Autonomous Assembly of a Reconfigurable Space Telescope (AAReST) – A CuubeSat / Microsatellite Based Technology Demonstrator

SSC-VI-5

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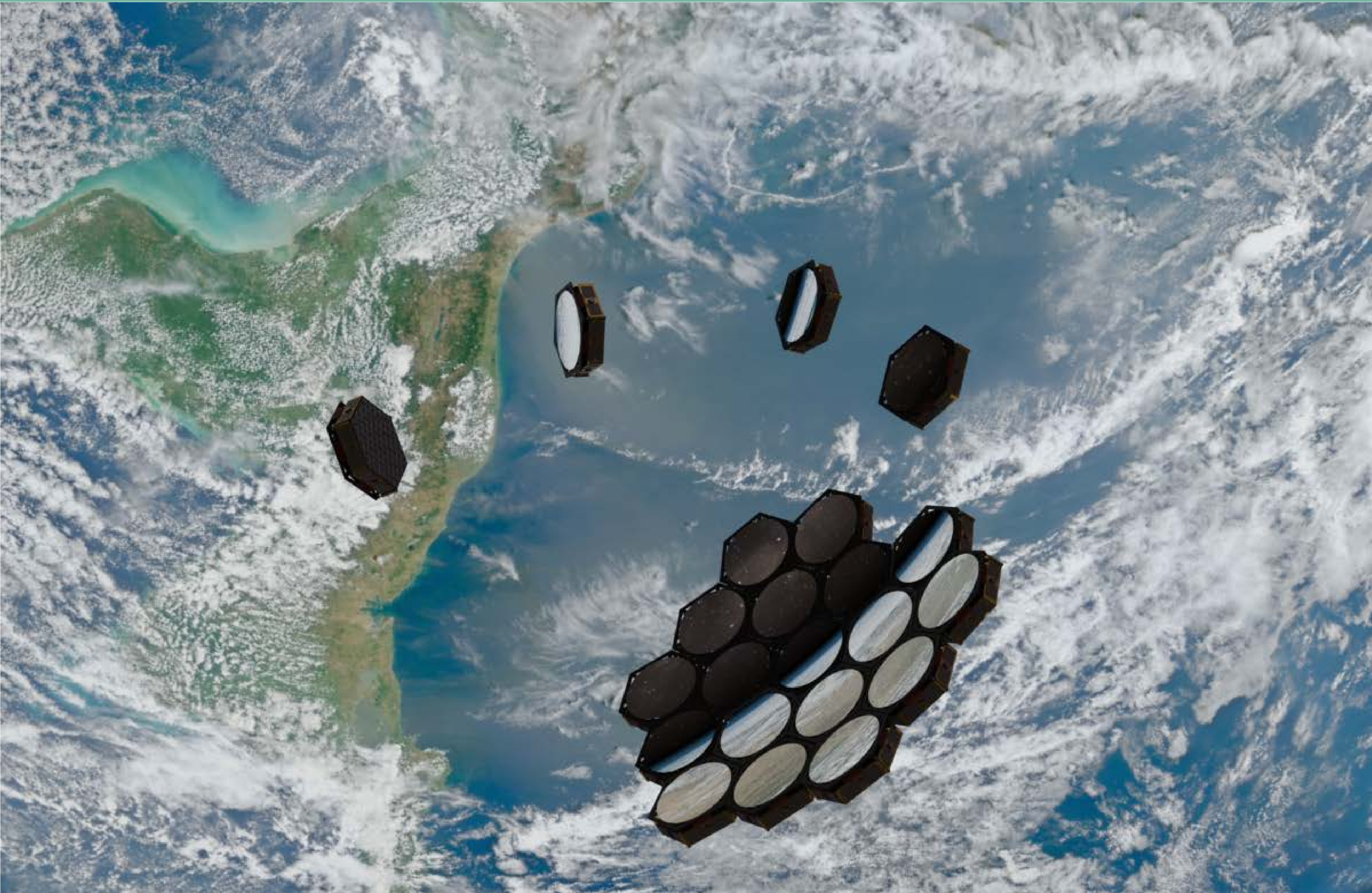
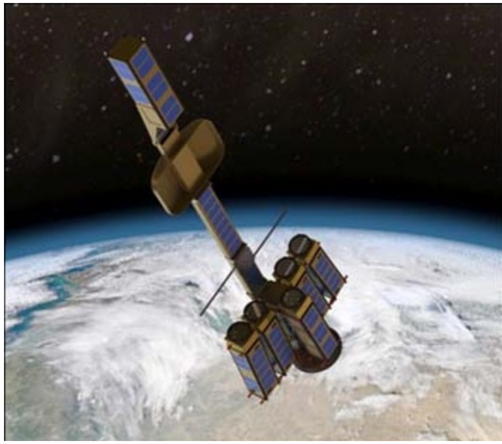
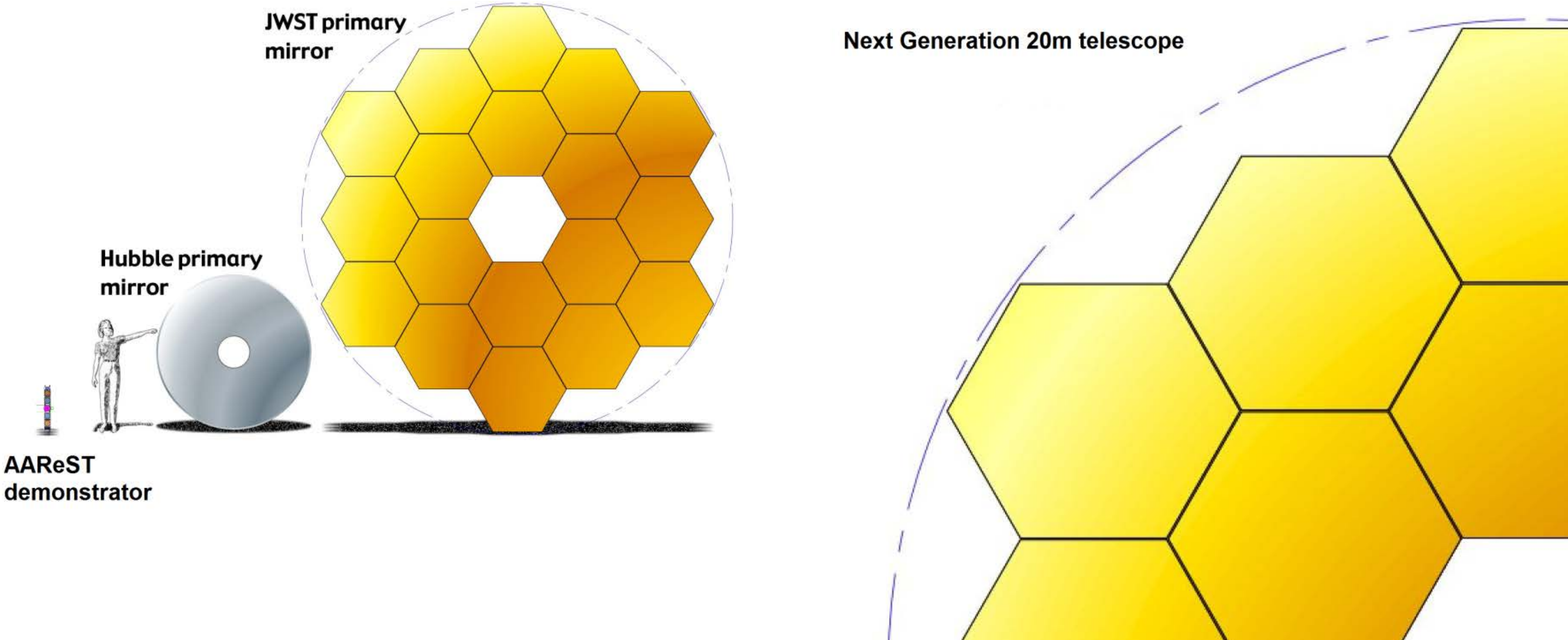
The Vision



Introduction

- **Project Scope:**
  - The James Webb Space Telescope (JWST) has the largest aperture feasible with today's launch technology at 6.6m.
  - Future larger aperture telescopes of ~20m diameter will require in orbit assembly.
  - Proposing a small scale CubeSat based demonstration mission.



