Deorbit Device for Cubesat

ADDUCT – Aerobrake Deorbit Device for a 1U CubesaT

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SpaceLab - University of Cape Town

Deorbit Device Competition, 4th UNISEC-Global Meeting

Varna, Bulgaria

Content

- Objective and Requirement
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- Further Development

Space debris in LEO, source: startlr.com

Objectives

- Design, prototype and test[*] a deorbit device for a 1U Cubesat
- Equippable onto any-1U CubeSat (Within specifications of P-POD)
- Require no special features for the 1U device.

Requirements

- Reduce Deorbit Time
  - << 25 years
- Light Mass
  - Final mechanism < 100g
- Size
  - Fit within 0.1U
- Install on Cubesat prior to launch
  - Be plug-and-play

[*] Up to NASA TRL 4

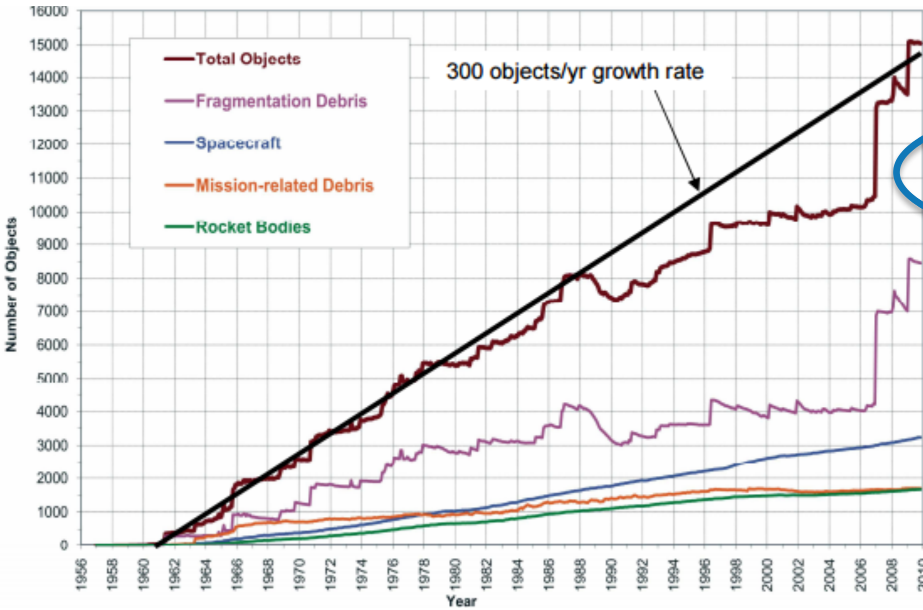
Research Institution: SpaceLab, University of Cape Town

Master of Philosophy (MPhil) in Space Studies

Convenor: Prof. P. Martinez

Course Content:
1. Space society and Space law
2. Space application
3. Space mission analysis and design
4. Launch Vehicles
5. Small satellite
6. Lunar Exploration

Background Investigation - Space Debris In LEO



Category	Danger-level	Size	Estimated population	Impact
Trackable	Catastrophic	Greater than 10 cm	1,9000+	Source of new debris
Non-trackable to partly trackable	Dangerous	1 cm to 10 cm	Several hundred thousand	“Bullets” which hit larger objects and create more debris
Untraceable	Bearable	Less than 1 cm	Many millions to billions	Minor threat to active satellites

Growing debris population in LEO: Kessler Syndrome

CubeSat: Another source of debris?

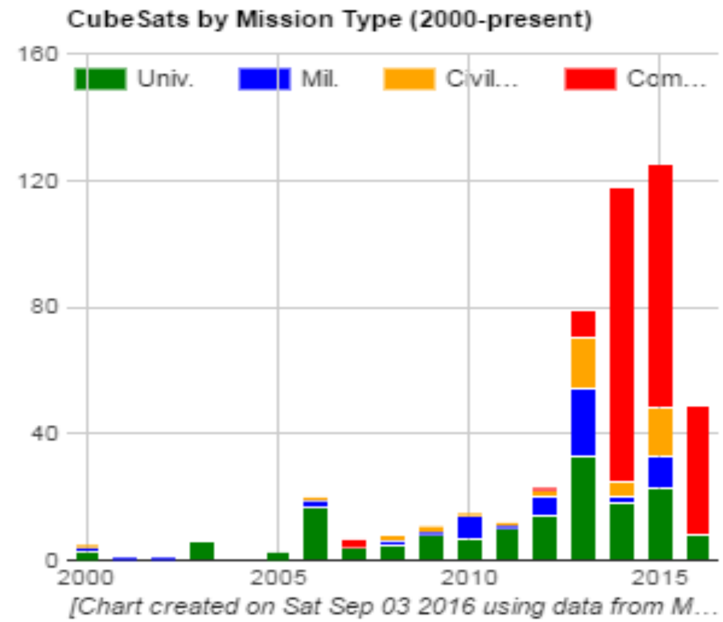
1-U CubeSat: 10 x 10 x 10 [cm]

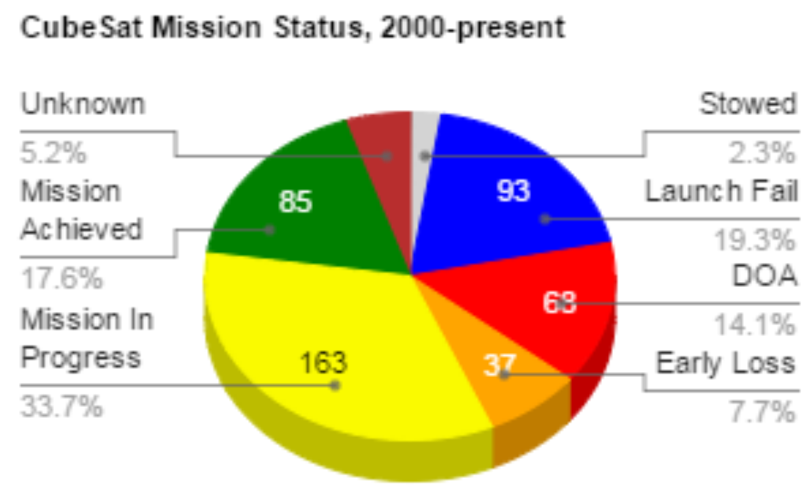
Source: Kessler et al. (2010)

.

Increasing Launches of CubeSat's

Year	Quantity	Category
2016 (up to 03 / Sep, Last launch on: 22 / Jun)	49	University: 8 Military: 0 Civil:0 Commercial: 41
2015	125	University: 23 Military: 10 Civil:15 Commercial: 77
2014	118	University: 18 Military: 2 Civil:5 Commercial: 77
2013	79	University: 33 Military: 21 Civil:16 Commercial: 9





Note:
University - A university or other educational institution, including high schools
Military - A government military / defence organization (e.g., the US Air Force).
Civil - Civilian government organization (e.g., NASA, JAXA, ESA).
Commercial - A private organization

Source: Swartwout, M. (2016)

51.3% CubeSat's launched fulfilled or fulfilling it's mission

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39% of all launched Cubesats are 1U*

* 125 out of 324 - Swartwout, M. (2014)

Preliminary Design of ADDUCT Device

- Reduce Deorbit Time

  << 25 years

- Light Weight

- Size

  Fit within 0.1U

Table 2.1 *Results of STK Orbital Lifetime Tool predictions for a 1U Cubesat with a variety of projected aerobraking surface areas at a range of orbital altitudes. These results indicate the maximum orbital lifetime in years. All calculations assumed a mass of 1kg.*

	Surface Area (m^2)				
Starting Orbital Height (km)	0.01	0.06	0.1	0.5	1
600	25.1	8.0	4.1	0.52	0.20
700	225	21.3	11.9	3.6	1.2
800	755.4	98.5	45.9	9.6	6.9
900	1670.5	265.2	152	20.8	10.3

Table 1.1 *Average orbital parameters for Cubesats in orbit as of May 2015.*

Period *minute*	**Apogee** *kilometre*	**Perigee** *kilometre*
97.0 ± 2.6	648 ± 136	581 ± 126

Selection: target sail cross-sectional area = 0.06m^2

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ADDUCT device compared to other aerobrake concepts

