A New Generation of Deployable Optical Systems to Increase Small Satellite Capability

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CEOI Project Showcase
10th December 2018
ECSAT, Harwell, UK.

Surrey Space Centre & SSTL

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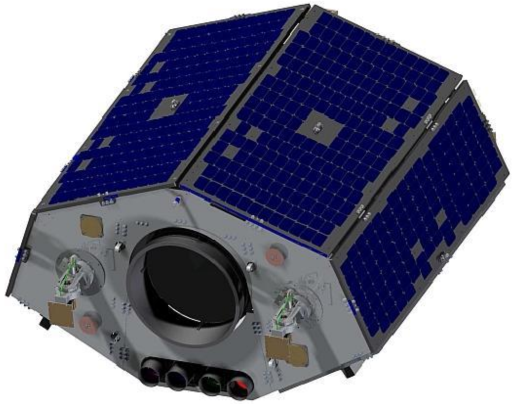
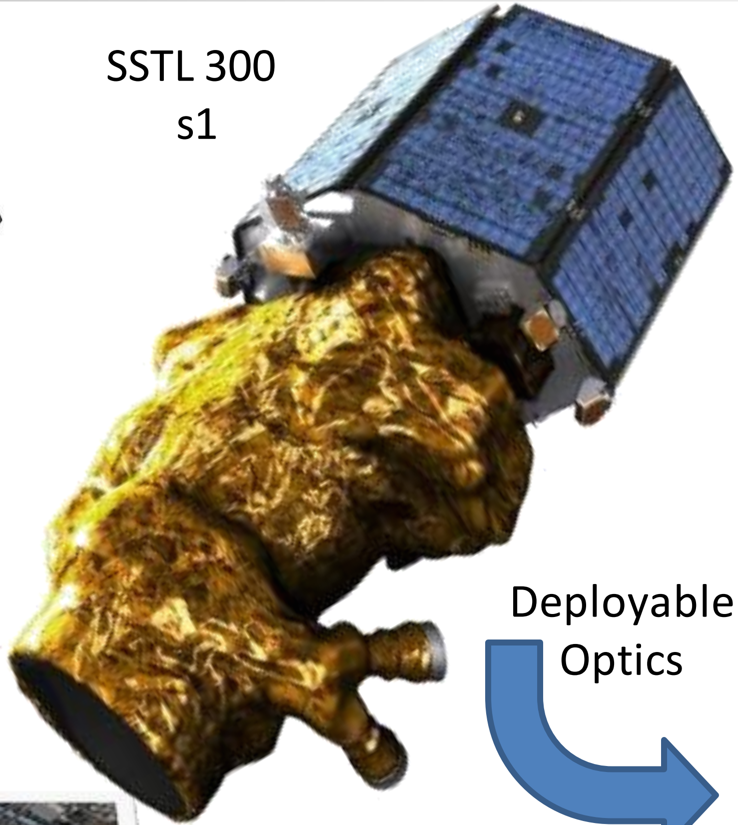


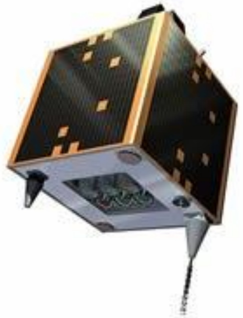
SSTL 300
(2.5m GSD Panchromatic)

SSTL 300
s1



SSTL 150

Deployable
Optics



SSTL 100
(22m GSD)

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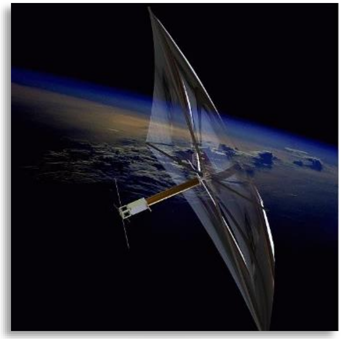
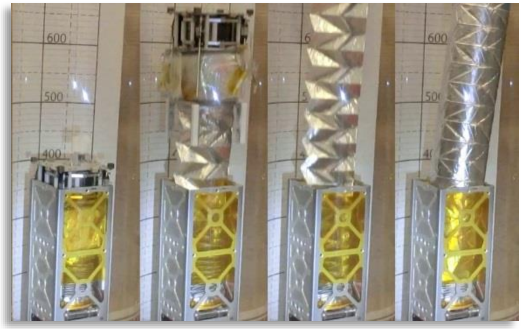
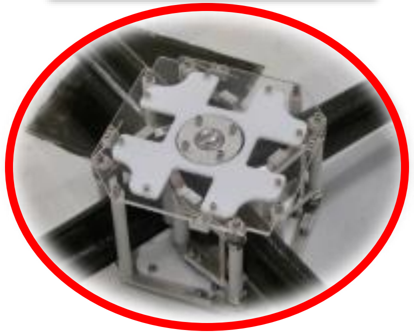
Project Objectives

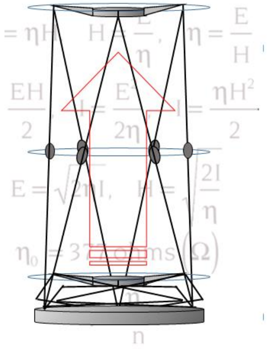
The specific project objectives were:

1. To define (and subsequently refine) a set of requirements for deployable structures to support the optical elements.
2. To determine the best technology to meet the requirements.
3. To design, analyse and refine/optimize a concept for the prototype (proof of concept) to assess its capabilities prior to prototyping, & to prepare test and validation plans.
4. To manufacture and assemble a single segment of the truss and perform repeated functional testing, critically reviewing results and impact on full prototype.
5. To manufacture and assemble the full prototype (including potential modifications resulting from the single element test activity) and perform repeated functional testing and desired environmental testing.
6. To evaluate the final design and both functional and environmental test results against original requirements.



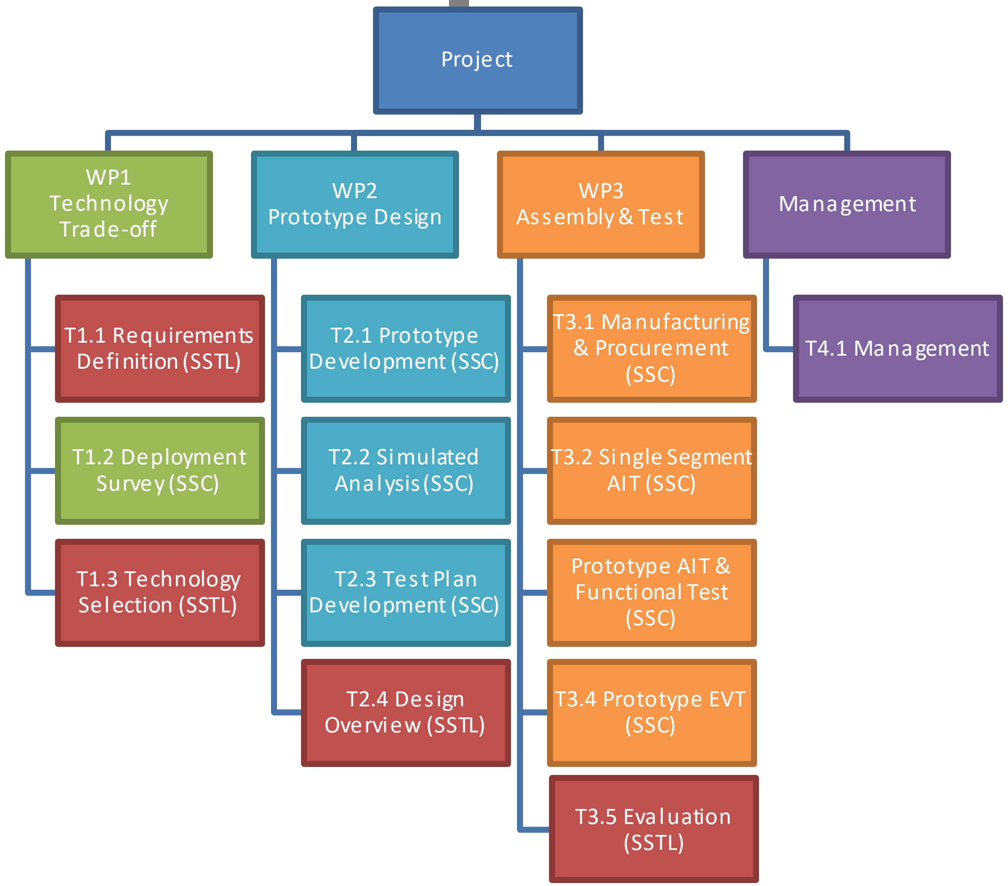






Mallikarachchi, H. M. Y. C. & Pellegrino, S. (2014), 'Design of ultrathin composite self-deployable booms', Journal of Spacecraft and Rockets
Feng, X., Li, C., Ren, G., "Medium-sized aperture deployable telescope for microsatellite application", SPIE 8196, International Symposium on Photoelectronic Detection and Imaging 2011: Space Exploration Technologies and Applications,

Project WBS & Schedule



ID	Description	Du te	Planned Delivery Date
D1.1	Requirements Definition	M1	14-Oct-17
D1.2	Technology Selection report	M3	13-Dec-17
D2.1	Design & Analysis report	M8	14-May-18
D2.2	Test Plan report	M8	14-May-18
D3.1	Single Segment Test report	M12	14-Sep-18
D3.2	Prototype	M14	14-Nov-18
D3.3	Test Results & Evaluation	M14	14-Nov-18
D4.1	Final Project report	M15	13-Dec-18

WP	Description	Start	Finish
1	Technology Trade off	14-Sep-17	13-Dec-17
2	Prototype Design	2-Jan-18	14-May-18
3	Assembly & Test	14-May-18	13-Dec-18

ID	Description	Month	Delivery Date	Actual Date	Status
MS1	Kick Off	M0	14-Sep-17	14-Sep-17	Complete
MS2	Technology review (TR)	M3	13-Dec-17	28-Feb-18	Complete
MS3	Proof of Concept (CDR)	M8	14-May-18	1-Aug-18	Complete
MS4	Final Project Review (FPR)	M15	13-Dec-18	Feb 19	

Requirements

These requirements are based upon the flight model and therefore the breadboard/engineering model may not meet all requirements. The breadboard will be used to de-risk some of the requirements.