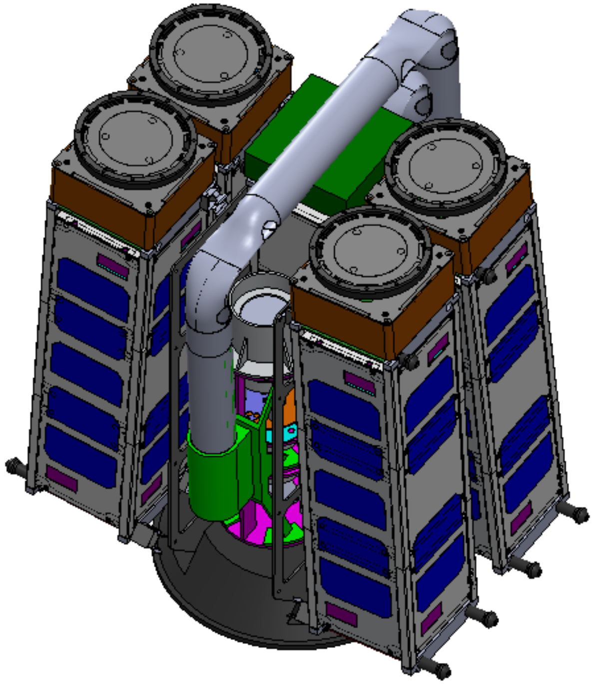


Mission Overview

- **Key Objectives:**
  - Demonstrate all key aspects of autonomous assembly and reconfiguration of a space telescope based on multiple mirror elements.
  - Demonstrate the capability of providing high-quality images.
  - Provide opportunities for education in space engineering at Caltech and University of Surrey and to foster links between the two.
  - To use this demonstration to provide outreach activities worldwide, to encourage participation of young people in science, technology and engineering.

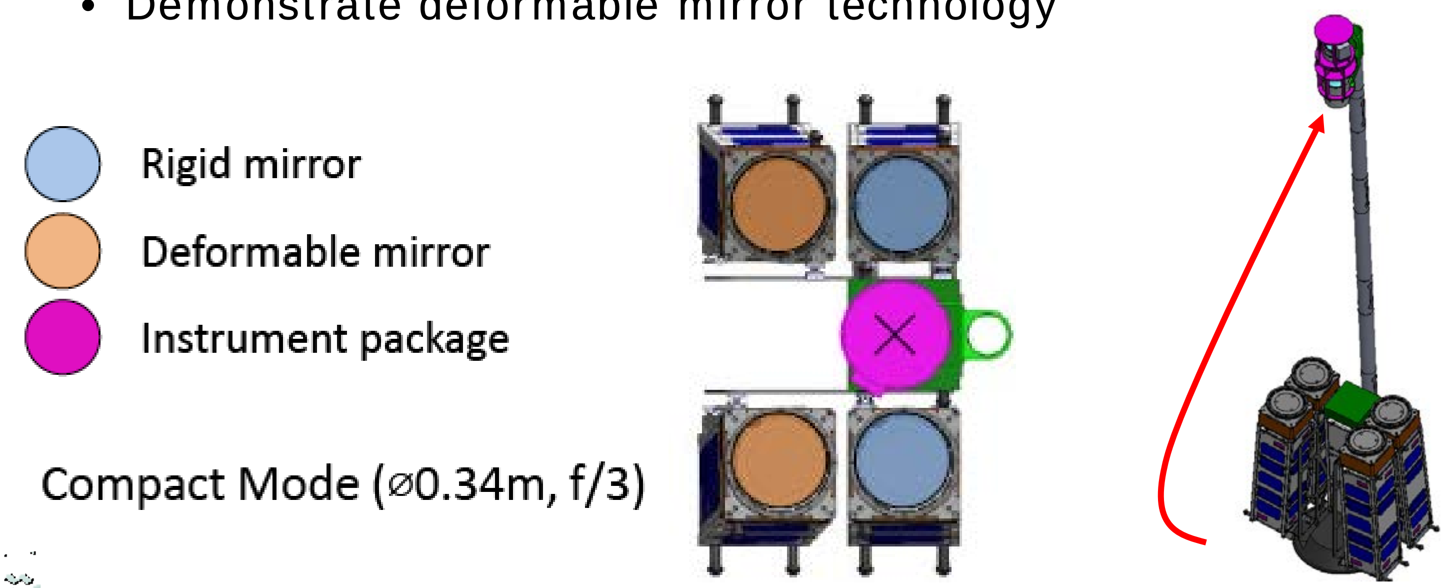
Mission Overview

- **Spacecraft and Mission Concept**
  - Launched as a single "microsat" into LEO
  - Comprises a "Fixed Core NanoSat" + 2 separable "MirrorSats"
  - Total Mass (incl. attach fitting) < 40kg
  - Envelope c. 40cm x 40cm x 60cm



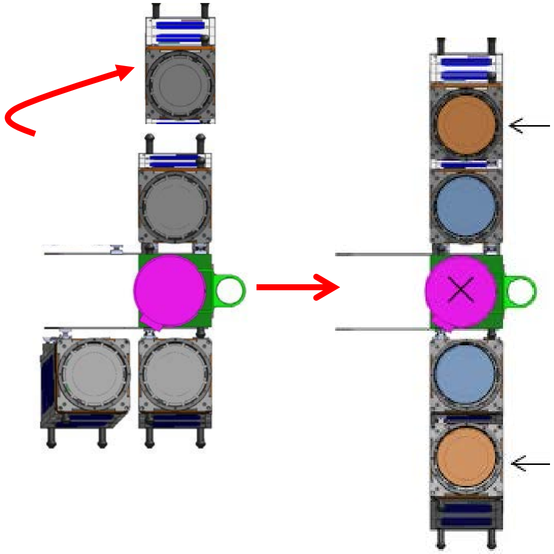
Mission Overview

- **Spacecraft and Mission Concept**
  - **Science Mission Phase 1**: (Minimum Mission Objective)
    - Image stars, Moon and Earth with fixed mirrors (c. 1^{o} FoV)
    - Demonstrate "precision" (c. 0.5^{o}) 3-axis control
    - Demonstrate acceptable jitter/drift (< 0.02 ^{o}/s)
    - Calibrate image sensitivity, noise, etc.
  - **Science Mission Phase 2**: (Key Science Objective 1)
    - Image with combined deformable and fixed mirrors in "compact mode"
    - Demonstrate deformable mirror technology