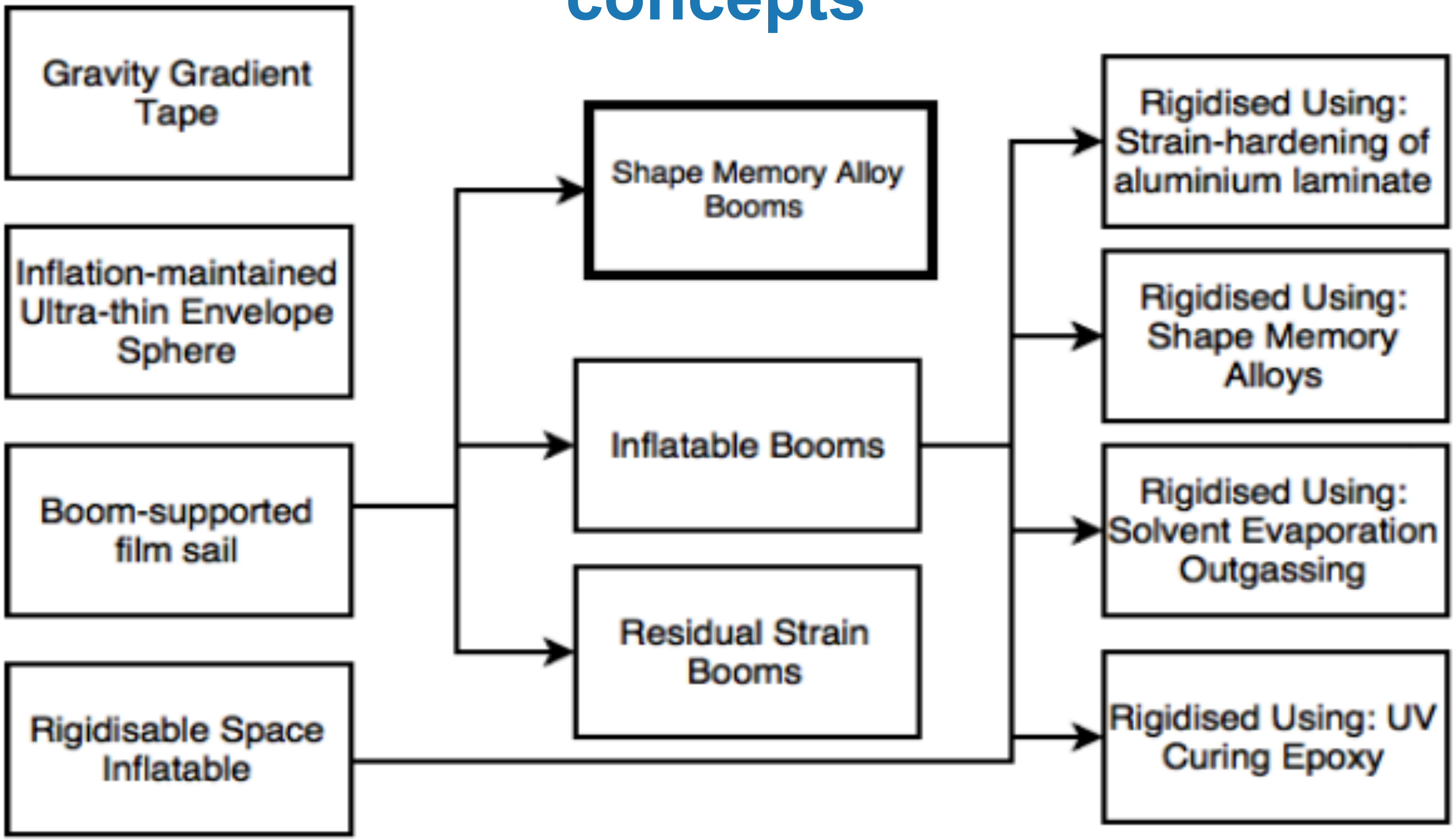
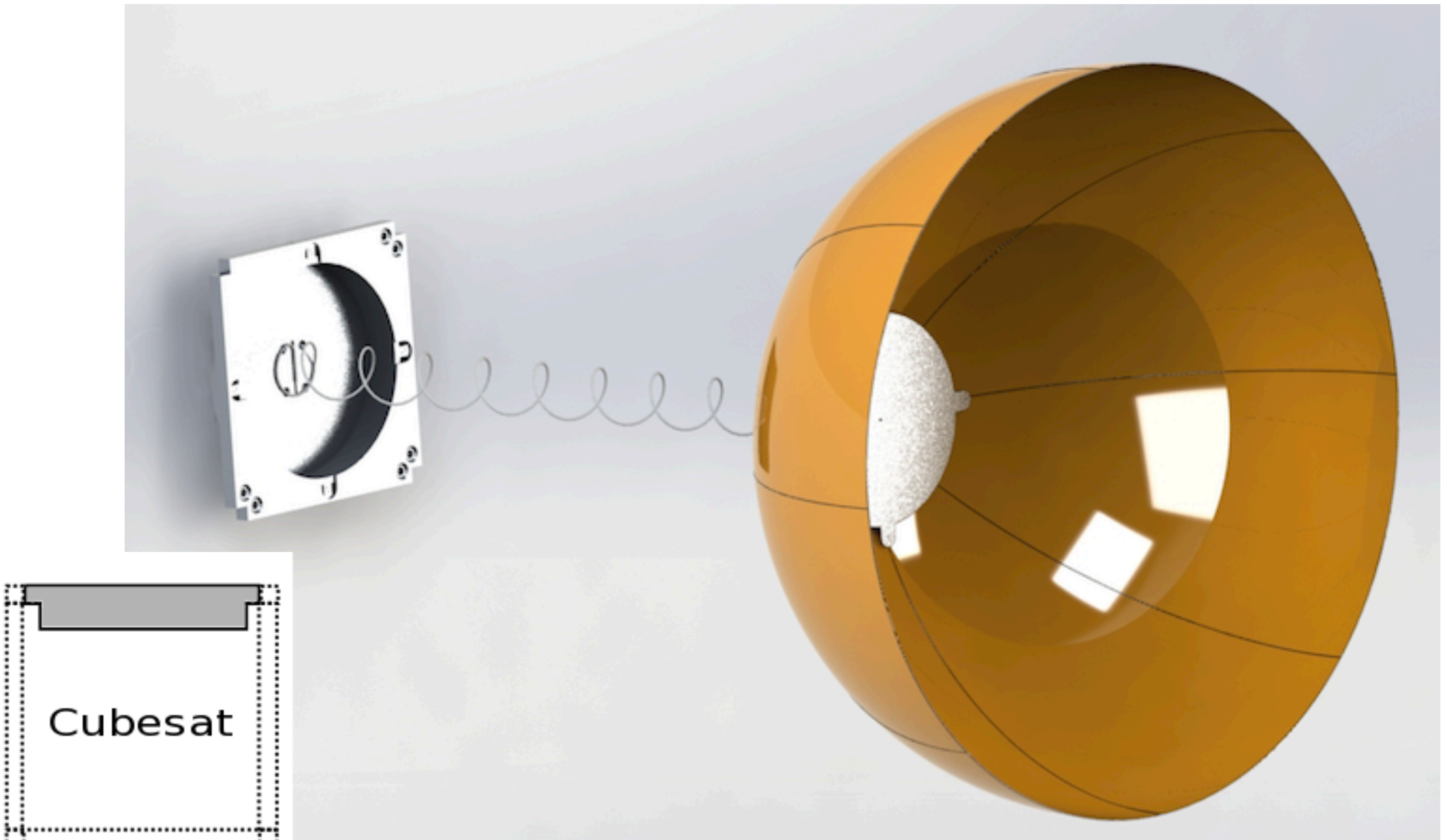


Figure 1.10 Different aerobraking concepts. The bold block indicates the main focus of this thesis.

ADDUCT – **A**erobrake **D**eorbit **D**evice for a 1**U** **C**ubesa**T** **Conceptual Design**

ADDUCT – Conceptual Design



10 uniquely designed components, including Nitinol Spring and Sail

Orientation of Craft

Aerodynamic Torque orientation

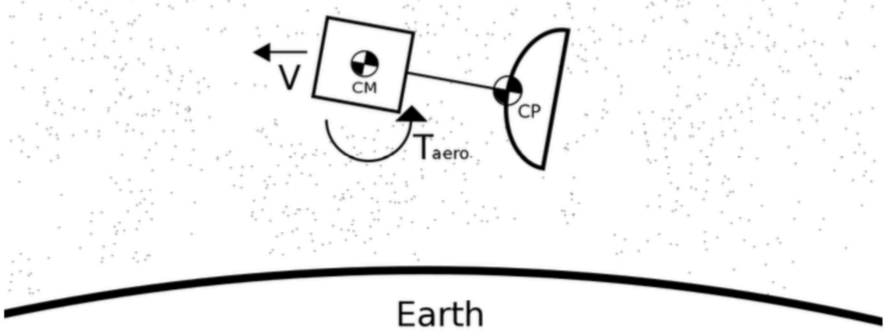


Figure 2.9 Aerodynamic torque experienced by a Cubesat in orbit with a hypothetical aerobraking device at the end of a boom. The moment arm is the distance between the centre of mass and the centre of pressure. The aerodynamic torque will tend to orient the satellite in the direction of the velocity vector.

Gravity Gradient Torque

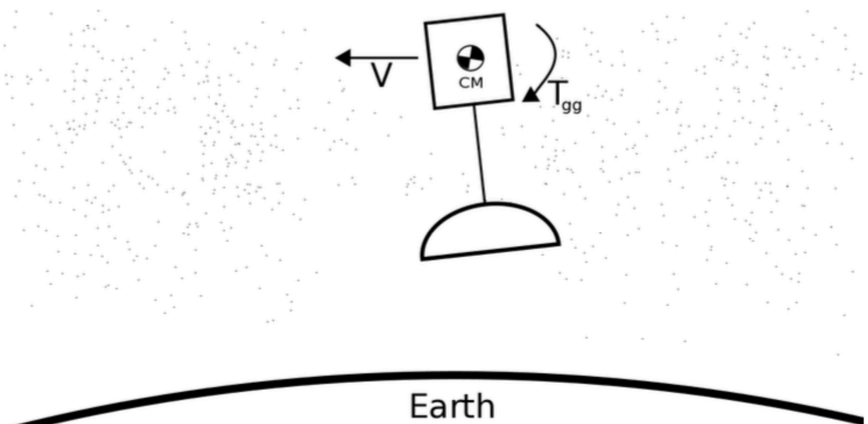


Figure 2.10 Gravity-gradient torque experienced by the Cubesat depicted in Figure 2.9. The Gravity Gradient torque tends to align the long axis of a satellite along a line pointing towards Earth's centre of mass i.e. perpendicular to the velocity.

Gravity Gradient Torque and Aerodynamic Torque will affect the orientation of the craft. Aerodynamic > GGT @ < 700km

Orbital Heights (km)	Aerodynamic Torque (N.m)	GG Torque (N.m)
900	4.56×10^{-10}	5.78×10^{-9}
800	2.51×10^{-9}	6.01×10^{-9}
700	1.39×10^{-8}	6.26×10^{-9}
600	7.64×10^{-8}	6.52×10^{-9}
500	4.22×10^{-7}	6.79×10^{-9}
400	2.33×10^{-6}	7.08×10^{-9}
300	1.28×10^{-5}	7.38×10^{-9}

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Unique Material Properties

Nitinol

Shape Memory Allpy

45% Nickel + 55% Titanium

Electrical Resistivity: 76 µΩ-cm

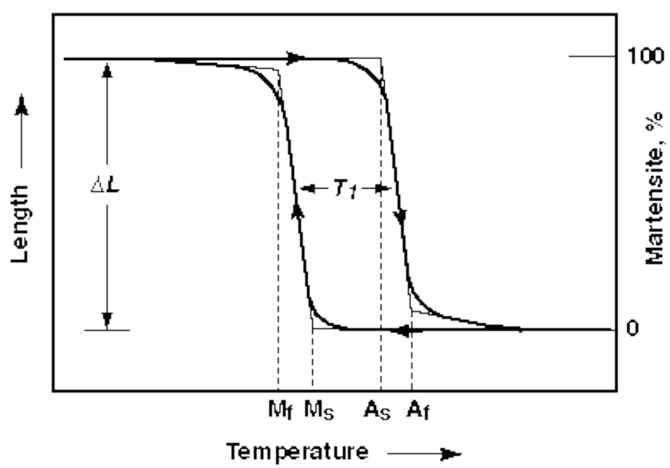
“Reprogrammable”

Force generated during state transition from Austenite staet to Martensite state.

Drawback:

Hysteresis effect

Space certified



Kapton HN (Polyamide) – Sail Material

Robust thermal properties

Operating range: -269°C (-452°F) and as high as 400°C (752°F).