General Requirements,

The design shall produce **controlled and repeatable deployment** (in a 1g environment, in the axial upward direction)

The design shall **not include hold down**/release mech. (secondary mirror assy can be considered rigidly grounded during launch

The design shall be constructed from **space compatible materials**

The design shall be **low shock**

Telemetry should be provided for successful deployment

Performance Requirements

Deployment repeatability shall be < 1mm at three reference points on the secondary interface flange (**secondary mirror** assembly of mass **1 kg**)

Thermoelastic distortion over the operational temperature range, shall cause a relative motion of the secondary mirror with respect to the primary of less than XXum decentration, XX deg tilt and XXum separation.

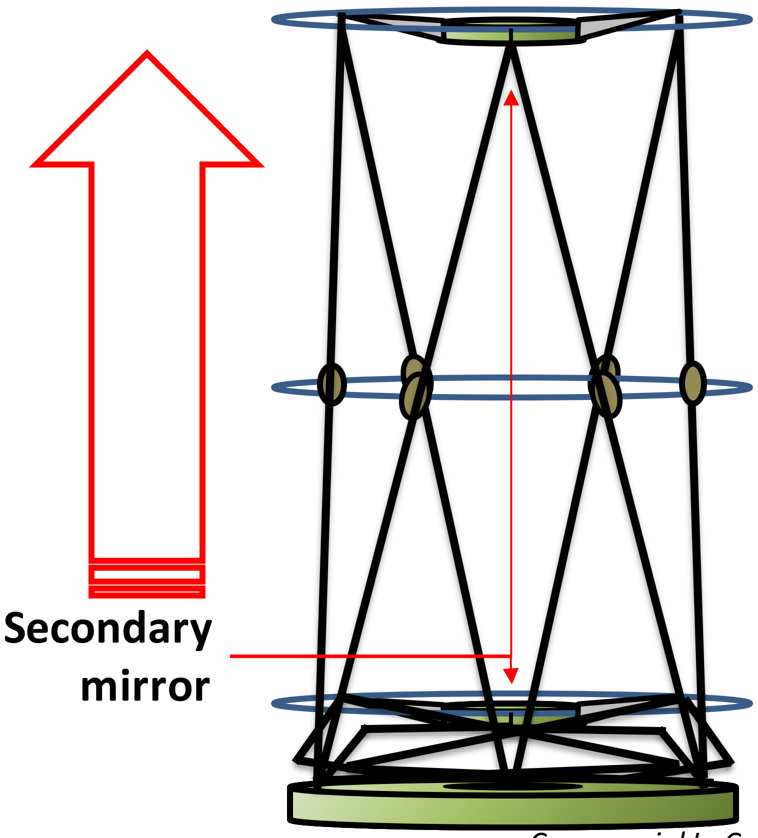
Distortions due to moisture shrinkage from Launch + 4wks to end of life shall not exceed the thermoelastic distortion requirements (BY ANALYSIS ONLY)

The design should **minimise mass** and shall not exceed 2kg

The design should **minimise the length of the imager in the launch configuration**

The design should **minimise the volume** in the launch configuration. In the launch configuration no part of the design shall be outside of a 450 x 450mm box

In the **deployed** configuration the first modal **frequency should be > 100 Hz**



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Requirements

These requirements are based upon the flight model and therefore the breadboard/engineering model may not meet all requirements. The breadboard will be used to de-risk some of the requirements.

Optical Requirements

The secondary mirror assembly shall be deployed from its stowed position close to the primary to it final position shown in Figure

The connection to the secondary mirror assembly in both the deployed and launch configuration shall be outside of the 300mm clear aperture

In the deployed configuration there should be **no parts of the structure in the light path**.

The design shall also be compatible with a **light management system/baffles**.

The required accuracy of baffle deployment is approx. 0.5 mm

In the deployed configuration the imager should be protected from the space environment by a complete **MLI blanket** from the plane of the Primary mirror bulkhead to the top of the secondary mirror assembly

The design shall support a harness of 10 24awg wires between the primary mirror bulkhead and the secondary mirror assembly.

Load Requirements

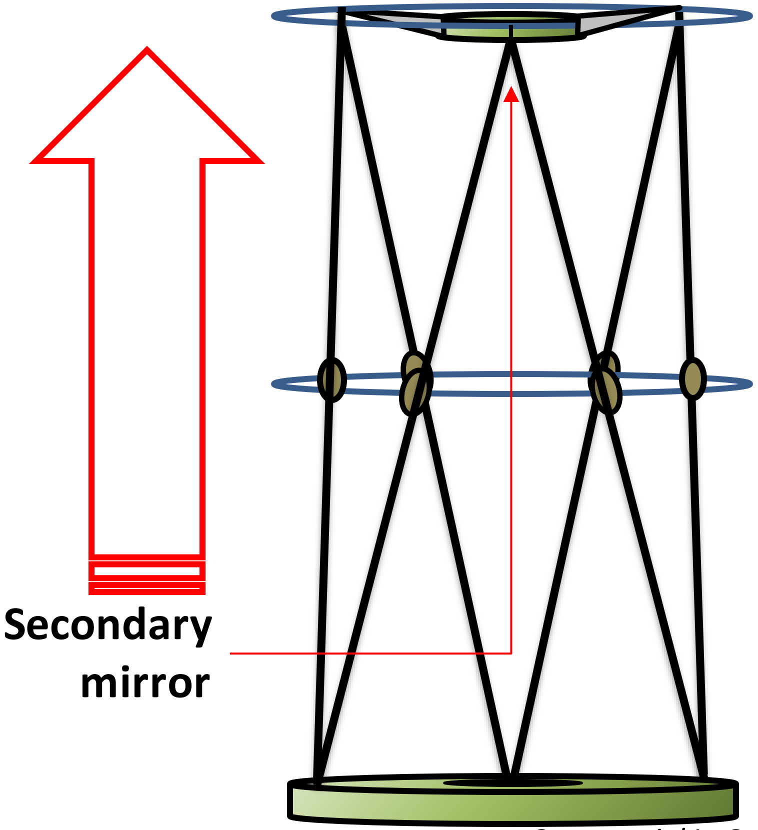
The Design shall be compatible with the following **temperature load cases**:

Integration temperature 20C, Operational temperature -5 to 0C mean superimposed with a gradient across the barrel of 5C (TBC)

Survival temperature -20C to +50C

The design shall withstand **QSL** in the launch configuration of **50g** in any axis

In the **launch configuration** the design should have a first modal frequency > **140Hz**



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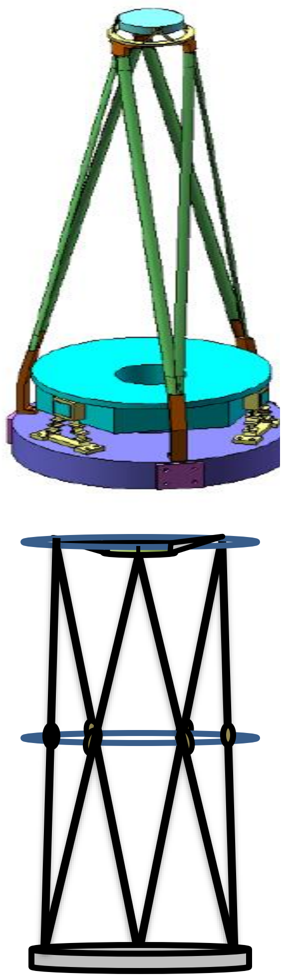
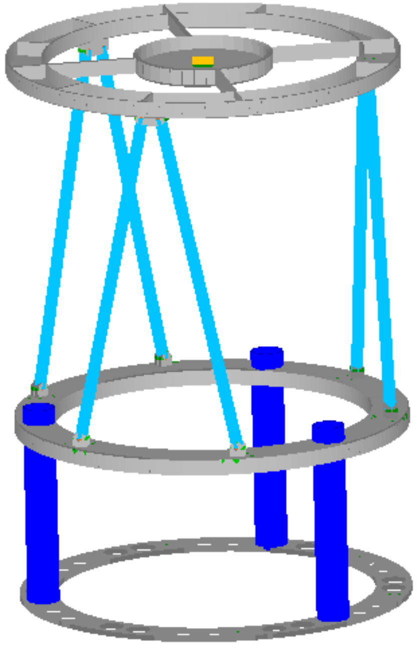
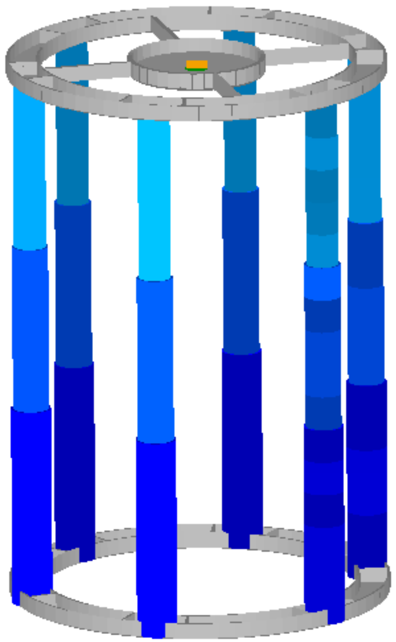
Configuration trade offs