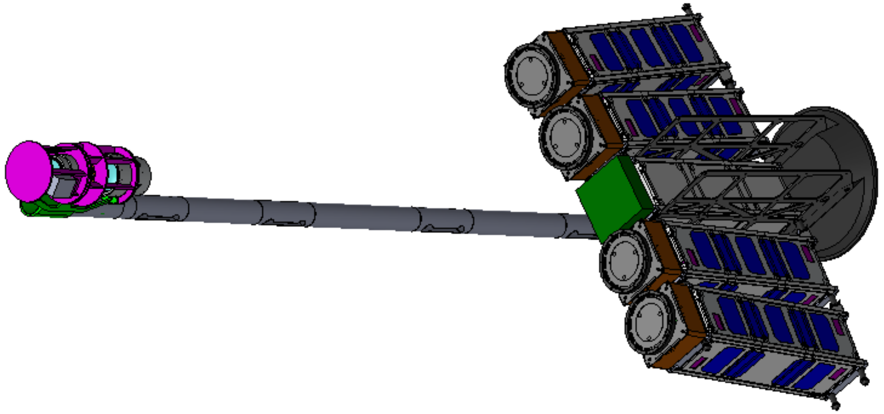


Mission Overview

- **Spacecraft and Mission Concept**
  - **Science Mission Phase 3**: (Key Science Objective 2)
    - Autonomously deploy and re-acquire "MirrorSat" (manoeuvres are within c. 20cm-30cm distance)
    - Demonstrate electromagnetic docking technology
    - Demonstrate ability to re-focus and image in compact mode
  - **Science Mission Phase 4**: (Key Science Objective 3)
    - Autonomously deploy MirrorSat and re-configure to "wide mode" (manoeuvres are within c. 3-4m distance)
    - Demonstrate Lidar/camera RDV sensors and butane propulsion
    - Demonstrate ability to re-focus and image in wide mode



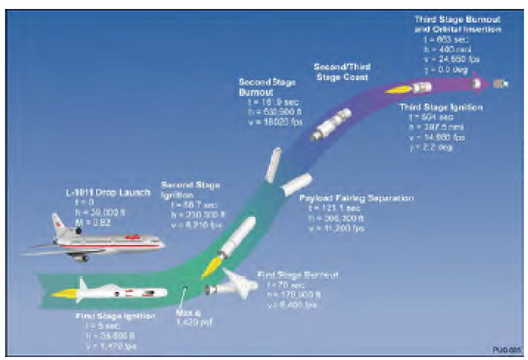
Wide Mode (⌀0.58m, f/2)



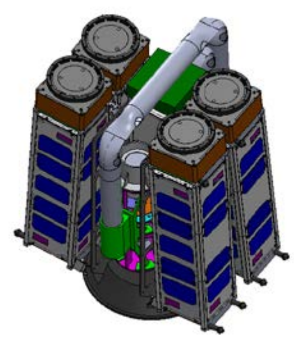
Mission Overview

- **Spacecraft and Mission Concept**
  - **Science Mission Phase 5**: (Extended Mission Objective)
    - Deploy and recover MirrorSat from beyond 10m (up to 1 km distance)
    - Demonstrate ISL/differential GPS
  - **Overall Mission Plan**:

Launch → Deploy Telescope/ Solar Arrays → Spacecraft Check-out → Telescope Calibration → Science Data Mode → Re-configuration → Complete Science Objectives → De-Orbit



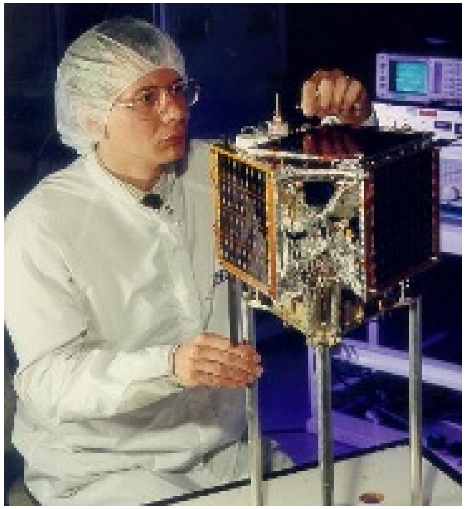
Pegasus Launch Vehicle (~11 minutes)



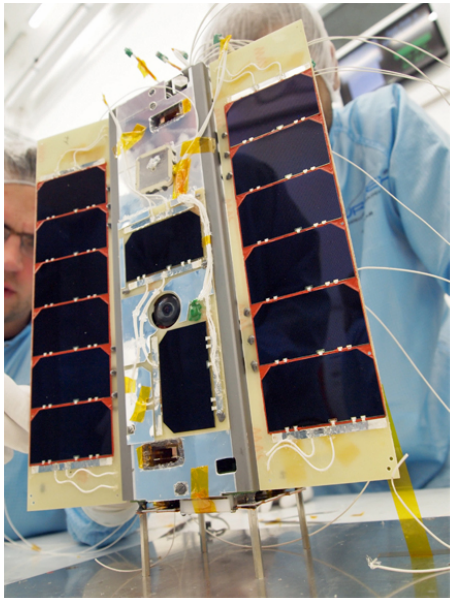
Launch Configuration

Spacecraft Bus

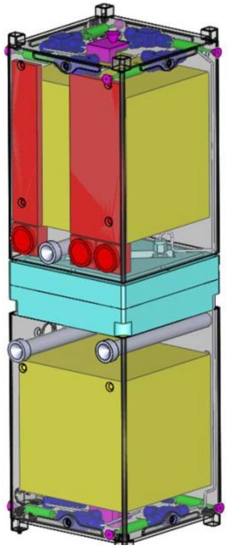
- **Spacecraft Bus – Design Approach**
  - **Low-cost** approach based on CubeSat technology
  - **Heritage** from Surrey's SNAP-1 NanoSat Programme (2000) (particularly butane propulsion and pitch MW/magnetic ADCS)
  - **Incremental** hardware, software and rendezvous/docking concepts developed through Surrey's STRaND-1, STRaND-2, and QB50/CubeSail missions currently under development.