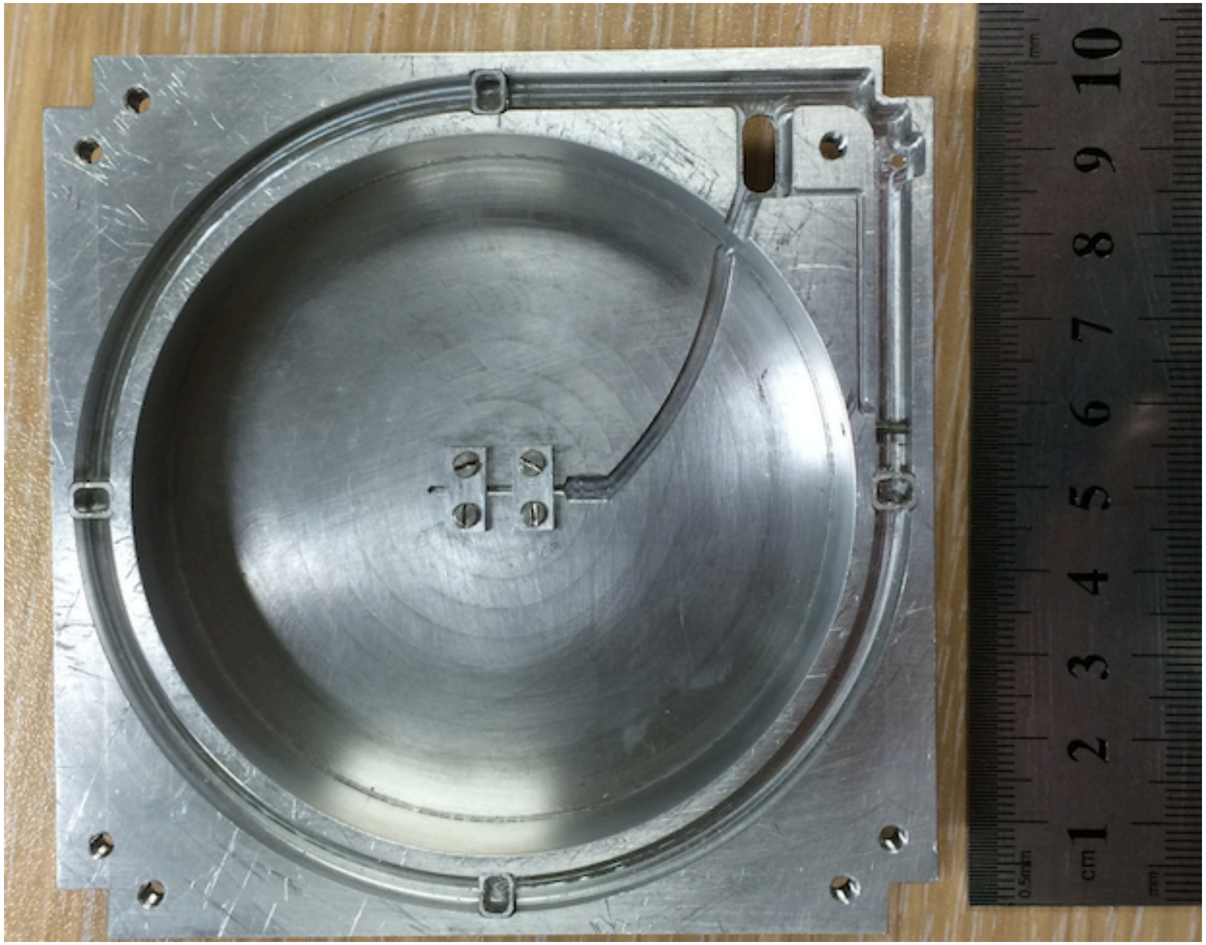
Electrical insulation

Laser cuttable

Low outgassing effect

Space certified

ADDUCT - Housing



ADDUCT – Top View of Housing

Housing:

Aluminum construction

Standard Cubesat width.
Height 0.08U

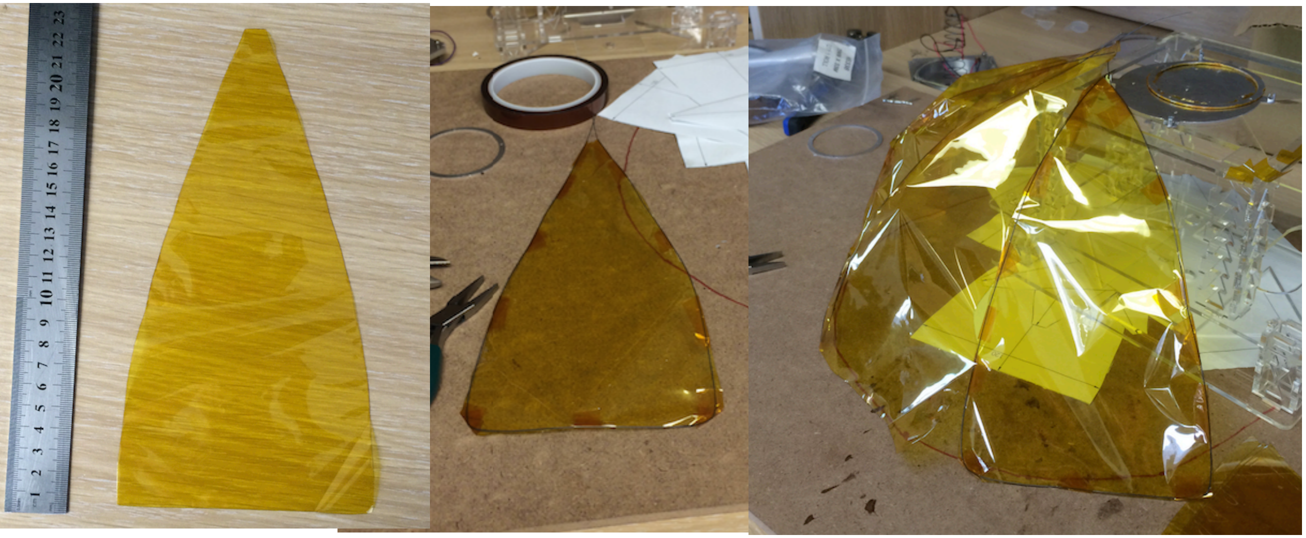
Central well for Sail.

Grooves for
Burn wire mechanism

Guiding Holes for Lid

Female Pins inserted

ADDUCT – Sail Fabrication



Sail Construction:

1. Design Gores
2. Create Mould
3. Bake Nitinol
4. Construct “Framed Gores
5. Complete Wiring

Hybrid - Wiring Option

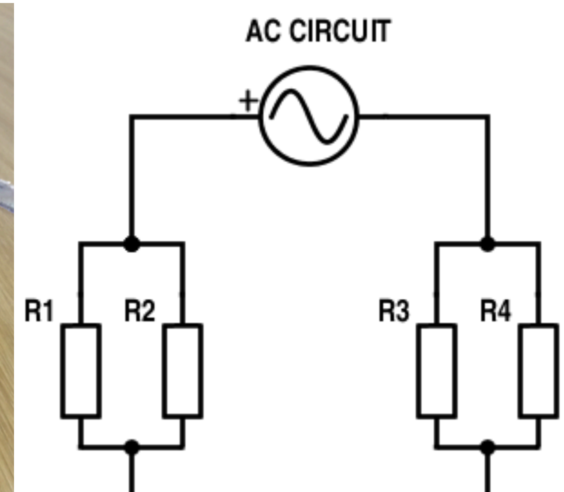
< Current than Parallel System

Greater Reduancy than in Series

Less wiring than a parallel system

Current: 1.5A, Voltage: 4.4V

R = 2.93 Ω Energy: 0.2174 Wh



ADDUCT – Nitinol Spring

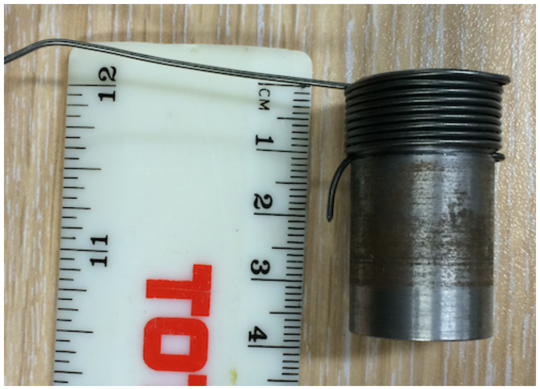


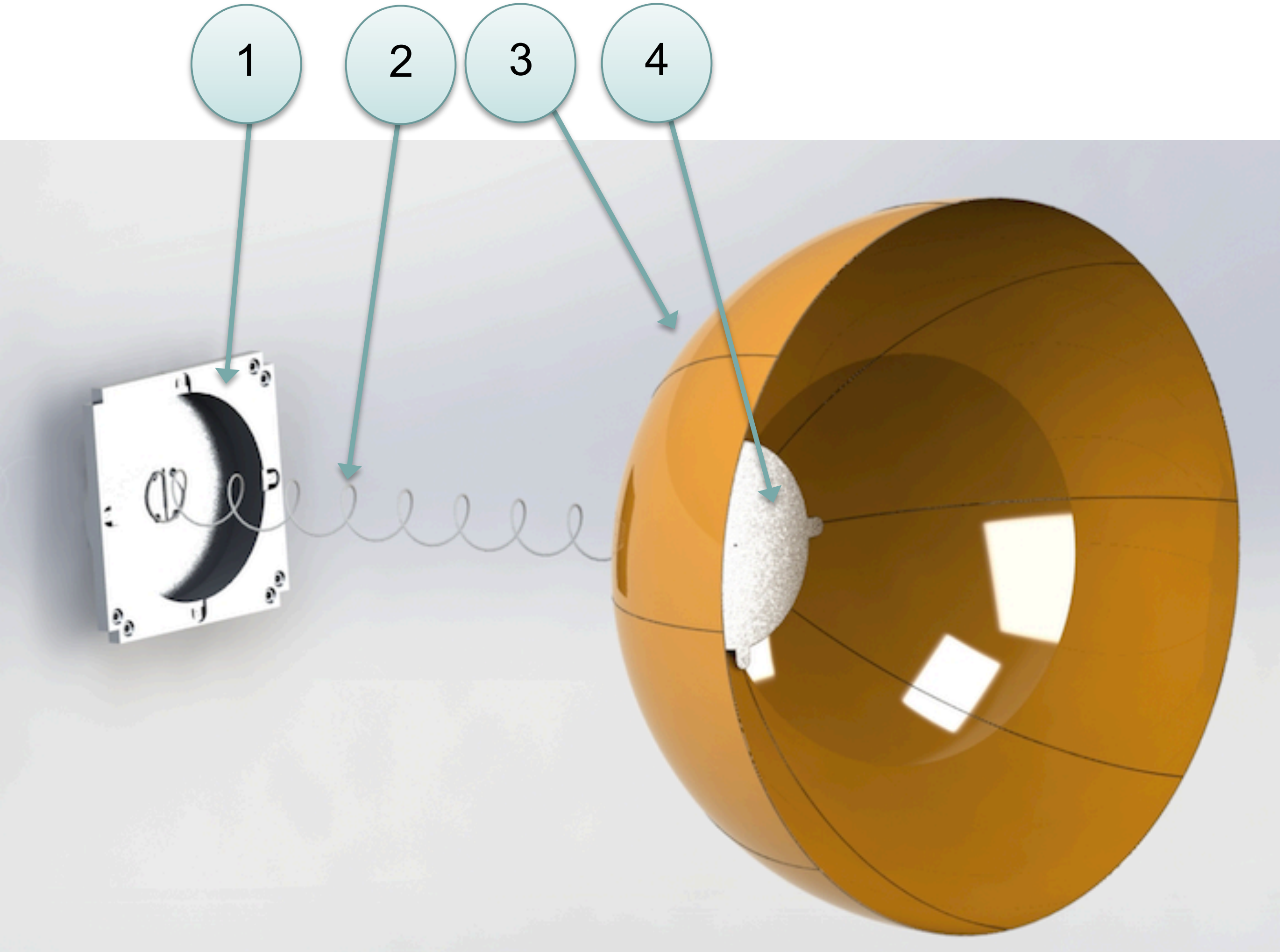
Table 4.9 *Properties of the Nitinol helical boom in its extended and compressed states.*

Nitinol Helix		
	Extended	Compressed
Chord Length	$270mm$	$11mm$
Arc Length	$626.6mm$	$628.37mm$
Pitch	$30mm$	$1.1mm$
Revolutions	10	9

- The Helical shape:
  - ensured stability while being lengthen.
  - Allowed for easy collapsing

The ϕ1mm Nitinol Helical boom was baked at 500°C for 10 minutes.