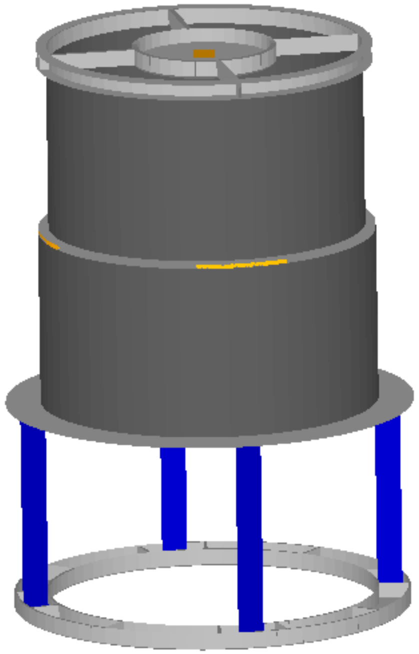
Deployable framework



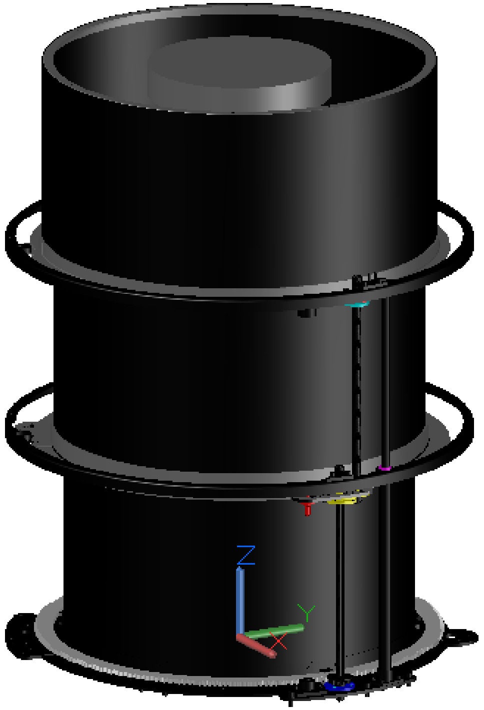
Truss



Telescopic Tubes



Telescopic Barrel



Full Telescopic Barrel

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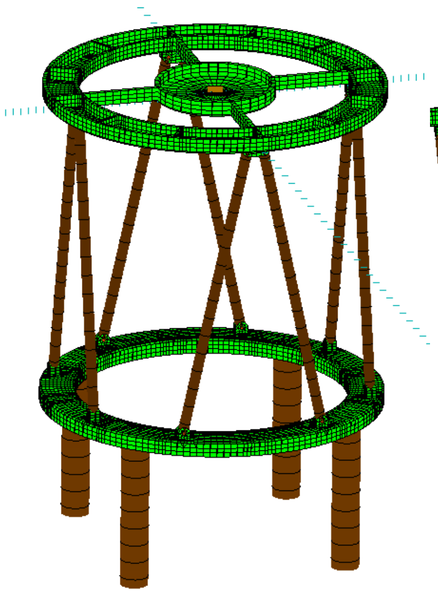
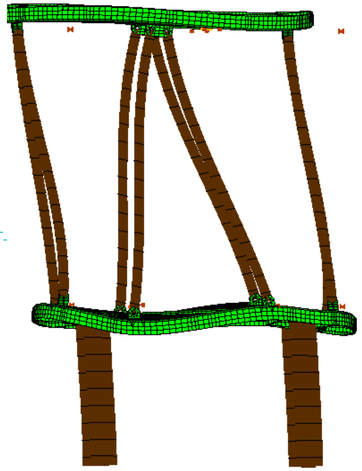
Modal analyses

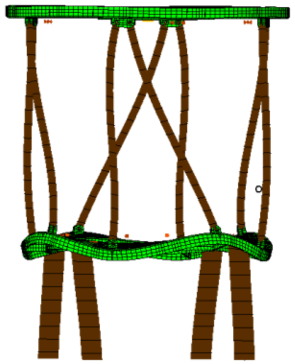


BaseLine4Struts.dat

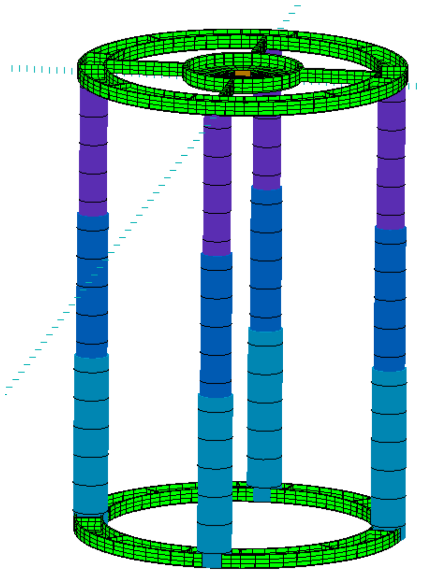


Modes 1 & 2 Typ
Bend / Shear

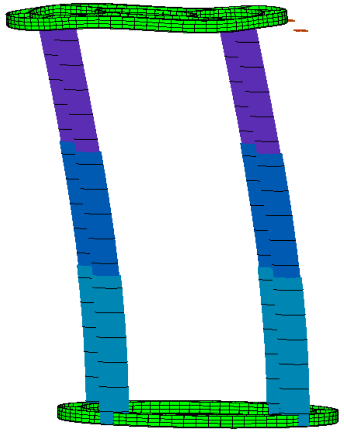
MODE	CYCLES
1	94.46
2	94.59
3	158.28
4	176.93
5	270.73



Modes 3
Torsional

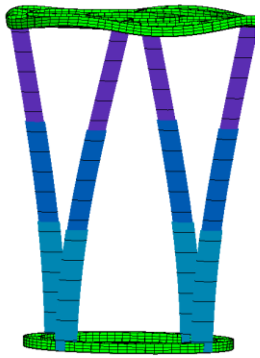


BaseLineTUBE4.dat

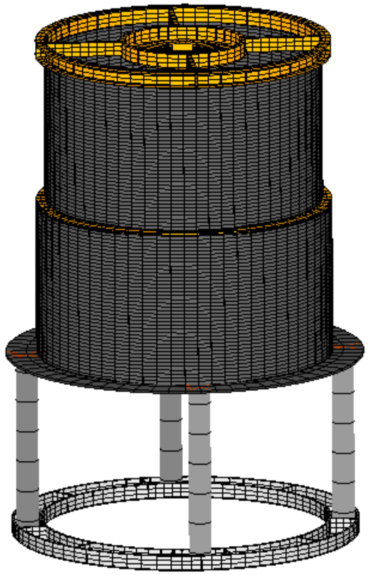


Modes 1 & 2 Typ
Bend / Shear

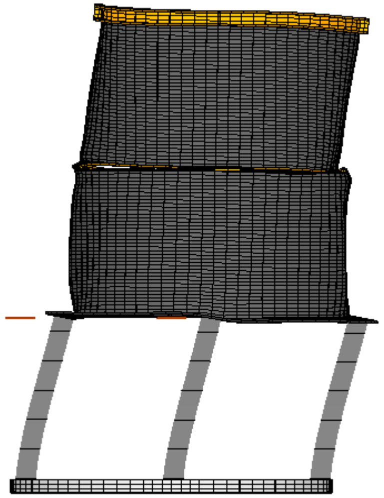
MODE	CYCLES
1	83.02
2	83.05
3	138.67
4	142.11
5	422.24



Modes 3
Torsional

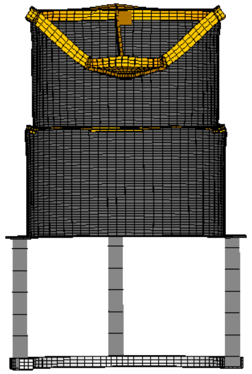


NewConceptBaseLine4.dat



Modes 1 & 2 Typ
Sway / Shear

MODE	CYCLES
1	127.02
2	127.02
3	143.90
4	226.97
5	304.47



Modes 3
Panting

Configuration trade offs

- **Truss**
  - Simple construction
  - Low mass
  - Passive deployment no electrical sys.

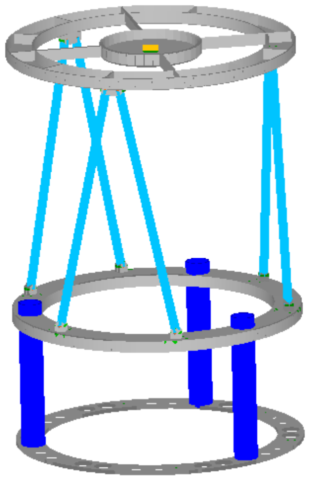
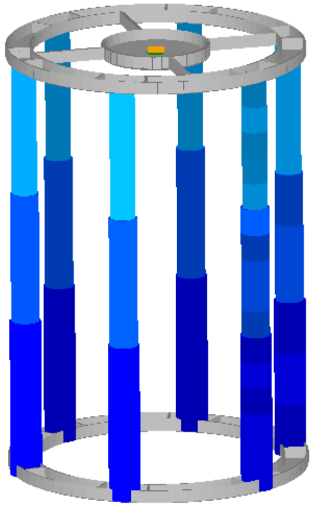
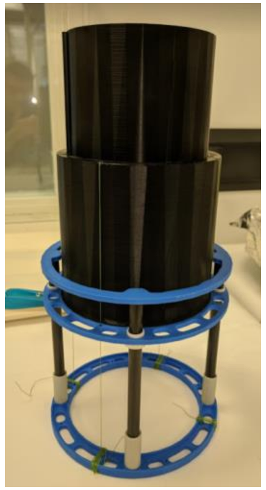
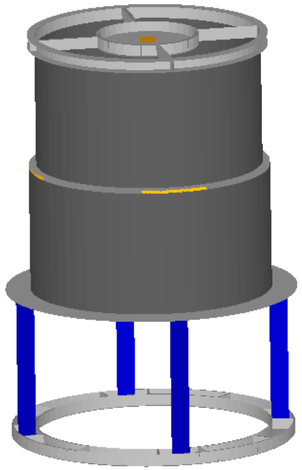
  - Difficult to maintain floor envelope
  - Fails modal requirement
  - Unlikely to meet thermal distortion requirements with Al joints
  - Passive deployment high shock/risk
  - Light management difficult

- **Telescopic Tubes**
  - Simple construction
  - Low mass
  - Fits in space envelope
  - Scalable

  - Fails modal requirement
  - Deployment difficult
  - Locking-out complications
  - Light management difficult