SNAP-1 (2000)



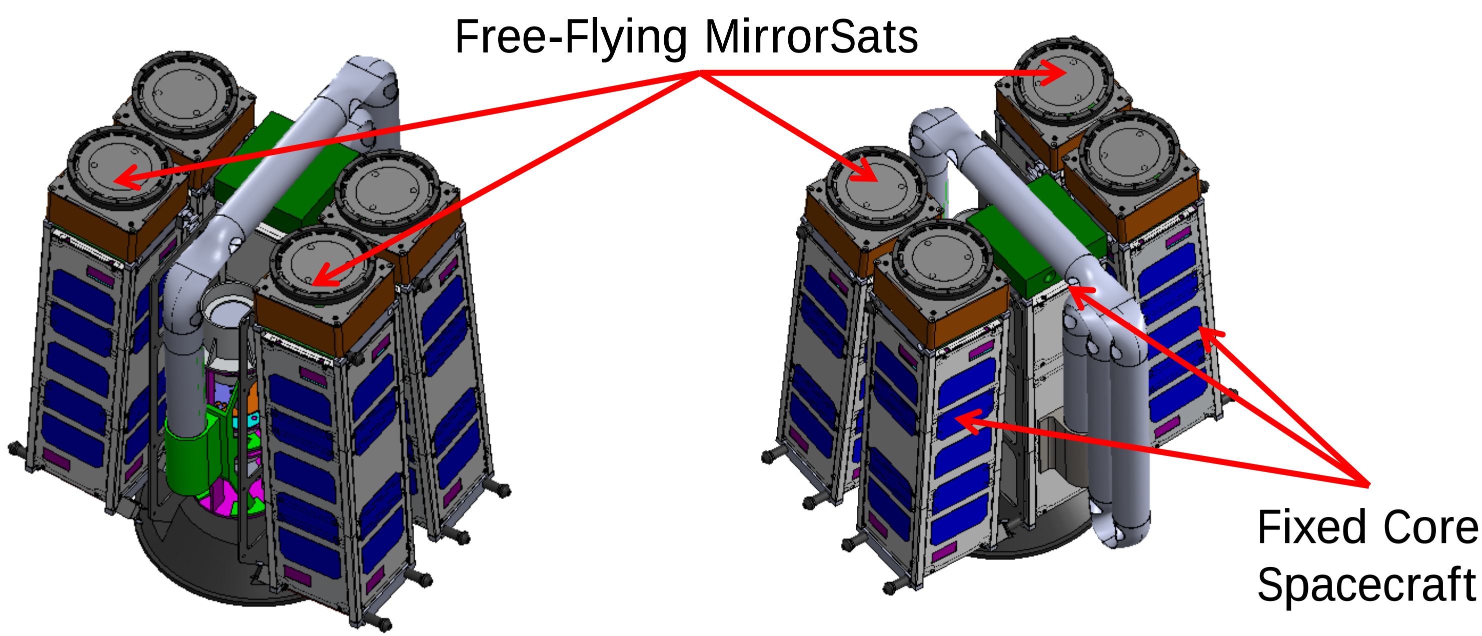
STRaND-1 (2013)



STRaND-2 (2014?)

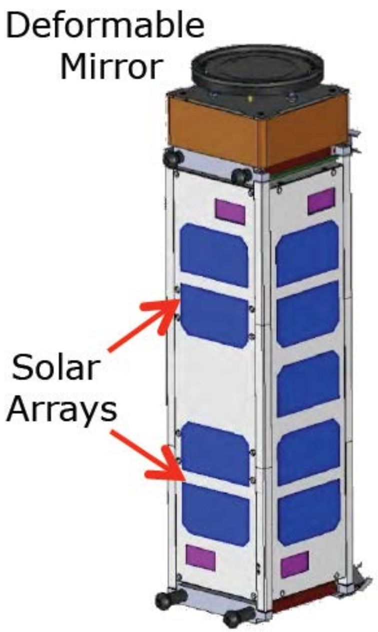
Spacecraft Bus

- **Spacecraft Bus – Design Approach**
  - Maximise use of COTS technology.
  - Modular approach, where each module is essentially a CubeSat
  - Spacecraft bus is treated as a **9U** and two **3U CubeSats** fitted to a framework/attach fitting structure.
    - Two fixed MirrorSats + Central Box = **9U Fixed Core Spacecraft**
    - Two Free-Flyer **3U MirrorSats** with Deformable Mirrors
  - Raw power is shared by MirrorSats through docking ports.

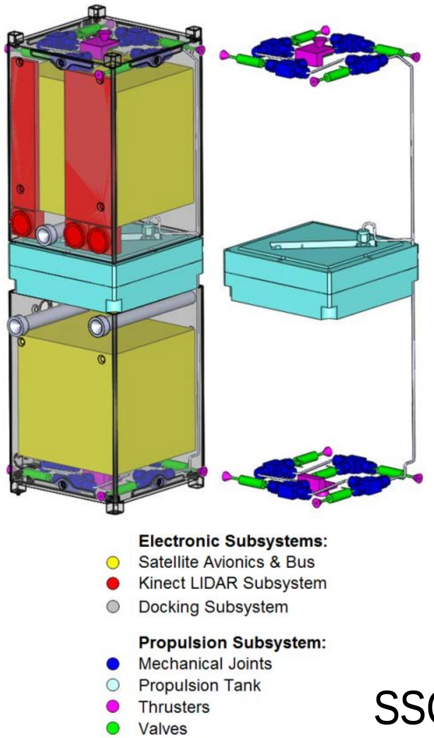


Spacecraft Bus

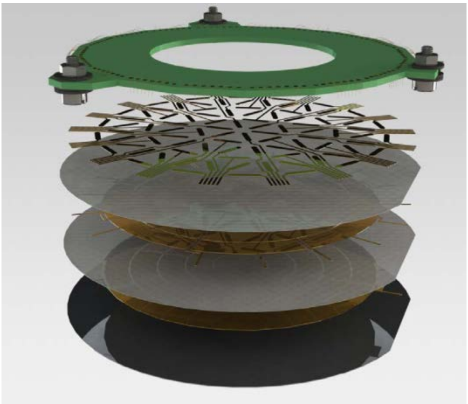
- **MirrorSat Requirements**
  - Based on Surrey's STRaND-1 and STRaND-2 developments
  - Supports Deformable Mirror Payload (DMP)
  - Must be able to operate independently of other units (at least over 3-4m separation – ideally out to 1km)
  - Must be able to communicate with the core spacecraft (ISL)
  - Must be able to undock, rendezvous and re-dock multiple times



Initial MirrorSat Concept



SSC/SSTL STRaND-2 Concept



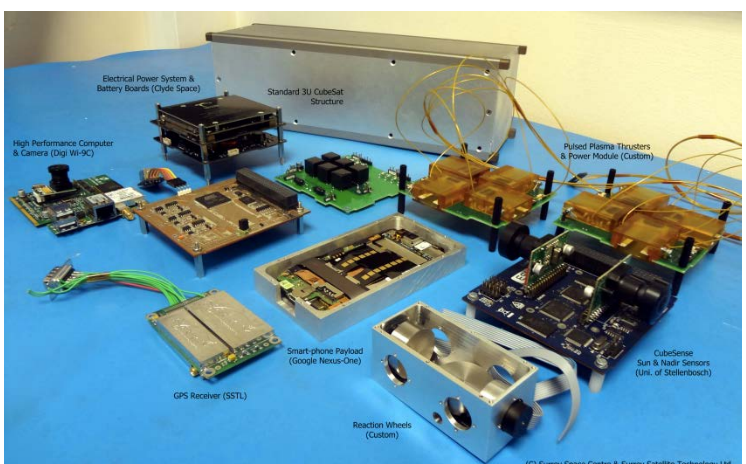
CalTech Deformable Mirror

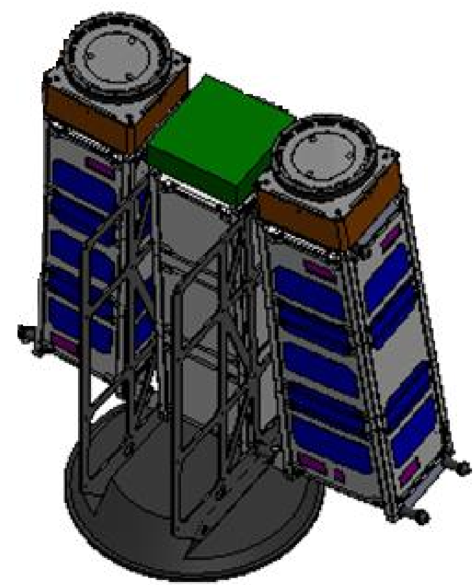
SURREY SPACE CENTRE

Spacecraft Bus

UNIVERSITY OF SURREY

- **Fixed Core Spacecraft Requirements**
  - Supports Space Telescope Payload (STP) and Science Imaging
  - Must be able to point accurately (< 0.5º error all axes)
  - Must be stable in attitude (< 0.02º/s for 600s)
  - Must be able to supply 2W dc continuous to 2 Deformable Mirror Payloads when in docked configuration during imaging
  - Must be able to communicate with the MirrorSat spacecraft and the ground at a minimum data rate of 9.6 kbps.
  - Must be able to operate with Sun >20º off optical (Z) axis.
- **Design Approach**
  - Mixture of COTS and bespoke technology