ADDUCT System Integration



1. Housing and Cover Plate
2. Helical Boom
3. Sail
4. Sail Housing Lid

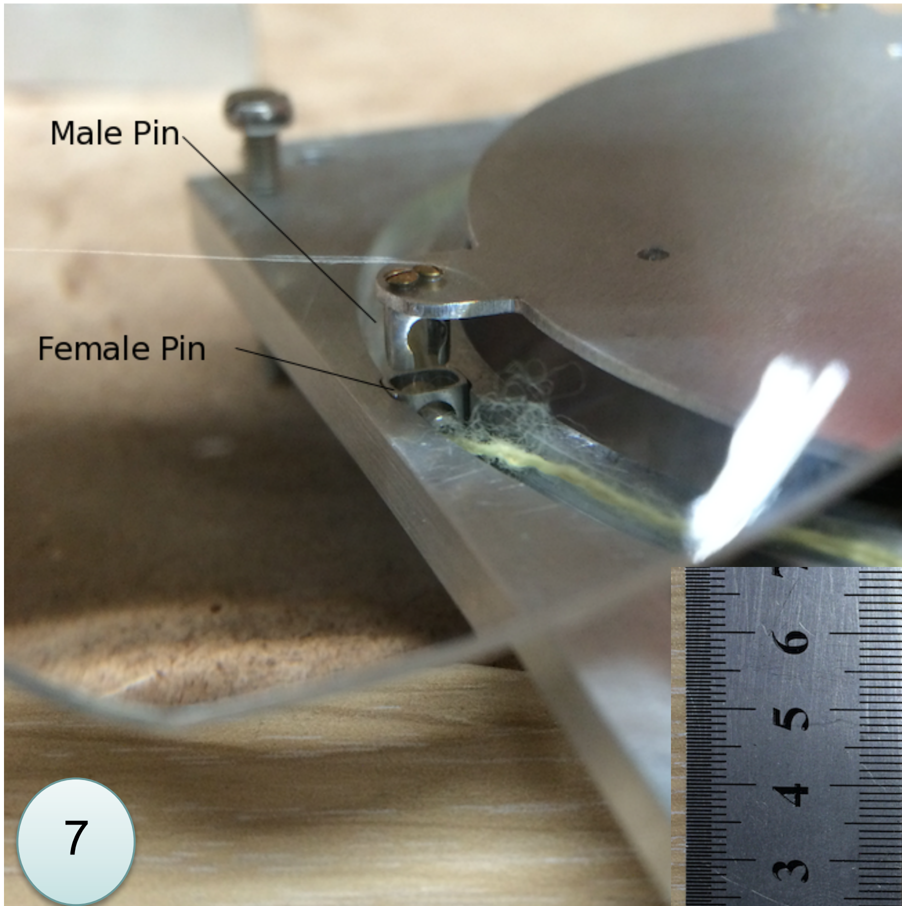
Hidden:

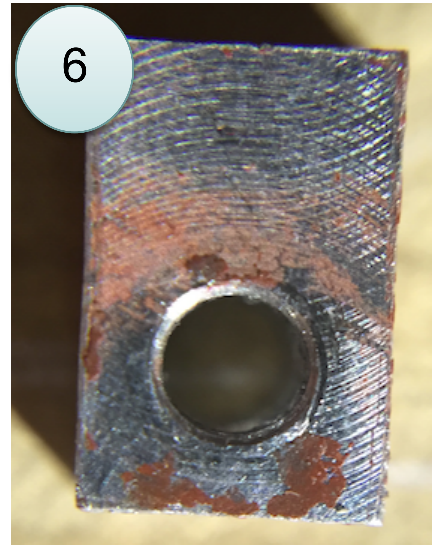
Lid Boom Housing

Sail Fastener

Female and Male Pins

ADDUCT System Integration

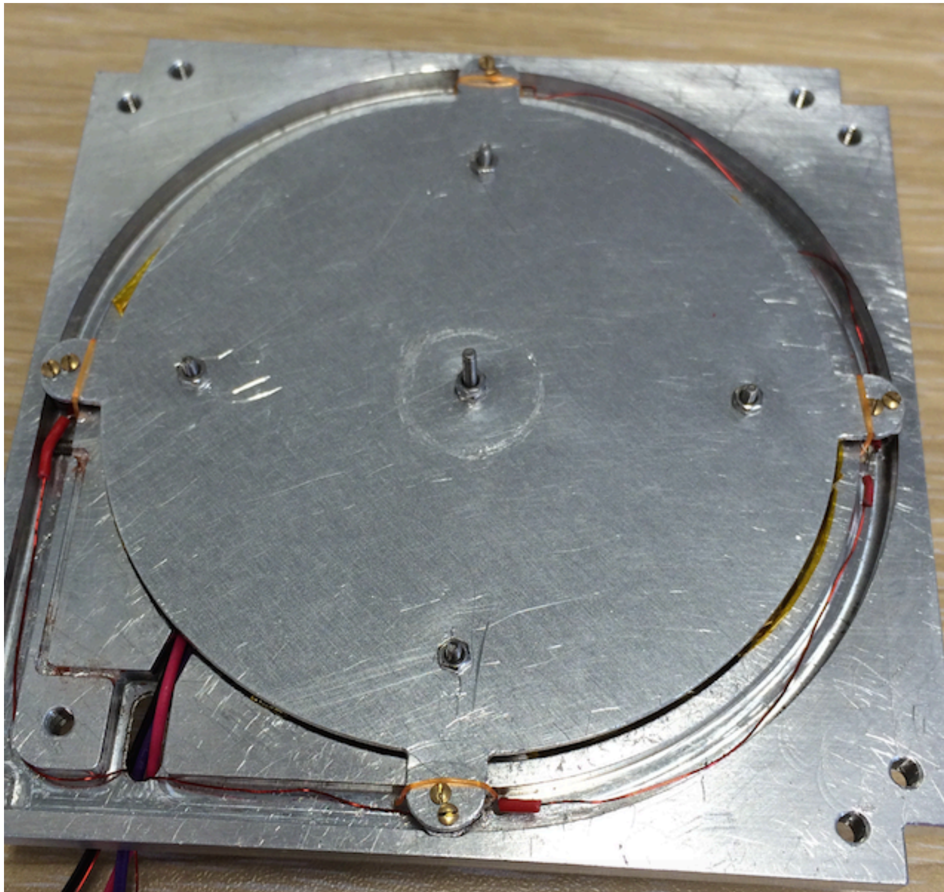




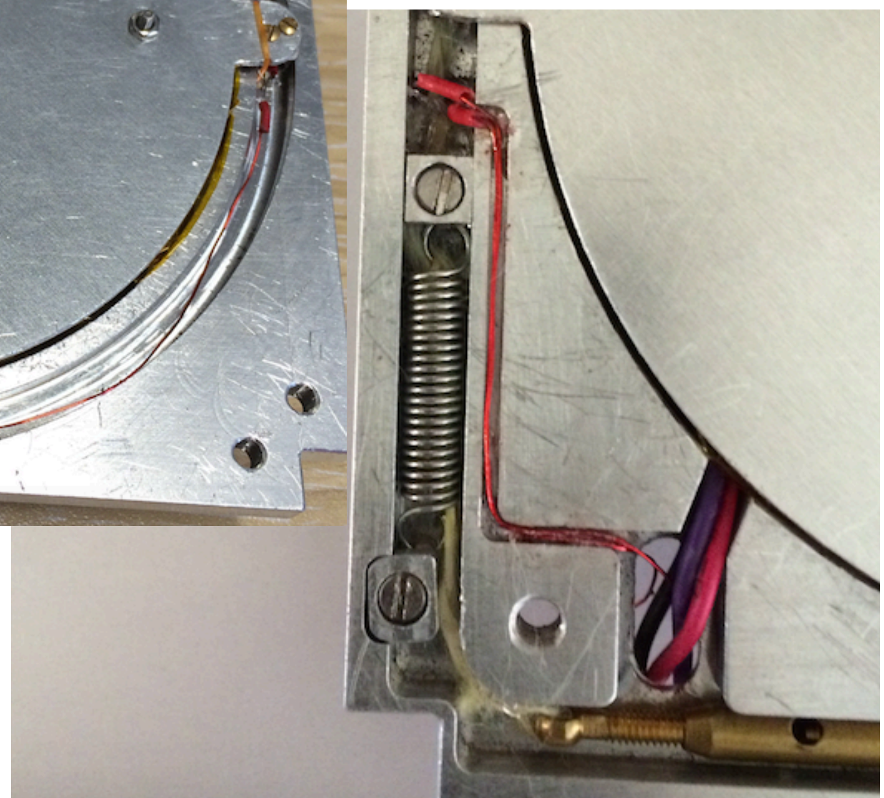
6. Lid Boom Housing
7. Male Pin and Female Pin
8. Sail Fastner