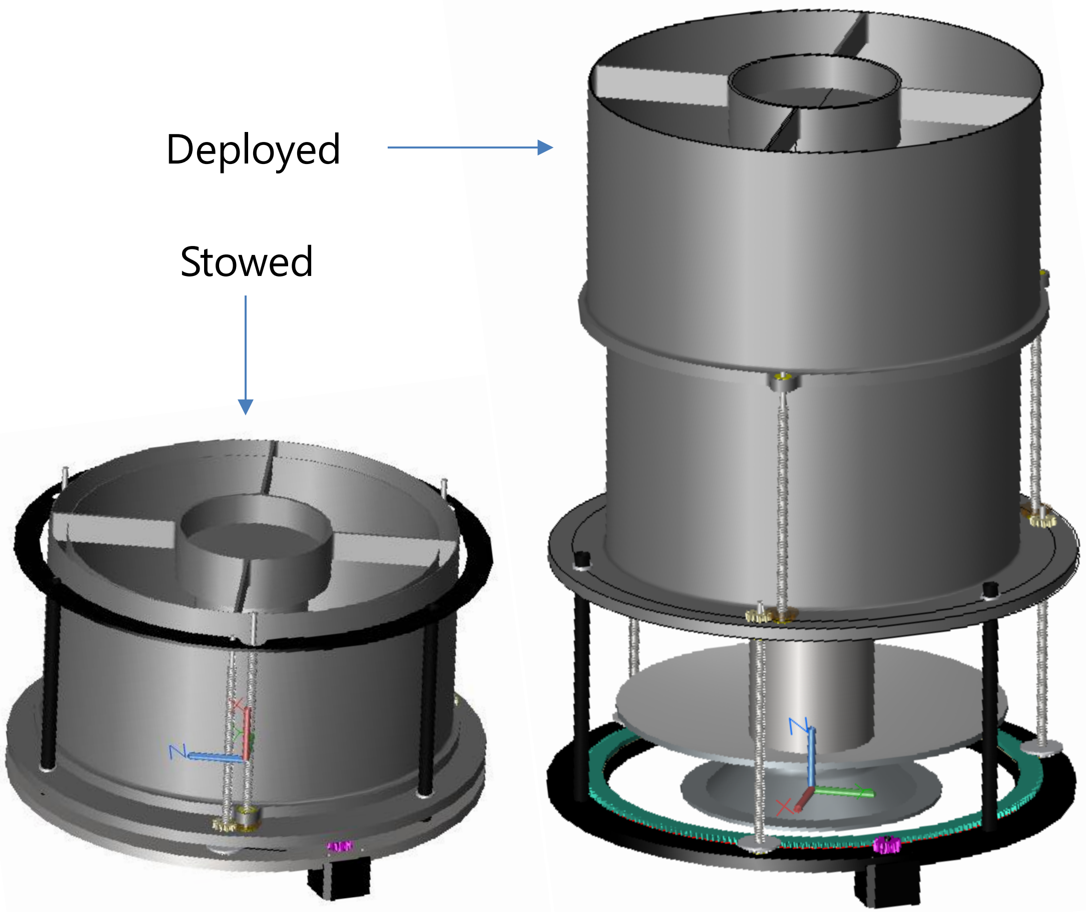
- **Telescopic Barrel**
  - Meets space envelope requirement
  - Meets modal requirement
  - Meets thermal distortion requirement
  - Active deployment – low risk
  - Light management naturally achieved

  - Difficulty in carbon barrel manufacture
  - Mass
  - Complex drive (mechanical)
  - Requires electrical system

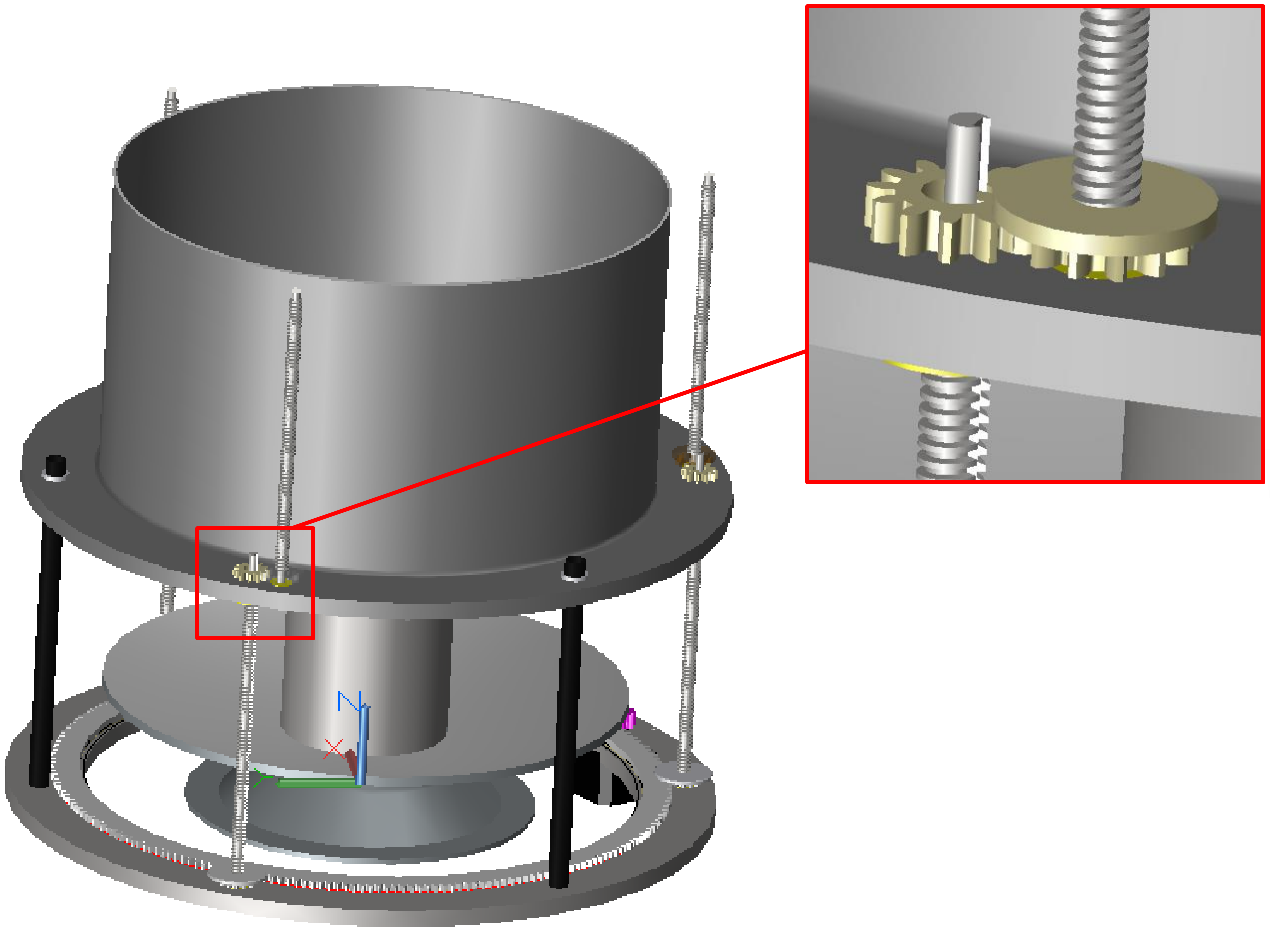






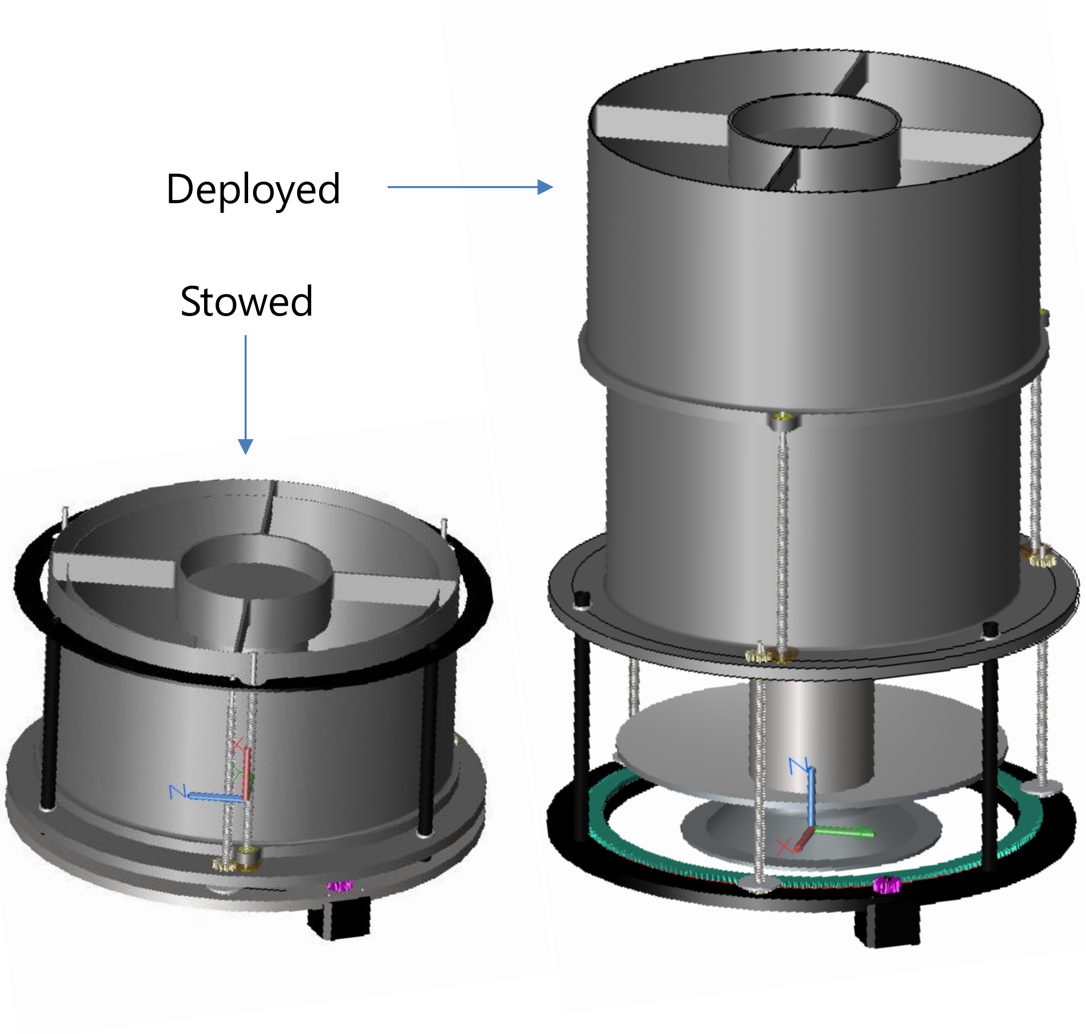
Trade-off table

Trade-off Criteria	Truss	Telescopic Tubes	Telescopic Barrel
Mass	3	2	2
Length Reduction	2	2	2
Thermoelastic Stability	1	3	3
Complexity	2	1	3
Scalability (deployment length)	1	2	3
Scalability (general)	1	2	3
Light management	1	1	3
Cost	3	2	1
Repeatability	1	3	3
Breadboard cost (risk of schedule)	3	2	1
Controlled Deployment	1	3	3
Micro vibration Load	1	1	3
Total	20	24	**30**