- **Example of Expected Imagery**
  - Optical Model Simulation of Telescope in “Compact“ and “Wide” Modes

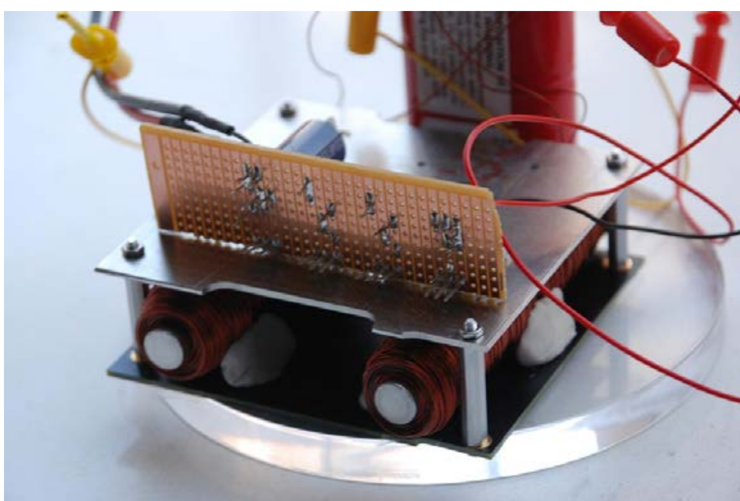
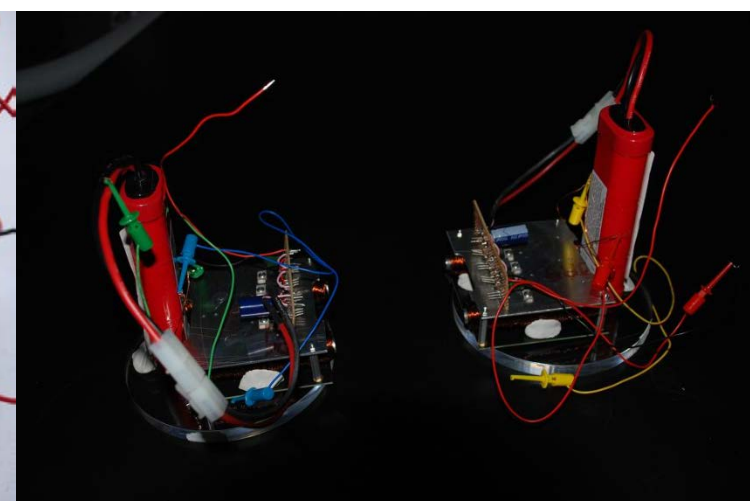
0.5° angular diameter
1280 x 1024 pixels

Perfect image

Aberrated image

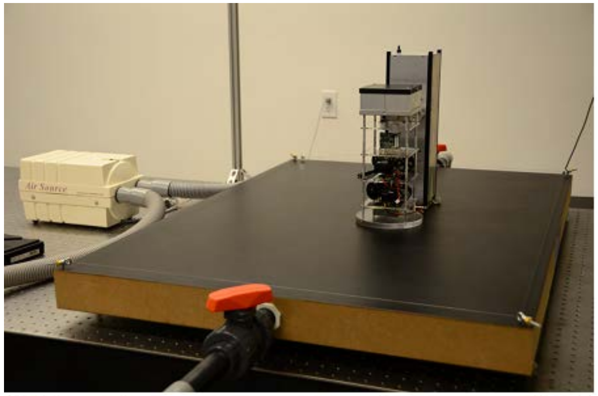
RDV/Docking System

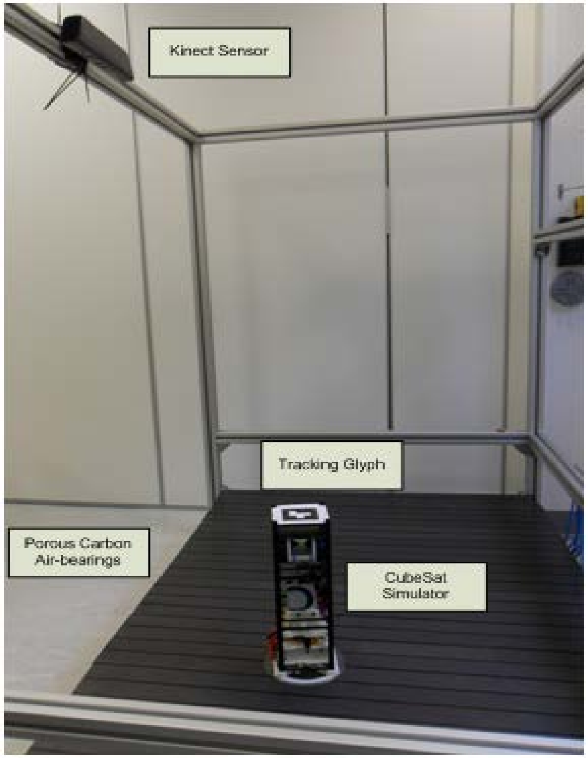
- **MirrorSat EM Docking System**
  - Investigations at CalTech by Prof. Underwood using Surrey's electro-magnets showed:
    - Capture distance was between 20-30cm for two pairs
    - Automatic self-alignment worked, but...
    - Choice of polarities was important to avoid miss-alignment/false-capture.
    - Attractive force was highly non-linear!
    - Biases due to the air-bearing table were problematic
  - Modelling by CalTech confirmed results.