Images not to the same scale

Release Mechanism



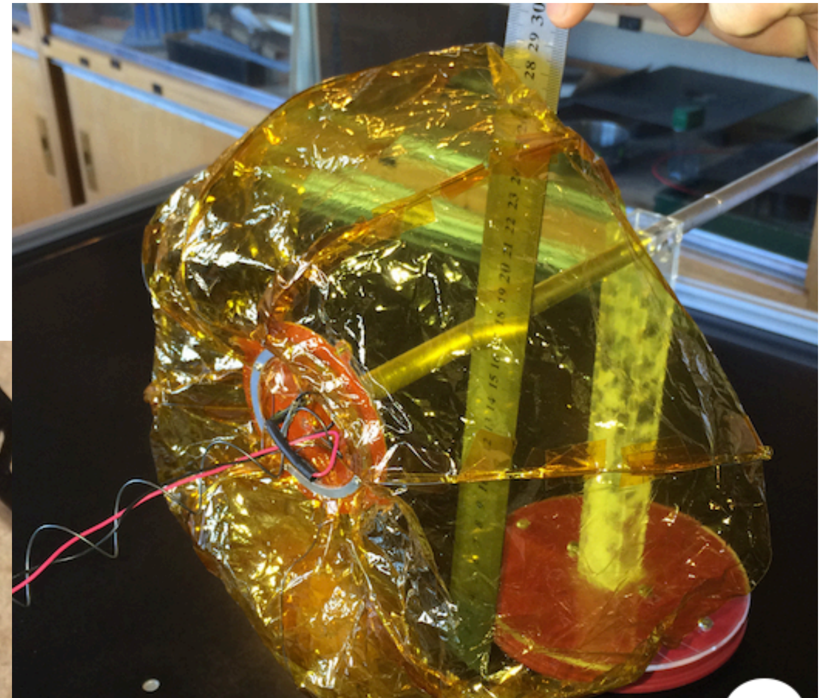
1st Iteration: Pin and Pawl



2nd Iteration: Spring and Cable

Completed ADDUCT

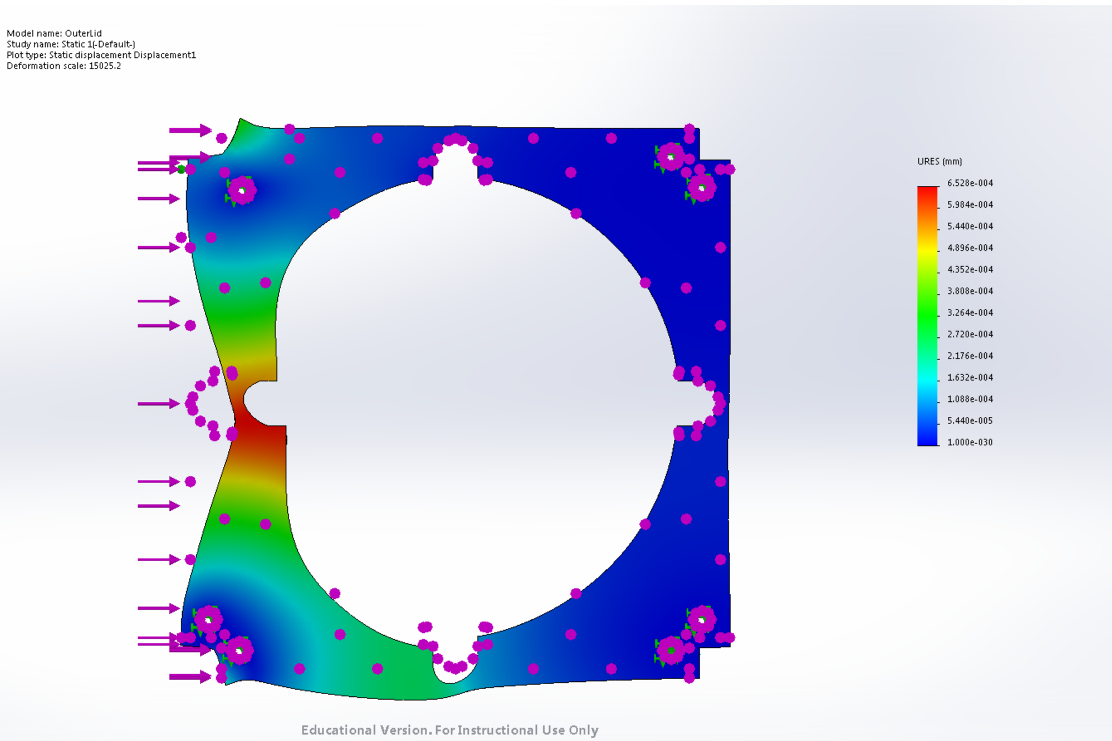
Collapsed Sail

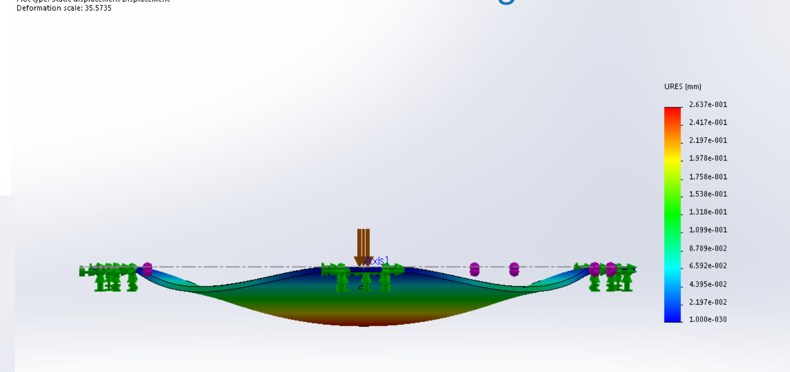


Expanded Sail

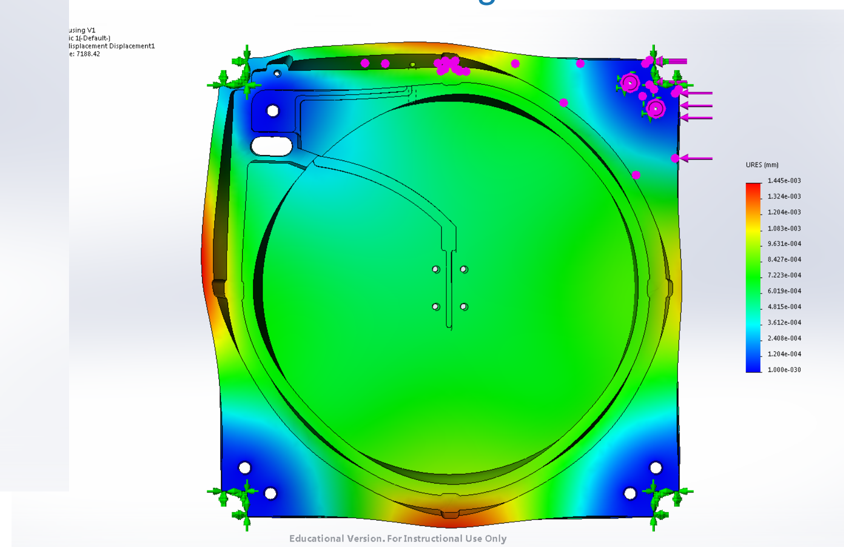
Finite Element Analysis - Simulation

- Simulating the forces experienced during a Dnepr rocket launch
- Maximum forces simulated: + 8.3 g axially and + 1 g laterally s
- 6.528 X 10^{-4}mm maximum movement of Cover Plate.



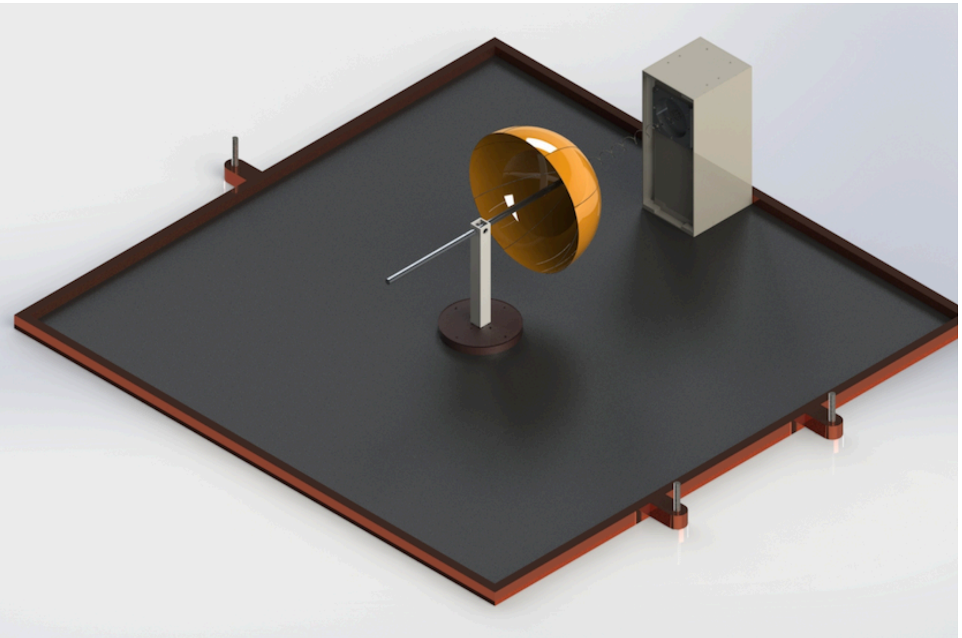


Magnitude Factor: 35



Magnitude Factor: 7188

Testing Rig



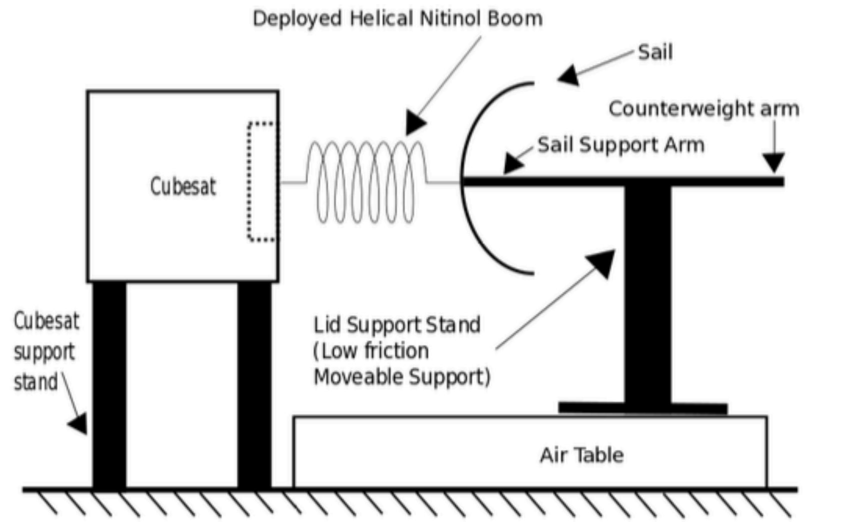


Figure 6.1 Concept of the setup for the air table tests. The ADDUCT device is attached to a fixed Cubesat support stand. The deployment of the sail is supported by a Lid support stand that rests on an air cushion.