Deployment driving mechanism





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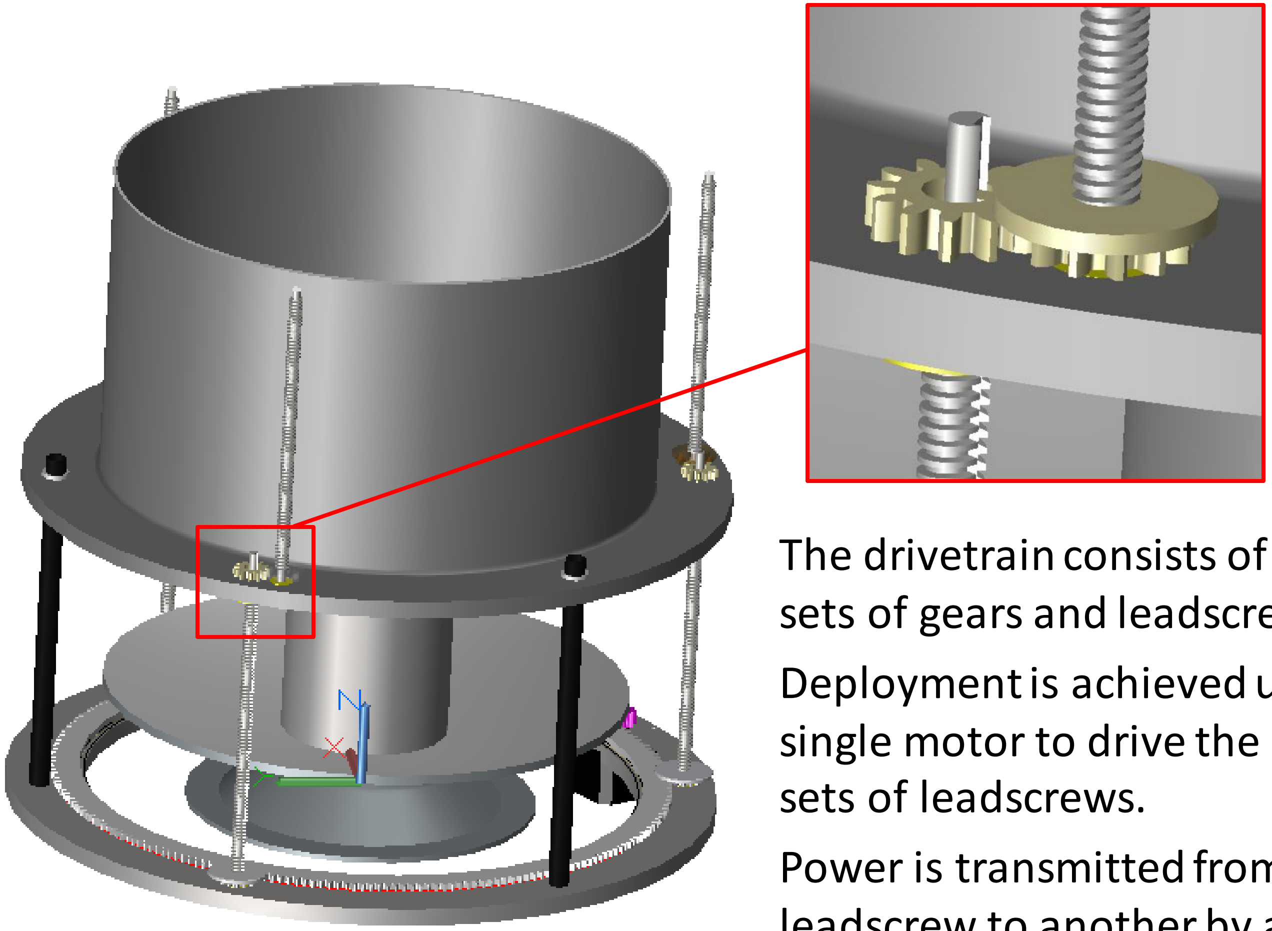
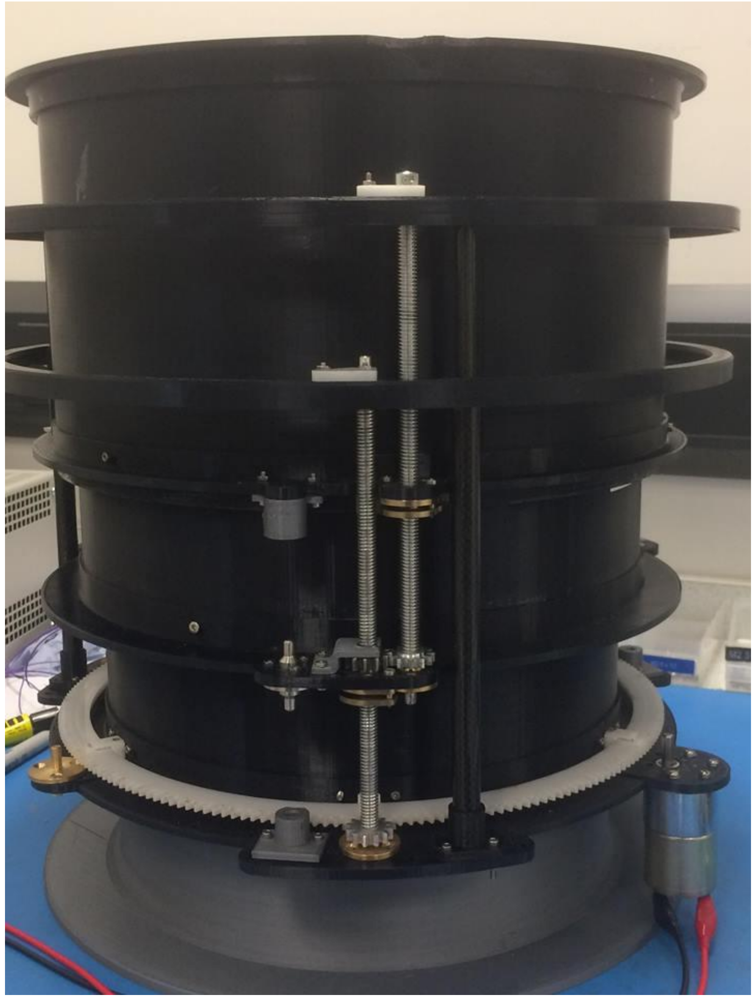
Deployment driving mechanism



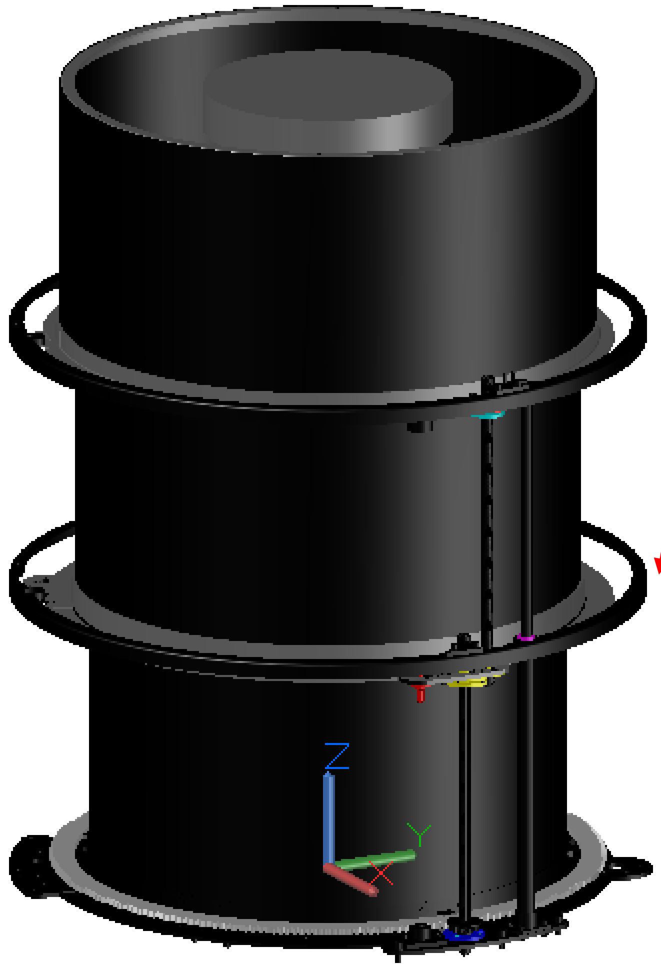


The drivetrain consists of three sets of gears and leadscrews.

Deployment is achieved using a single motor to drive the three sets of leadscrews.

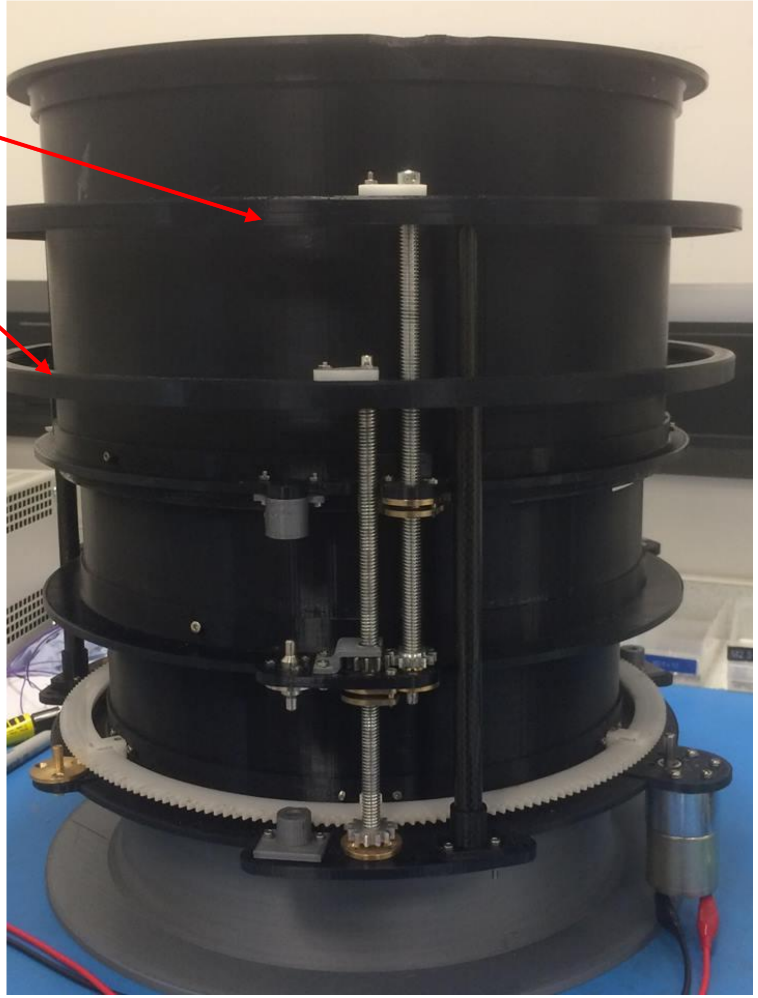
Power is transmitted from one leadscrew to another by a keyed gear that travels up the leadscrew during deployment.