RDV/Docking Research

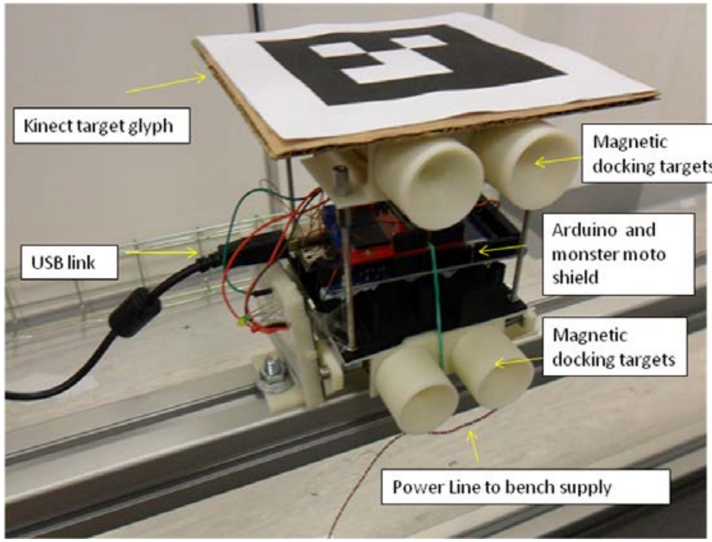
- **Developed New RDV / Docking Test-Bed**
  - CalTech (air jet) air bearing table was easy to work with, but residual biases made it hard to establish the effect of (tiny) magnetic forces at distances beyond 30cm.
  - Established at SSC a new instrumented 2D Air Bearing Table based on micro-porous carbon technology. (100x150cm)
  - First results look promising – no sign of bias – but very hard to align all units level to the micron accuracy needed!

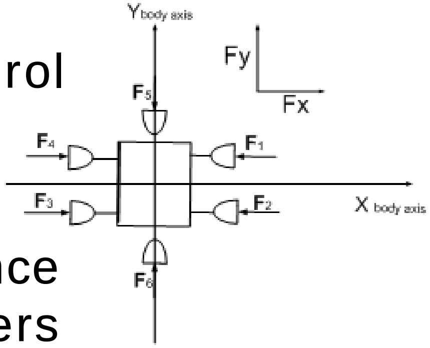


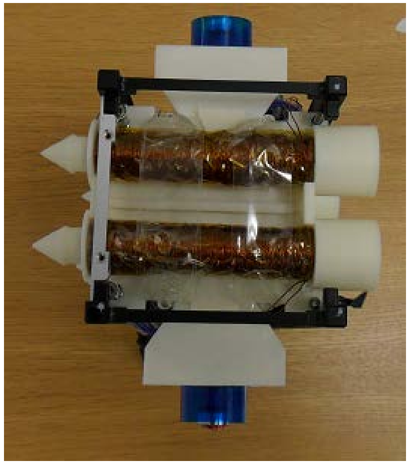


RDV/Docking Research

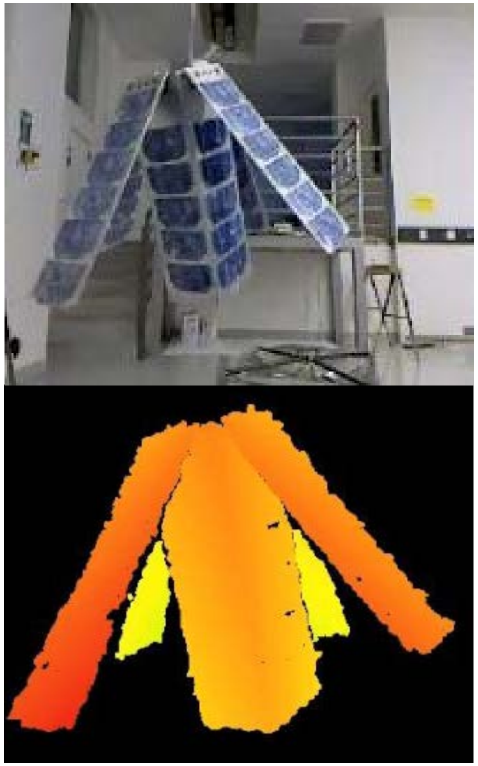
- **Developed Test-Bed CubeSat and RDV Target**
  - Used a combination of COTS CubeSat parts (e.g. ISIS structure) and 3D printed rapid-prototyping to develop a host CubeSat and RDV target.
  - Used Zigbee and Arduino technology to establish ISL, and autonomous command and control from a PC.
  - Used 6 compact high-performance ducted-fans to represent thrusters
  - Re-fabricated EM docking system using 3D printing RP technology.

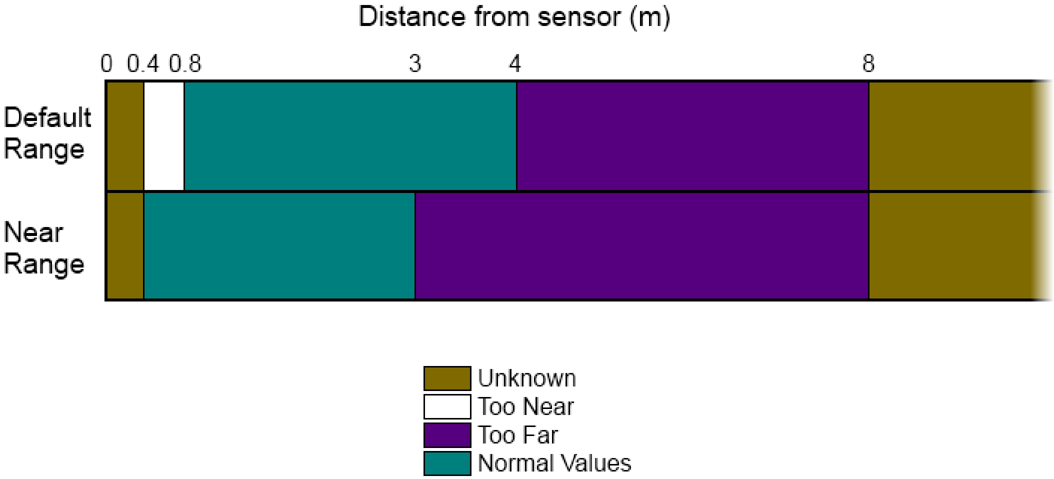






- **Investigated Microsoft Kinect®**
  - We calibrated the Kinect® and assessed its accuracy at providing pose and range estimates.
  - Accuracy was good (<3mm lateral error, <2cm depth error) from within the EM docking system's acquisition distance (30cm) out to 8-10m.