Simulates Micro Gravity in the Horizontal Plane

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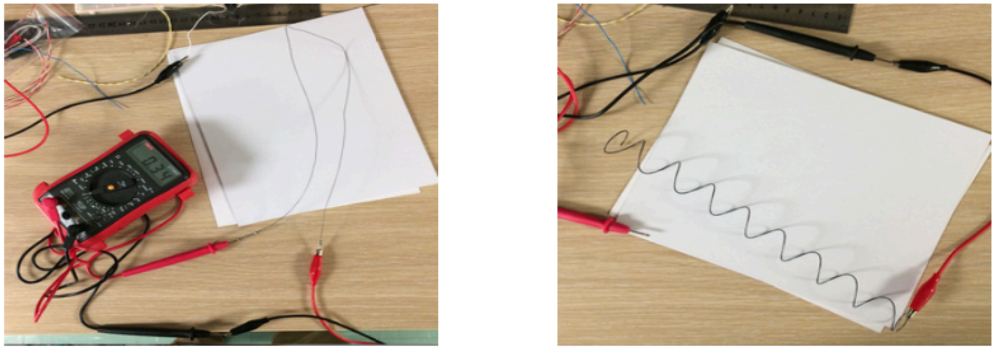
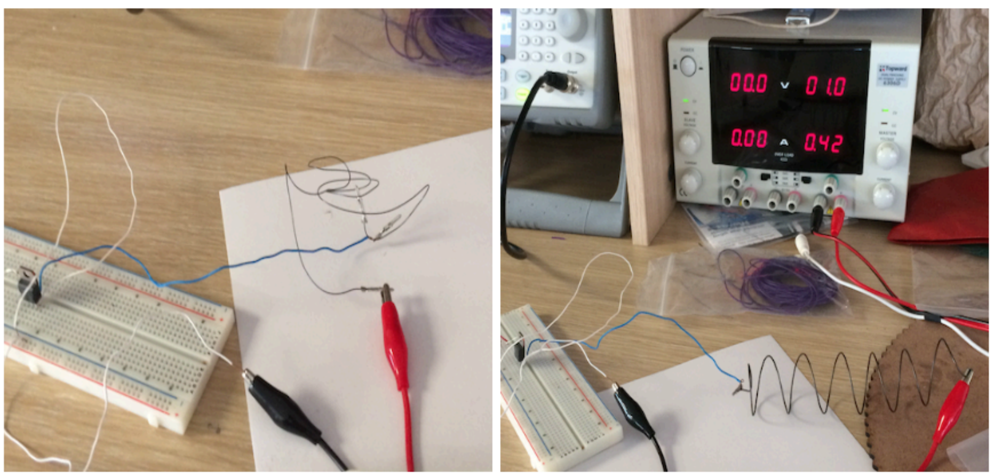
Preliminary Tests - Nitinol



(a) The sail was connected in series with a multimeter and the DC power source.

(b) The Nitinol helical boom was connected in series with a multimeter and the DC power source.

Figure 6.4 Resistance test setup.



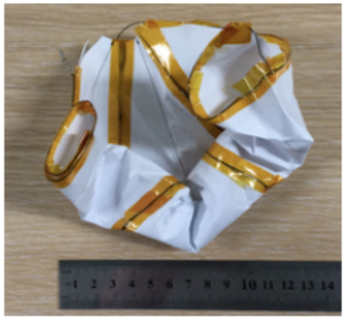
(a) This is a view of the Nitinol sail frame in a compressed state. Current was applied across to wires to test Nitinol's recovery ability.

(b) Once the current was applied, the Nitinol helical boom extended to its full length. This test proved that the Nitinol concept was worth pursuing.

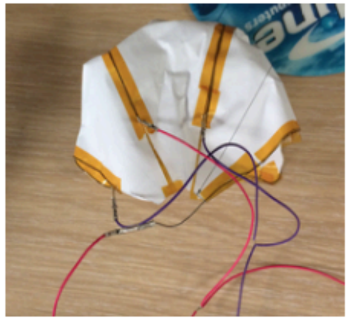
Figure 6.6 Deployment current test.

- Nitinol Resistance Test
  - Multiple tests were done on the Φ1mm and Φ0.5mm wires.
  - Result: 2.93Ω for sail frame and 1.25Ω for the Helical Spring
- Nitinol Deployment Current Test
  - Result: 1.5A chosen using Pulse Width Modulation
  - This oscillation of power allows the wire to heat up evenly and reduces the formation of 'hot' spots.

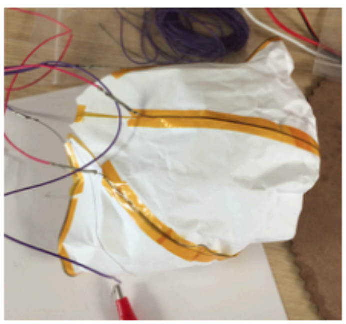
Preliminary Testing – Flat Sail and Paper Sail



(a) The image shows the paper in its collapsed state prior to being wired up and having current flow through it.



(b) The paper sail with the two different sails that were connected in parallel.

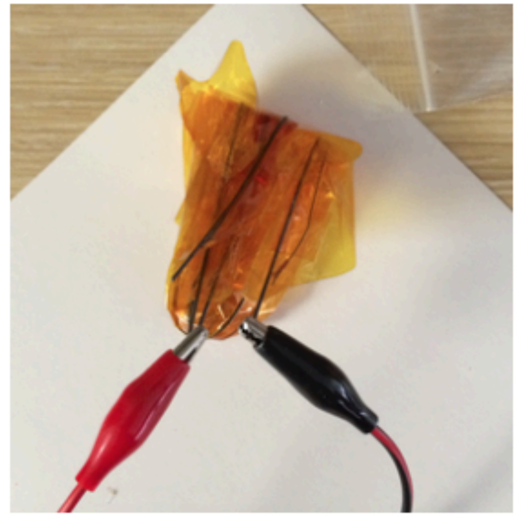


(c) The partially deployed paper sail as the current is applied through it and it starts to unravel.

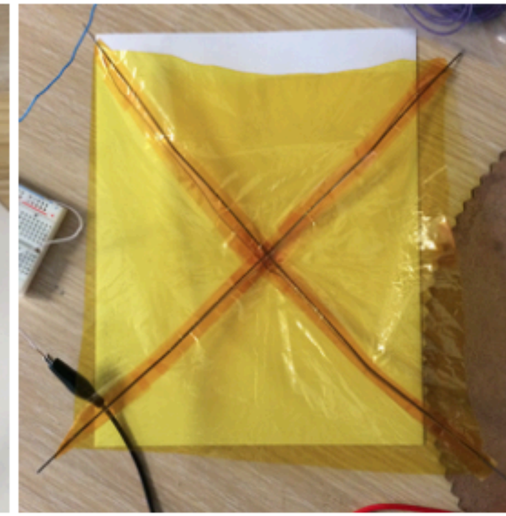
(d) The final configuration of the paper sail.

Figure 6.8 Paper sail test.

Paper Sail Test



(a) This is a view of the square sail in a folded state. Current was applied across two wires to test Nitinol's recovery ability.

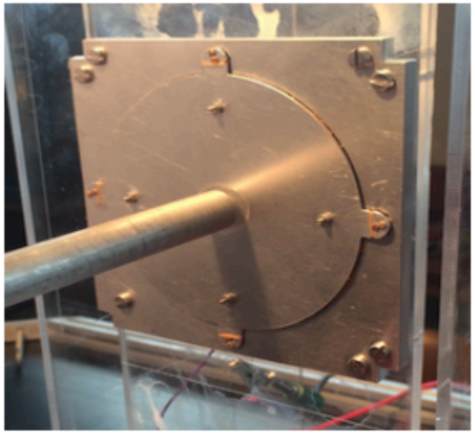


(b) Once the current had been applied, the square sail was found to open. This test proved that the Nitinol concept was worth pursuing.

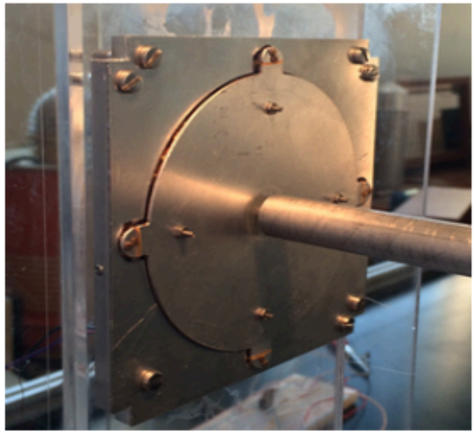
Figure 6.7 Preliminary square sail test.

Flat Square Sail Test

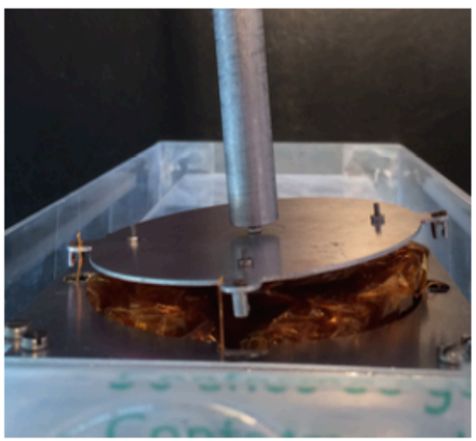
Test 1 – Release Mechanism Tests



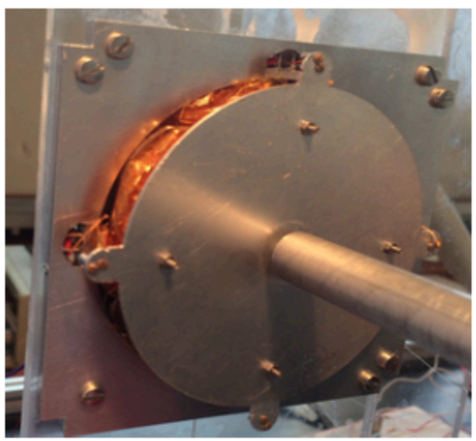
(a) Image of the ADDUCT device with secured lid, which has be integrated into the testing rig, but the burn wire has not been activated yet.



(b) Another image of the device before the burn wire has had current applied to it.



(c) A side view of the ADDUCT device after the burn wire has been activated. The sail is partially pushed out of the housing by the compressed Nitinol helical boom.



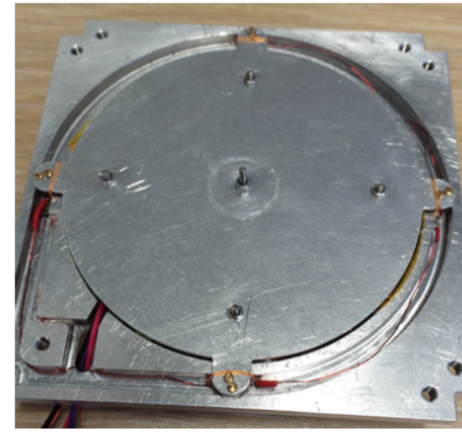
(d) A top view of the device after the burn wire has been activated.

Figure 6.35 Images of the lid release test of the ADDUCT device showing the successful operation of the spring-and-cable release mechanism.

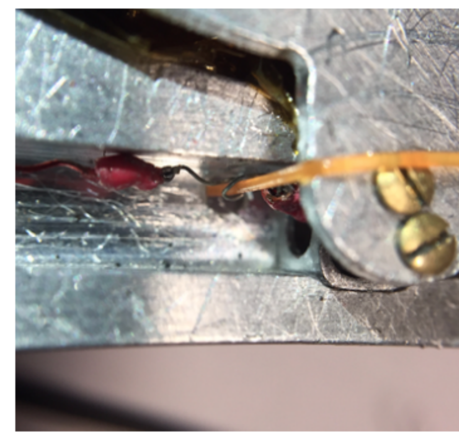
- Multiple Tests
- Cut time was within seconds.
- Reliability experimental determined.

