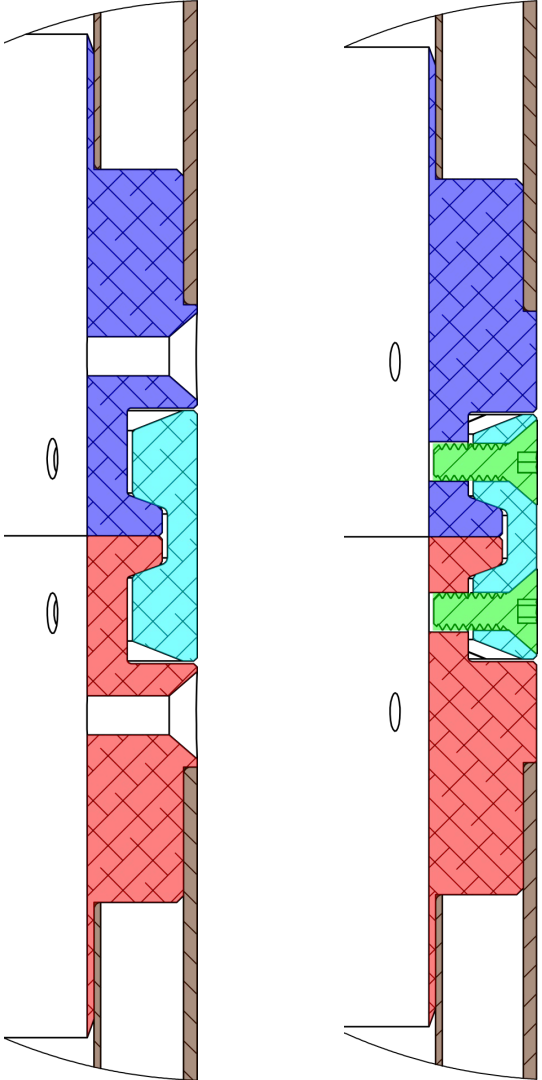


Strengthened module layup process

LV 3.1 Changes

- ➔ Clamped wedge for coupling rigidity
- ➔ Extra external layers because undergraduates
- ➔ More sensors (inertial, thermal, possibly strain)
- ➔ More strict design rules





Next State: Testing

- ➔ **3-point bend test**
- ➔ **Puncture tests**
- ➔ **Launch 14: April 2019**

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