Secondary structure



A **secondary outer structure**, in the forms of two rings, which are also deployed:

- Restrains the top of the leadscrews
- Provides an attachment point for the MLI shielding
- Prevents wire harnessing engrossing on the mechanism.



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Deployment is achieved using a single motor to drive the three sets of leadscrews.

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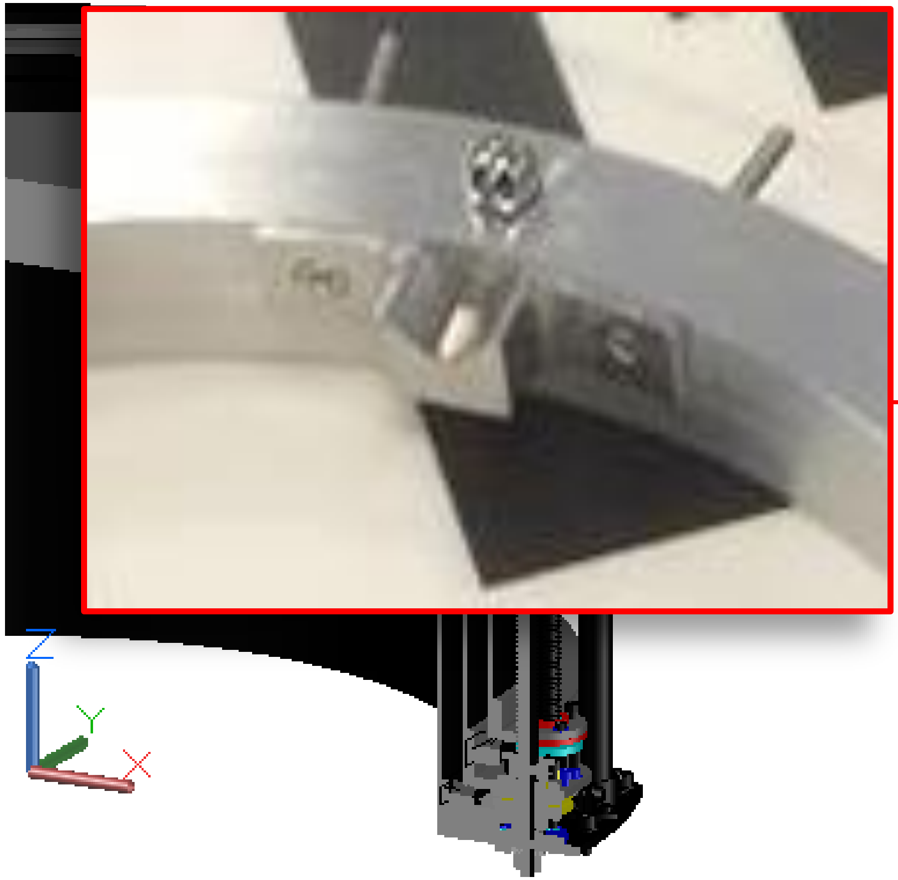
lockout

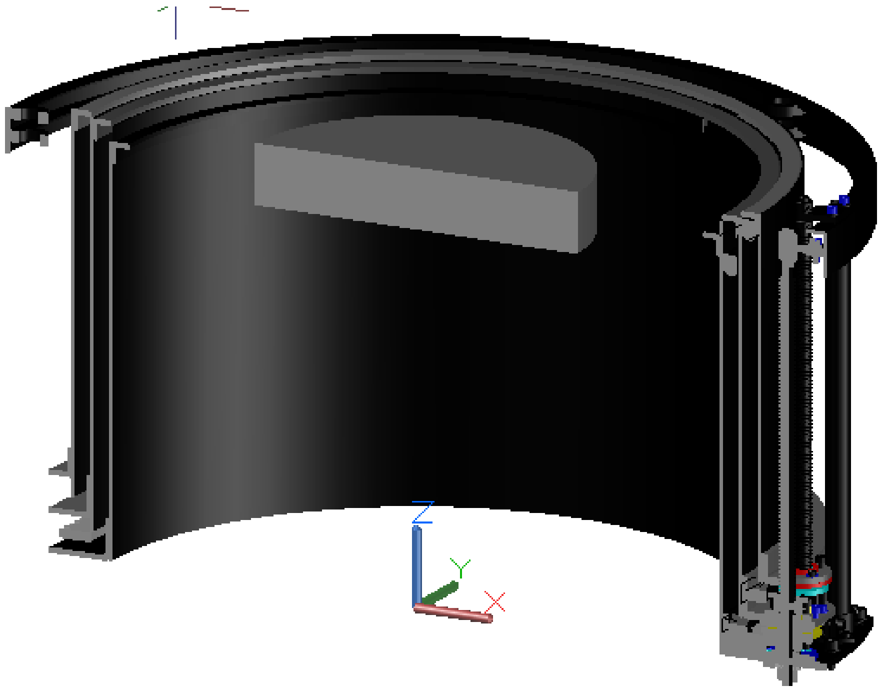
Invar ball and vee arrangement locks and aligns the structure in a unique statically determinate deployed configuration.

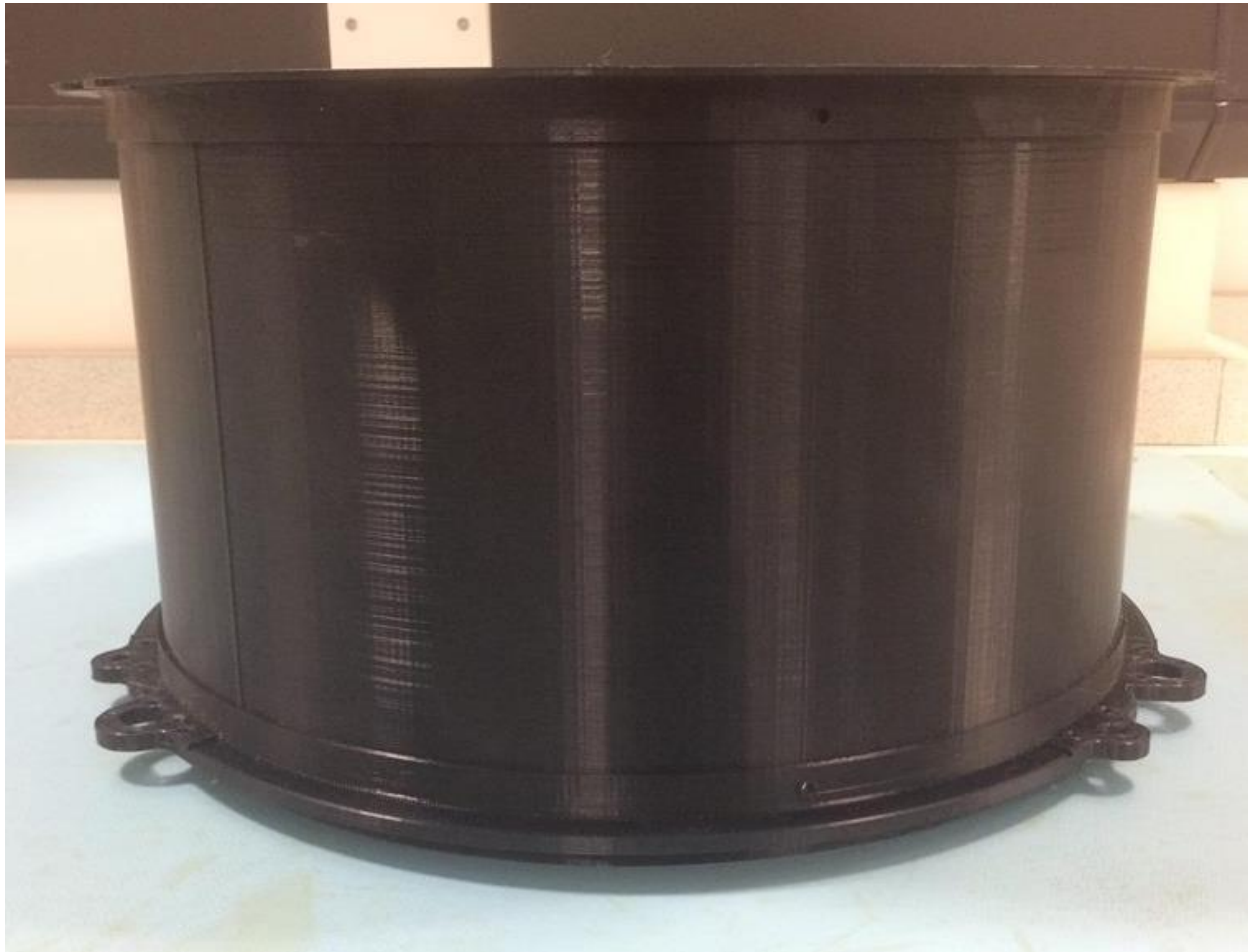
Invar ensures a low coefficient of thermal expansion.