Reliabilty Table

Cut Locations	Lid released
4	Yes
3	Yes
2	Yes
1	No



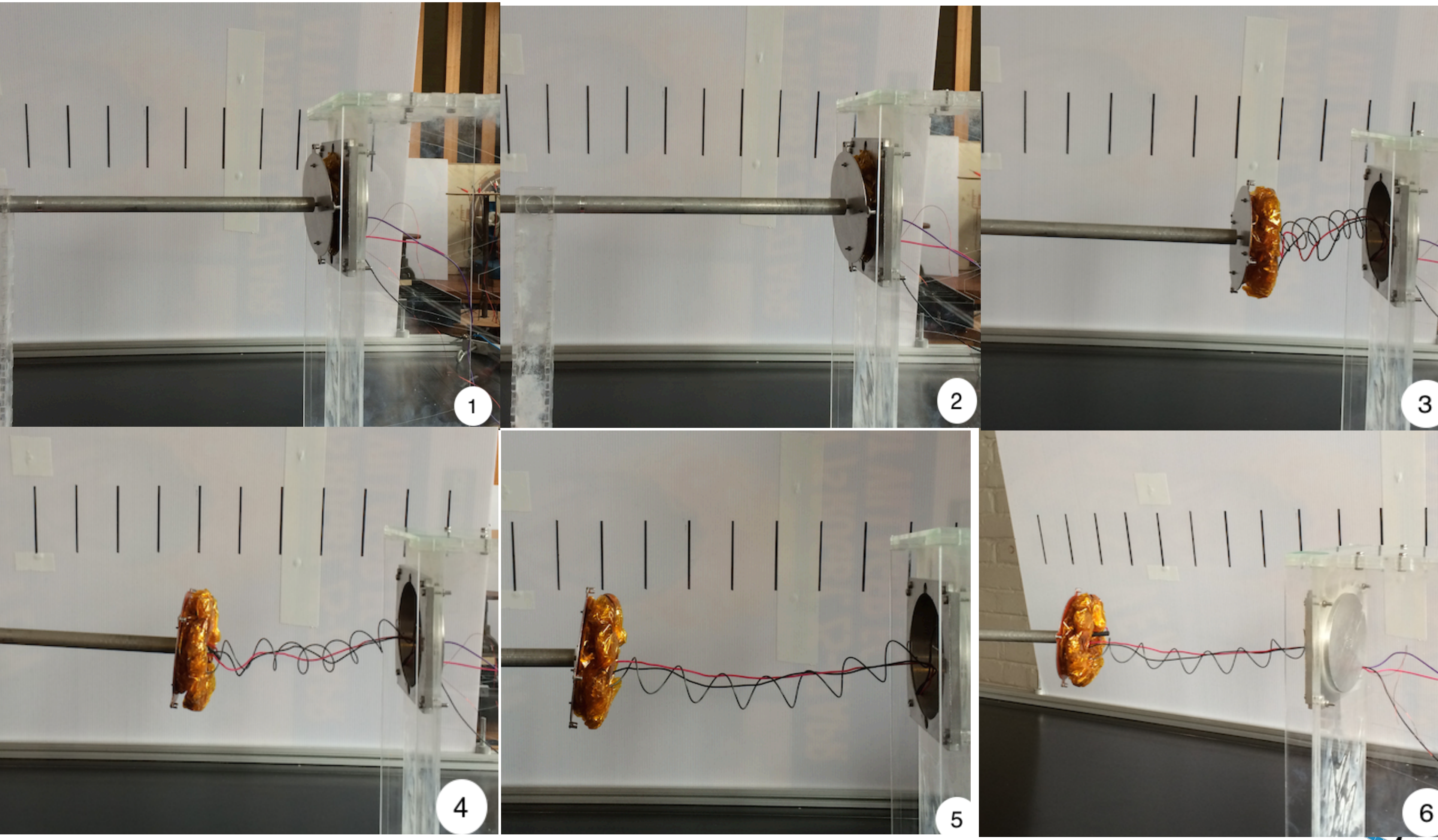
(a) A view of the burn wire routing around the housing. The Nichrome was wrapped around one end of each Nylon rope to ensure that it burns through.



(b) The burn wire was bent into hooks and soldered like original burn wire. It was looped around the Nylon rope in four locations.

Figure 6.34 Burn wire for the second concept of the Spring-and-Cable release mechanism.

Test 2 – Helical Boom Tests



Test condition: 1G lab environment, DC power supply and square wave signal generator

Final Length Elongated Length 27cm

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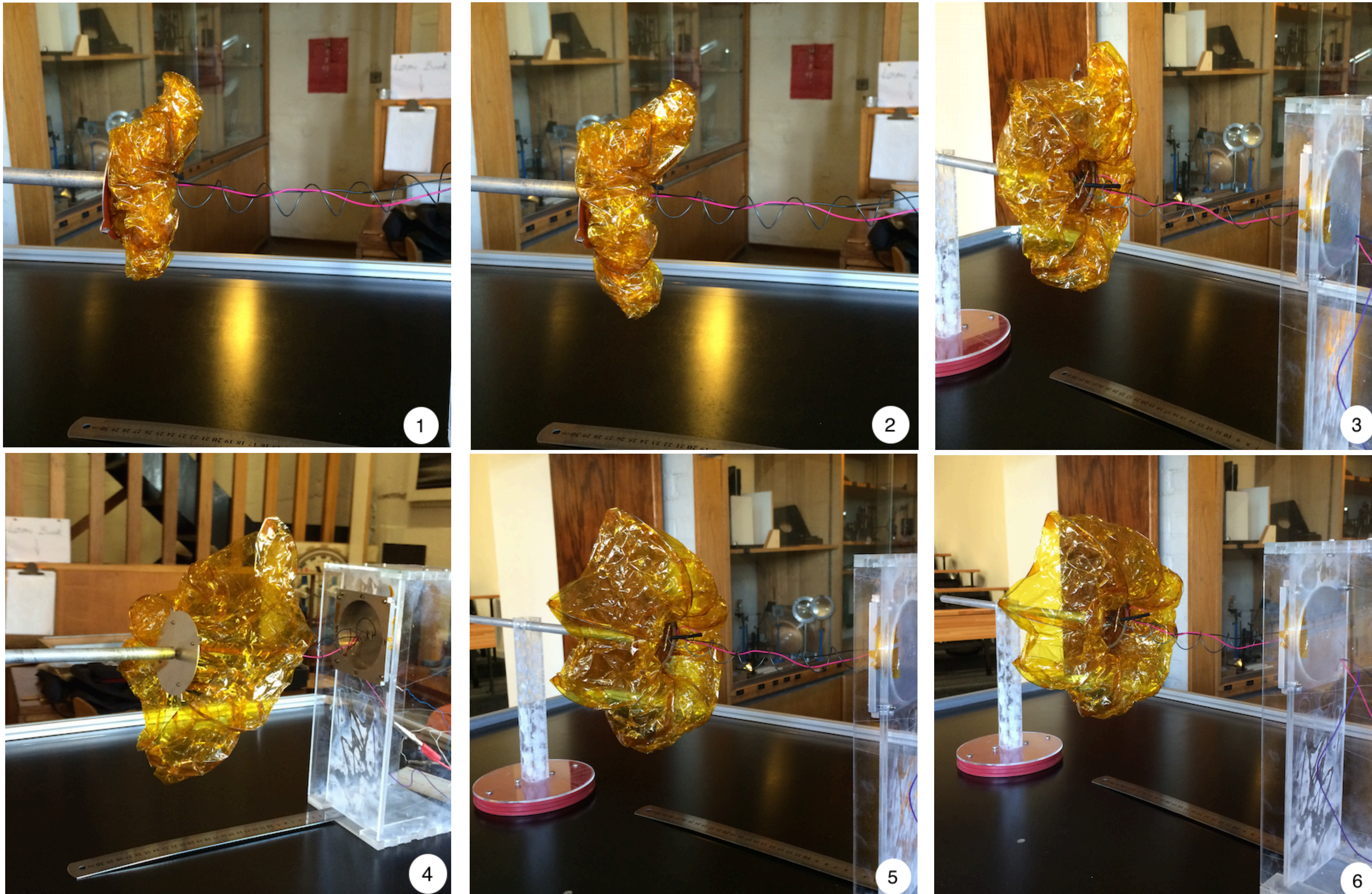
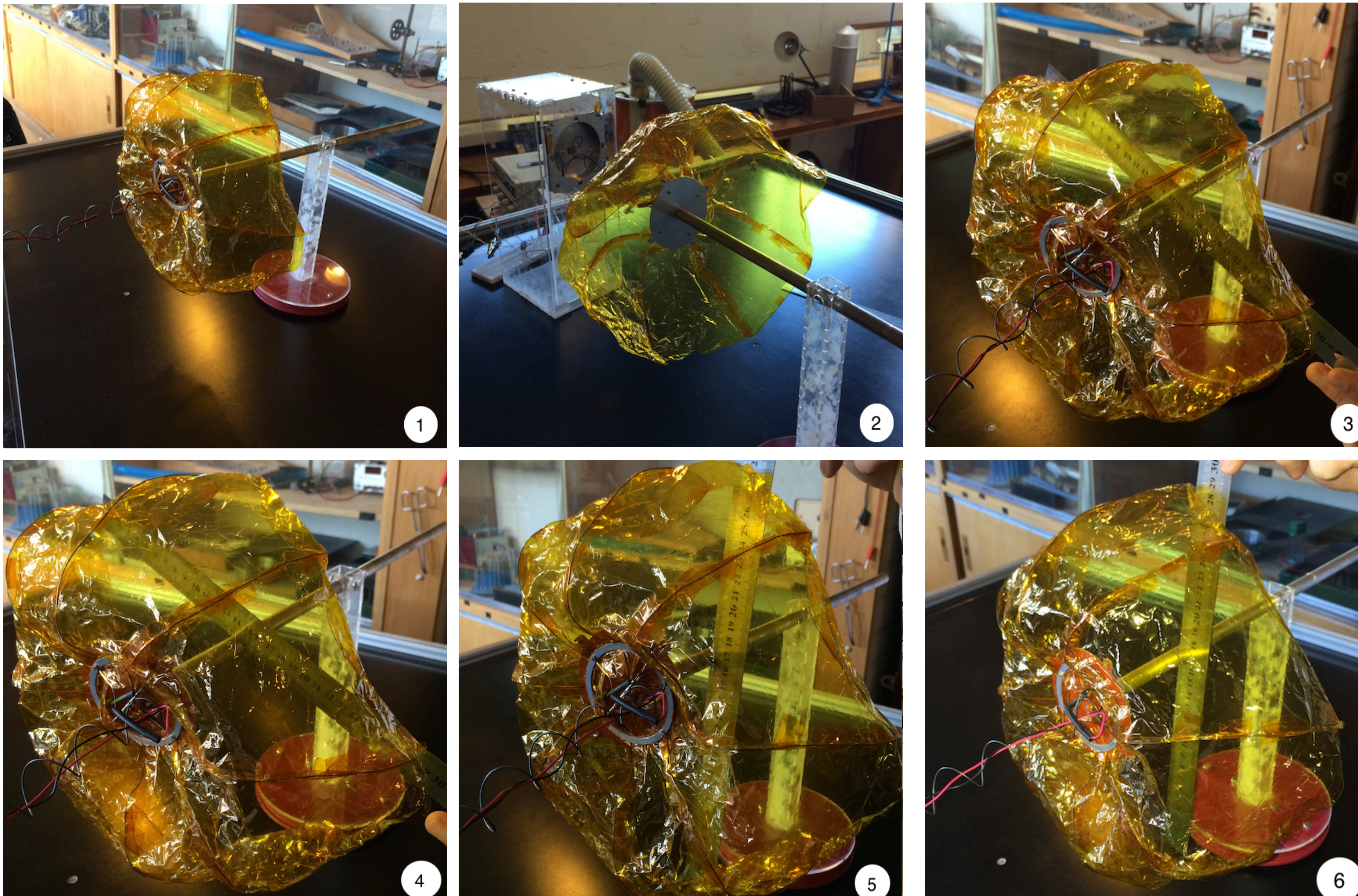
Test 3 – Sail Deployment Tests