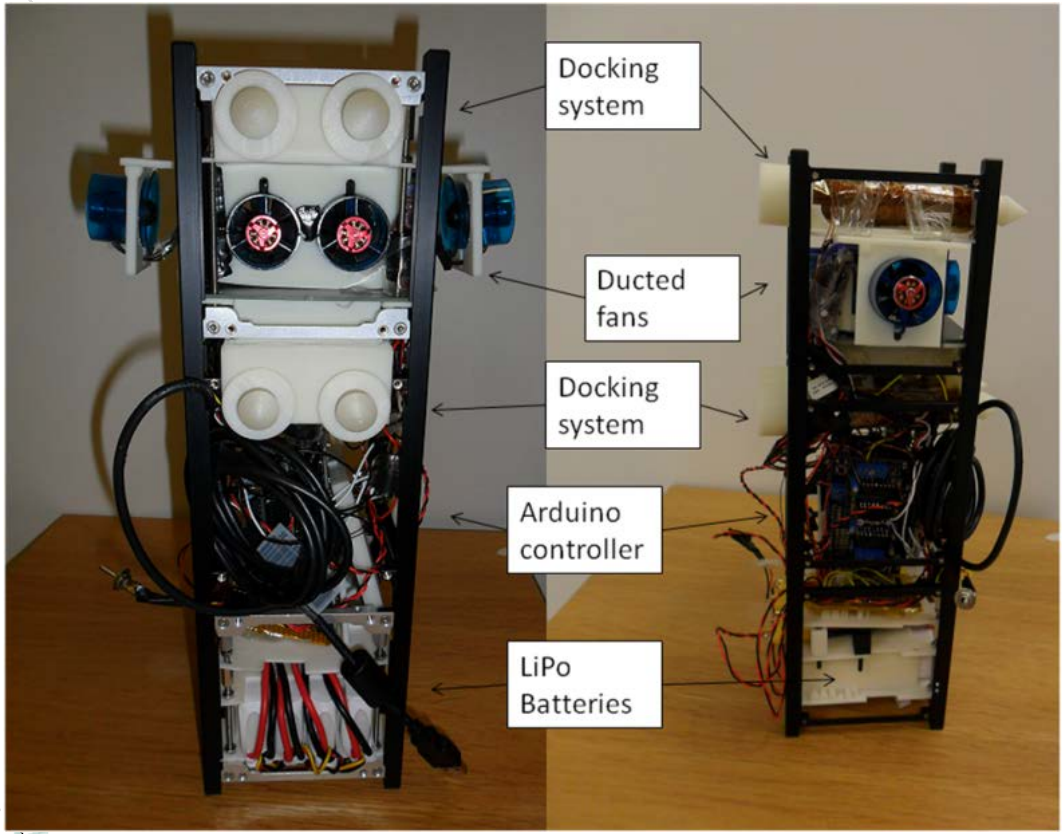


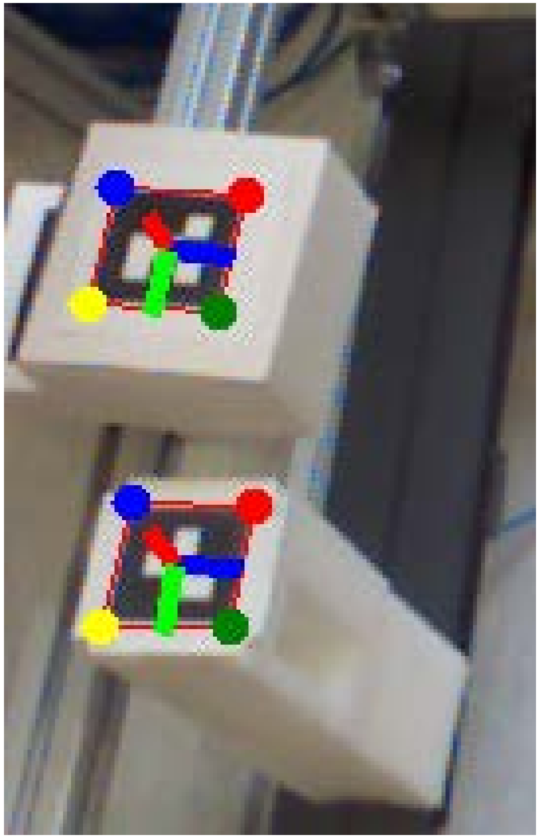


Kinect® Depth View from a 3U CubeSat Model with Solar Panels in the SSC Space System Development Laboratory

RDV/Docking Research

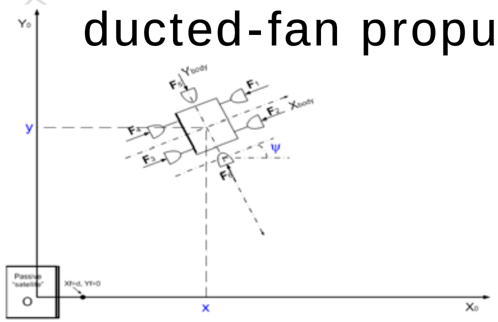
- **Developed Initial Autonomous RDV Controller**
  - Used machine vision techniques in combination with “gyphs” to establish unique ID, pose and distances between targets
  - Developed and demonstrated a initial Steering Controller and a Continuous Feedback Controller to control RDV and docking.

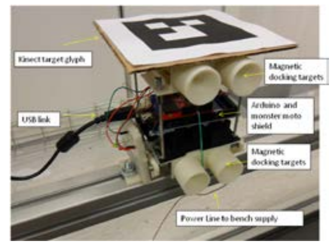


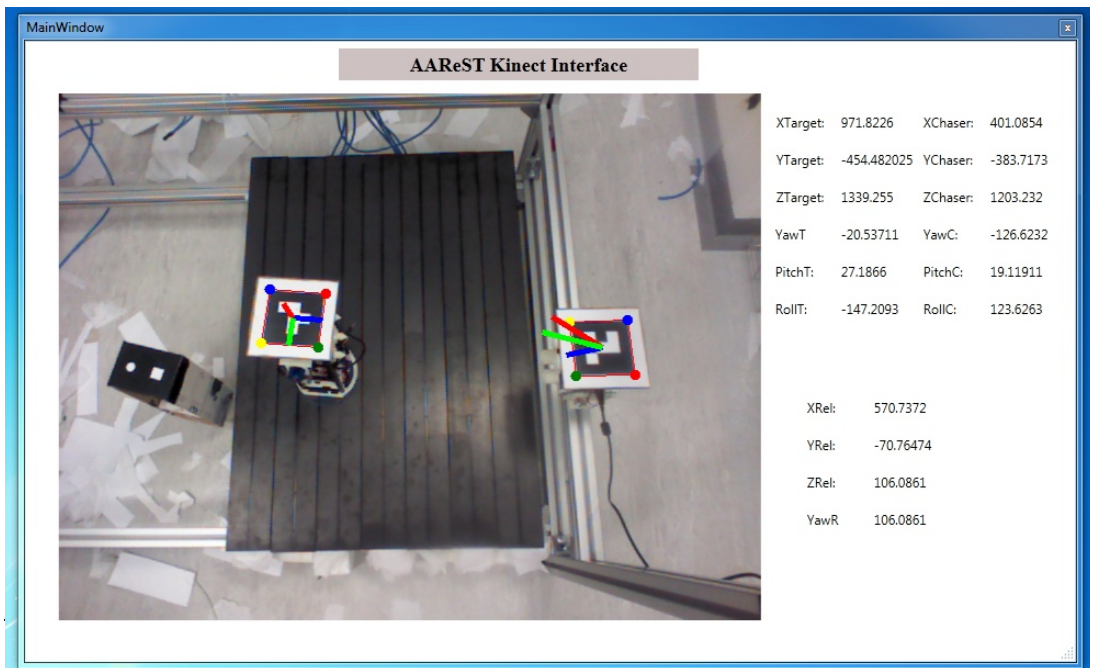


RDV/Docking Research

- **Performed Autonomous Docking / Un-Docking**
  - Multiple autonomous rendezvous docking/un-docking manoeuvres were carried out using EM docking system and ducted-fan propulsion under wireless computer control.