Barrel and flanges Manufacturing

- Each barrel has a stiffener flange top and bottom
- All flanges and barrels are carbon fibre reinforced polymer to meet the thermal requirements.
- Flanges provide a mounting surface for the deployment mechanism i.e. gear train, leadscrew nuts, lockout pins, microswitch





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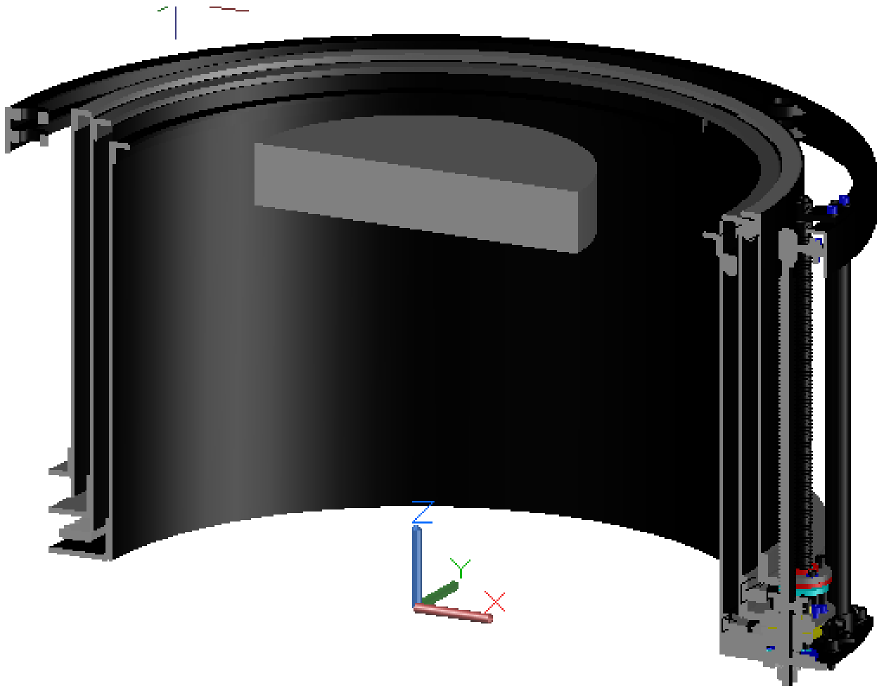
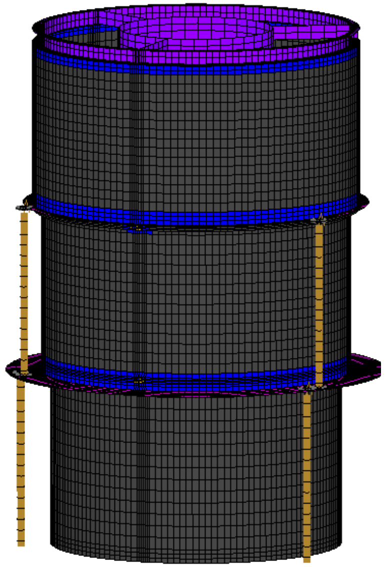
Barrel and flanges Analysis

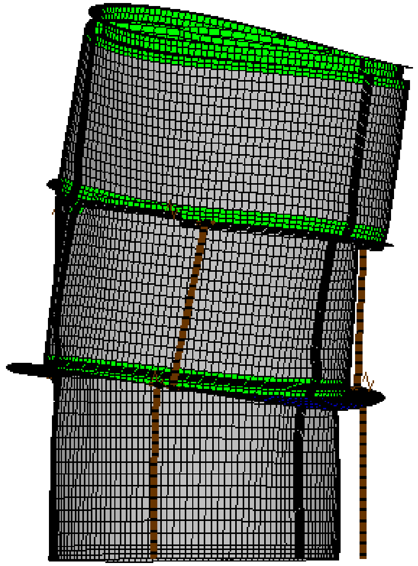
- Each barrel has a stiffener flange top and bottom
- All flanges and barrels are carbon fibre reinforced polymer to meet the thermal requirements.
- Flanges provide a mounting surface for the deployment mechanism i.e. gear train, leadscrew nuts, lockout pins, microswitch



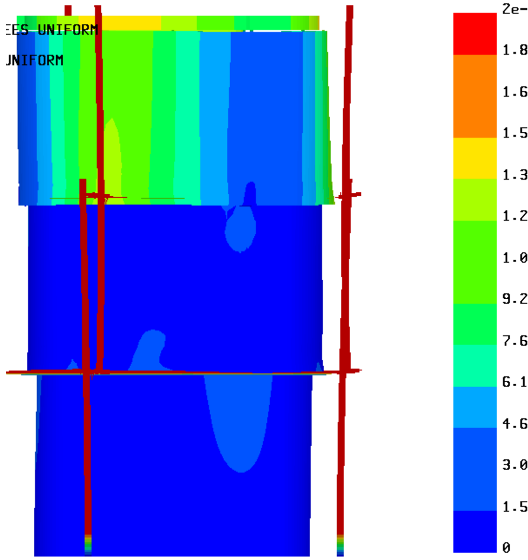
FEM Deployed



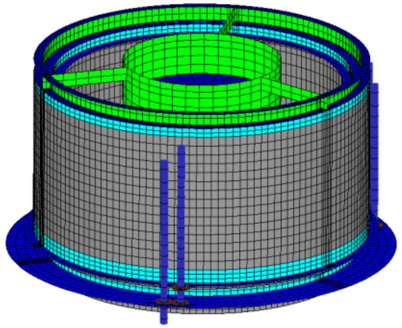
Modal Analysis



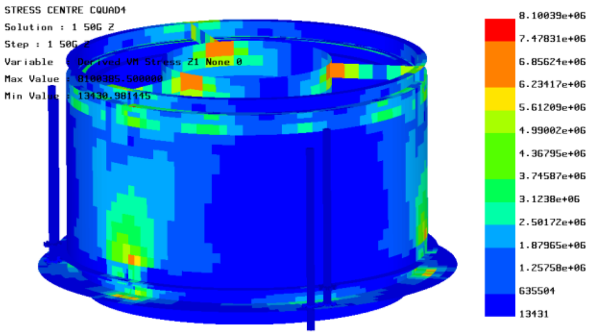
Thermoelastic



FEM Stowed



Quasi Static Analysis



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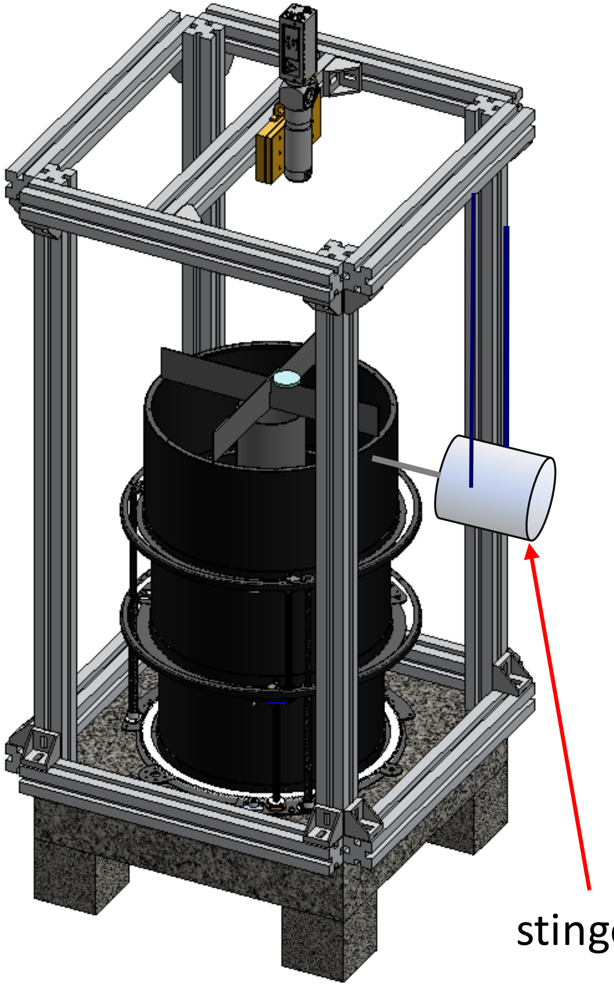
Testing

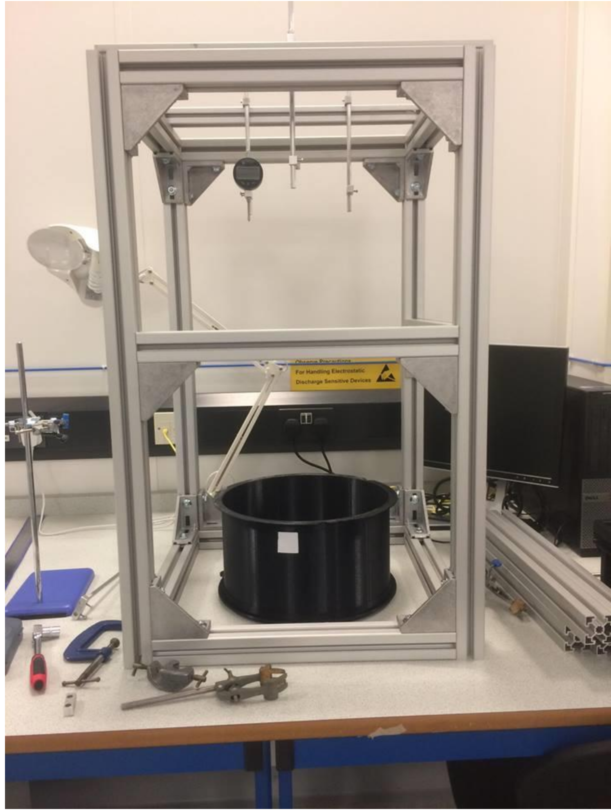
Testing will consist of deployments with and without MLI, Harness, Additional Mass

Test sequence:

- Ambient temperature deployment 1 kg, 2kg mass
- Deployed frequency test (minishaker – stinger)
- Deployment repeatability test (DTIs)
- Thermal stability test (autocollimator & mirrors)
- Life testing (20+ deployment)
- Cold deployment (-5C) at ½ power
- Repeat – Deployed Frequency
- Repeat – Deployment repeatability



stinger -minishaker



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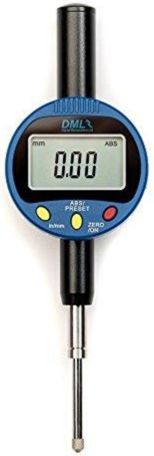
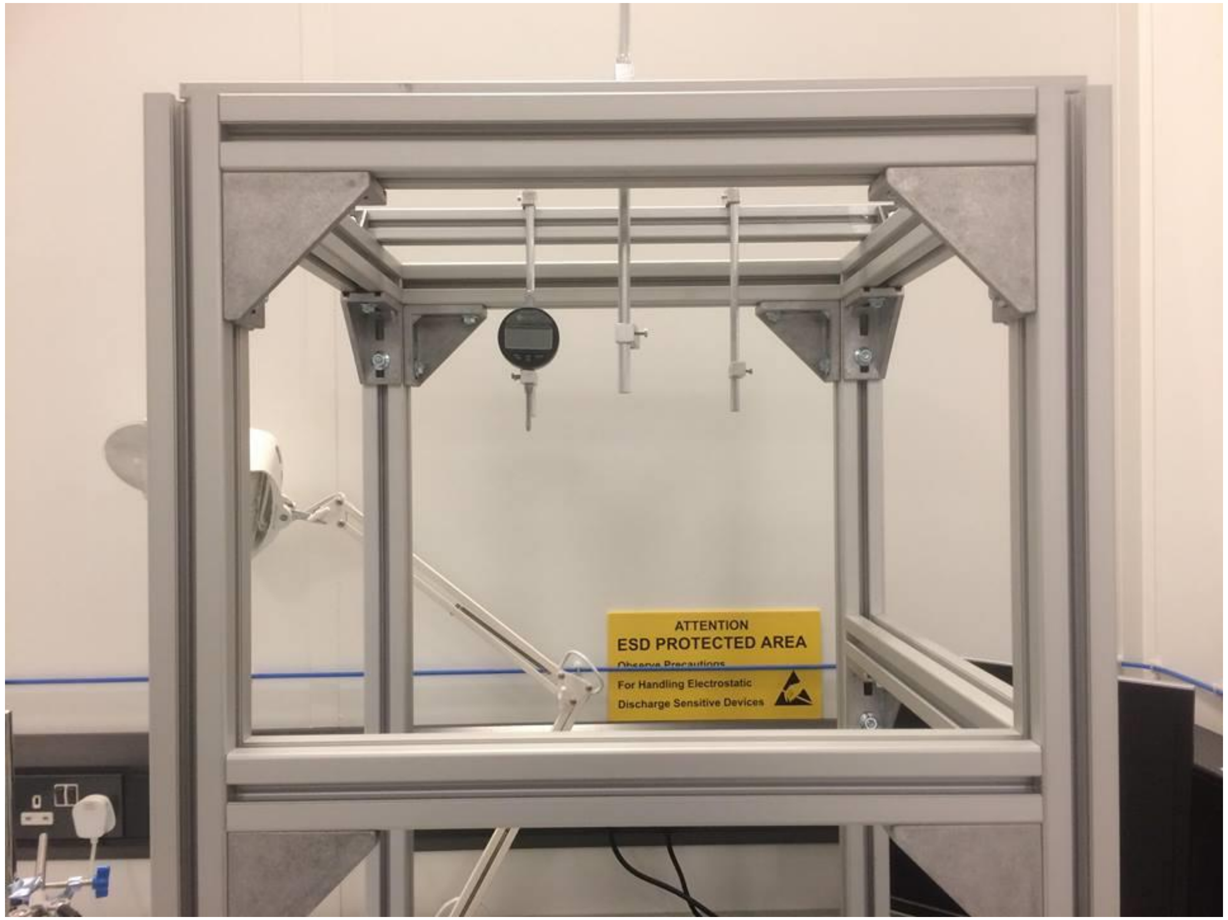
Testing Repeatability

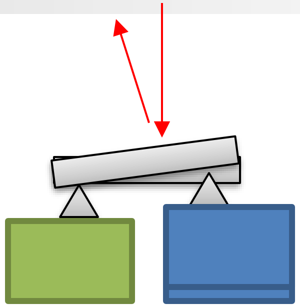
- The breadboard model will be tested for its vertical repeatability using three DTIs digital dial gauges.
- The three vertical positions will also give the repeatability of tilt.
- Further digital dial gauges will be positioned to measure the radial repeatability.

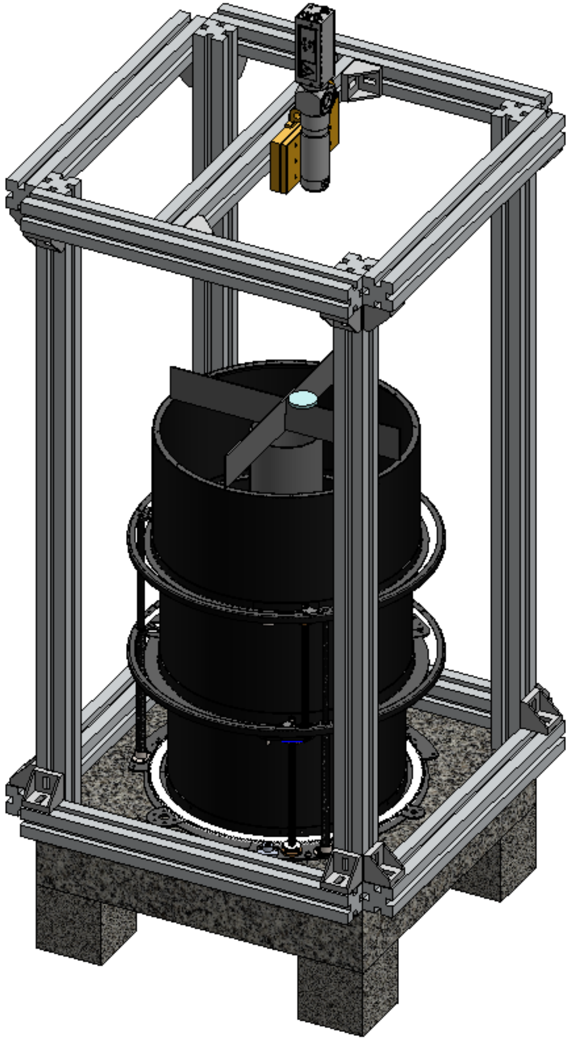




Thermal Stability Testing

- The thermal tilt stability will be measured using an autocollimator and a series of mirrors.
- From -5C a reading on the collimator will be taken.
- Then at 0C another reading will be taken to quantify tilt of the secondary mirror.
- The rest of the thermal verification has been conducted using FEA.





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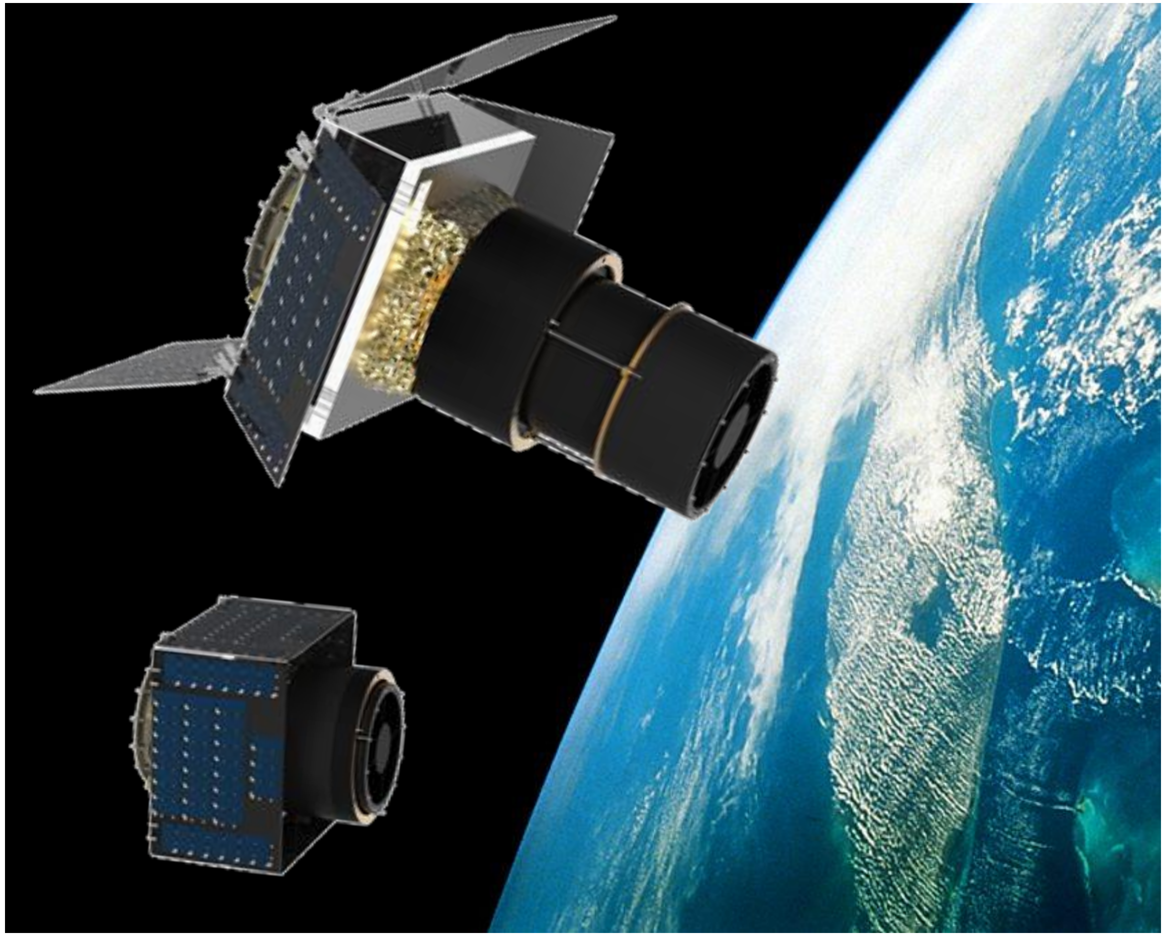
Summary

Concept de-risked to a level that can be implemented in space missions



Project

- WP1 Technology Trade-off
  - T1.1 Requirements Definition (SSTL)
  - T1.2 Deployment Survey (SSC)
  - T1.3 Technology Selection (SSTL)
- WP2 Prototype Design
  - T2.1 Prototype Development (SSC)
  - T2.2 Simulated Analysis (SSC)
  - T2.3 Test Plan Development (SSC)
  - T2.4 Design Overview (SSTL)
- WP3 Assembly & Test
  - T3.1 Manufacturing & Proc. (SSC)
  - T3.2 Single Segment AIT (SSC)
  - Prototype AIT & Functional Test (SSC)
  - T3.4 Prototype EVT (SSC)
  - T3.5 Evaluation (SSTL)
- Management
  - T4.1 Management

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Acknowledgements:
CEOI: Fast Track, New Generation of Deployable Optics

Thank you

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