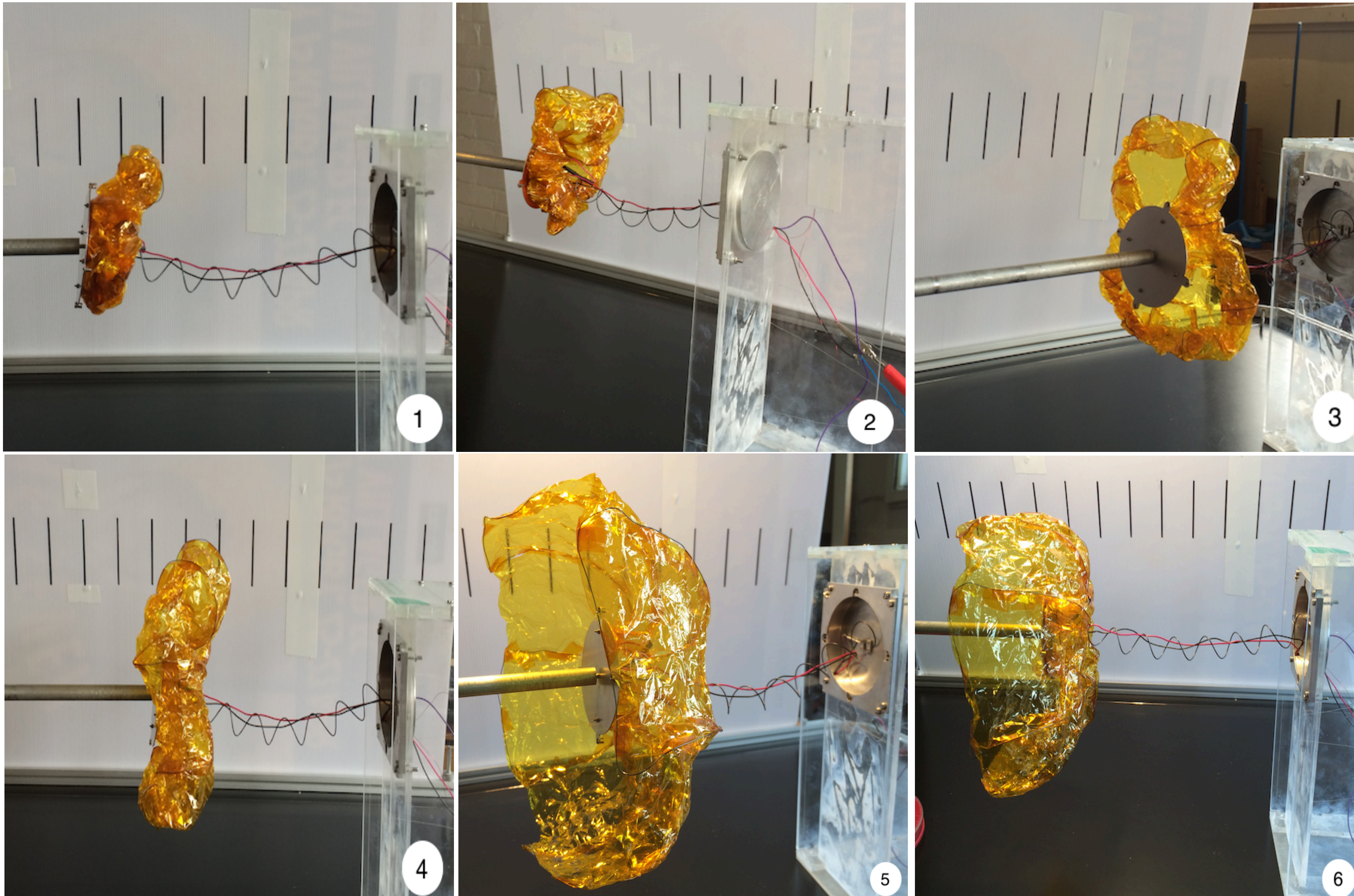
Test 3 – Sail Deployment

Test condition: 1G lab environment, DC power supply



Test 3 – Third Sail Deployment

Test condition: 1G lab environment,
DC power supply, Square Signal Generator



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Test 3 – Final Integrated Test

Figure 6.36 Images of the ADDUCT device once the Nitinol helical boom has been deployed.

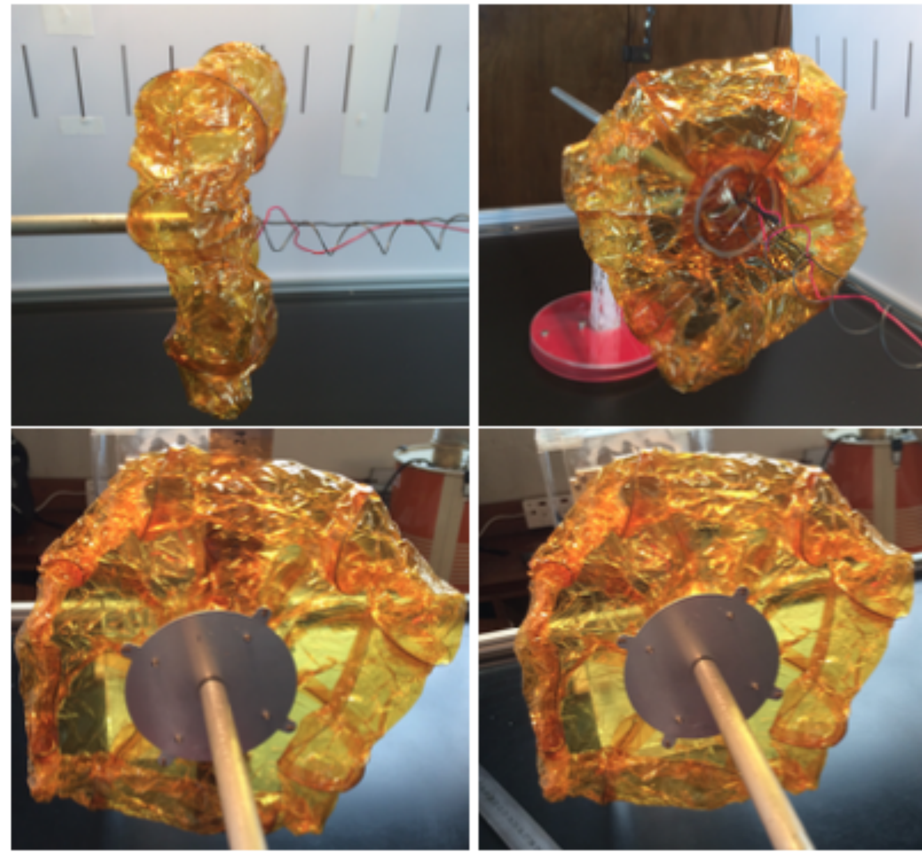

Figure 6.37 Deployment of the sail following the release of the lid in the final integration test.

Hysteresis affecting the boom and sail deployment. Current had been applied 15 times to the sail. Length: 24.5cm. Frontal diameter: 24cm and frontal area: $0.045m^2$.

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Budgets

Final Dimensions

Table 6.12 *Final ADDUCT device*

Dimension	Value (mm)	Limits (mm)
Height	17.66/17.20	Protrusions <6.5
Side 1 Width	98.02	< 100
Side 2 Width	98.00	< 100
Side 3 Width	98.00	< 100
Side 4 Width	98.02	< 100
Usable Length Occupied	9.98	< 10
Unusable Space Occupied	6.30	< 7

Cost Budget

Table 6.10 *Summary of Prototype Cost*

Prototype Cost	Total Project Cost
R 6 223 ($ 482)	R 11 554 ($ 895)

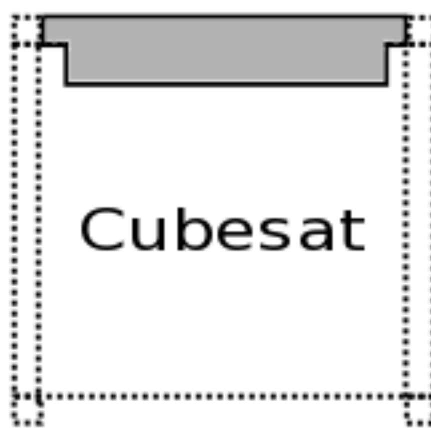
Mass Budget

Component	Mass (g)
Housing	88.7
Sail	11.0
Sail Fastener	1.7
Nitinol helical boom	4.5
Lid	12.3
Cover plate	9.8
Total	128.0

Power Budget

Table 6.13 *Power and energy consumption of the ADDUCT device.*

	Burn wire	Helical boom	Four sail frames
Voltage (V)	0.16	N/A	4.4
Amp (A)	1	1.5	1.5
Resistance (Ω)	N/A	1.24	N/A
Power (watt)	0.16	2.79	6.6
Time (seconds)	5	120	120
Time (hours)	0.0014	0.033	0.033
Energy (watt.hours)	0.000224	0.09207	0.2178
Total Energy (watt.hours)	0.310		



Conclusion and Future Works

- ADDUCT device was designed and tested up to TRL 4 successfully. It also provided:
  - Deorbit << 25 years, light mass and correct size
  - Passive Aerodynamic Stability
  - Low interference with an antenna
  - Potential to increase the radar cross-section
  - Potential for Sail to become antenna

- Redesign version 2 with improvements, such as:
  - Improve the burn wire mechanism
    - Reduce the groove size, insert a circular board with holes to improve reliability.
  - Machine out the housing to reduce mass
  - Change the aluminium to 7075, 6061, 5005 or 5002 anodised aluminium.
  - Substitute the Nylon with Vectran
  - Drill ventilation holes.
  - Increase Rail Indentations from 5.50 mm to 7.50 mm
  - Insert Camera for deployment verification
  - Design Sail Connection board
  - Improve Nylon Cable secured location

Thank you for your attention

Any questions?

References

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