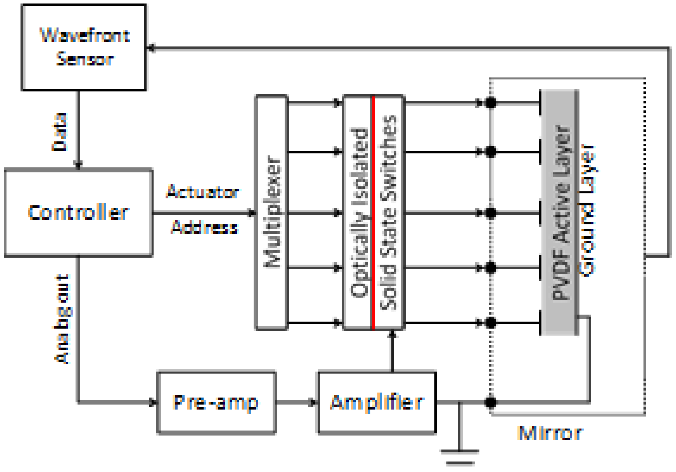




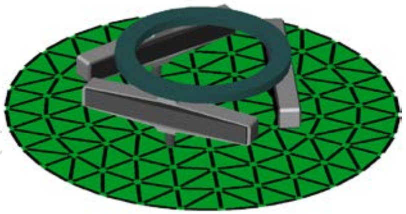


CalTech Mirror Development

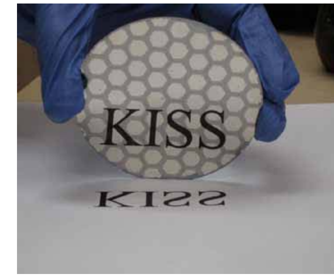
- Design and Fabrication of 10cm Diameter Thin Shell Mirrors
  - Shape correction capability
  - Low CTE materials
  - PVDF piezoelectric, flexible polymer active layers
  - Actuator addressing and multiplexing electronics
  - Supporting mount and spacecraft interfaces
- Optical Testbed for Mirror Behavior /Capability Validation
  - Wavefrontsensing for mirror shape determination
  - Electronics and software for closed-loop active mirror shape control
  - Later on: Setup to be expanded for telescope mirror array

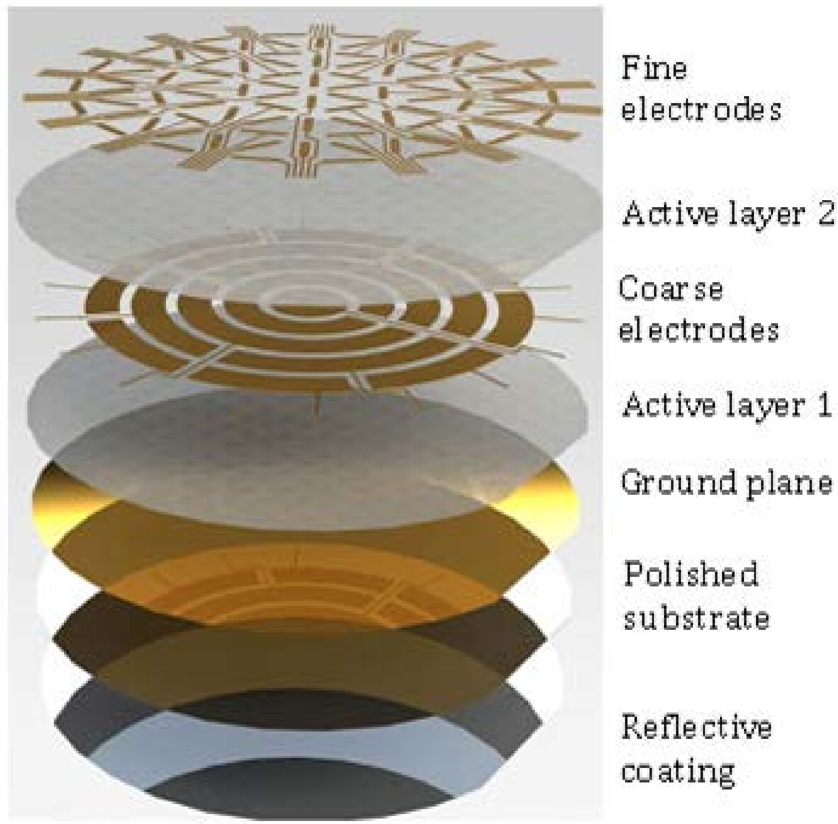


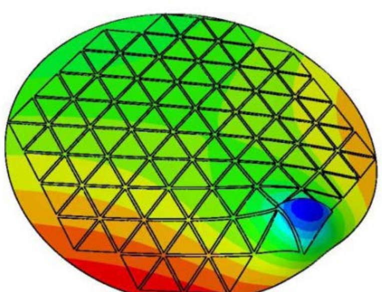
CalTech Mirror Development



10cm ϕ Adaptive Mirror







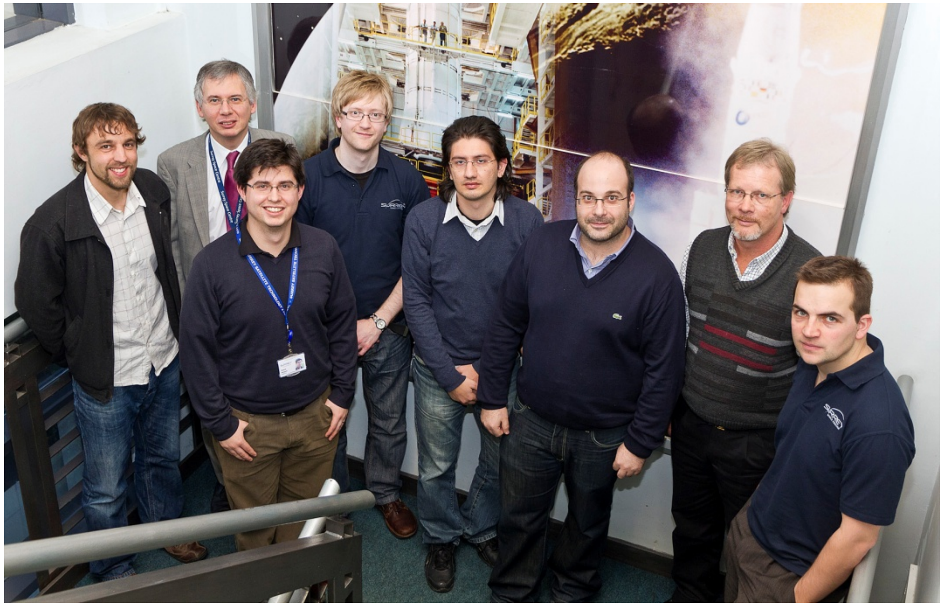
Courtesy of Keith Patterson

Conclusions

- AAReST demonstrates how nano-satellite technology can be used to provide confidence building demonstrations of advanced space concepts.
- This joint effort has brought together students and researchers from CalTech and the University of Surrey to pool their expertise and is a good model for international collaboration in space.
- The spacecraft bus and docking systems will be based on flight proven systems through Surrey's SNAP-1 and STRaND programs, whilst the optical payload is undergoing extensive design and ground testing.
- The mission will demonstrate autonomous rendezvous and docking, reconfiguration and the ability to operate a multi-mirror telescope in space.
- Launch is planned for 2015.

Acknowledgements

- We wish to acknowledge and thank the teams at the University of Surrey and CalTech contributing to the AAReST project – in particular, Keith Paterson at Caltech for the work on the mirrors; Chris Bridges, Pete Shaw, Theo Theodorou, Lourens Visage, Vaios Lappas at the Surrey Space Centre and Shaun Kenyon at SSTL for their work on STRaND-1.



- The air-bearing table simulator was developed through funding from the UK Engineering and Physical Sciences Research Council (EPSRC) under grant EP/J016837/1.

Thank-You

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