CLYDE SPACE

CubeSat Capability:
Enabling EO Mission Cost Reduction

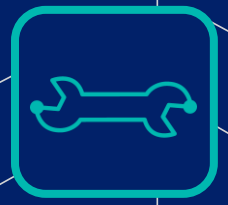
4th CEOI Emerging Technologies Workshop, Cosener's House 2017

Alasdair J. Gow, Spacecraft Sales Engineer

Outline

Our Market Vision

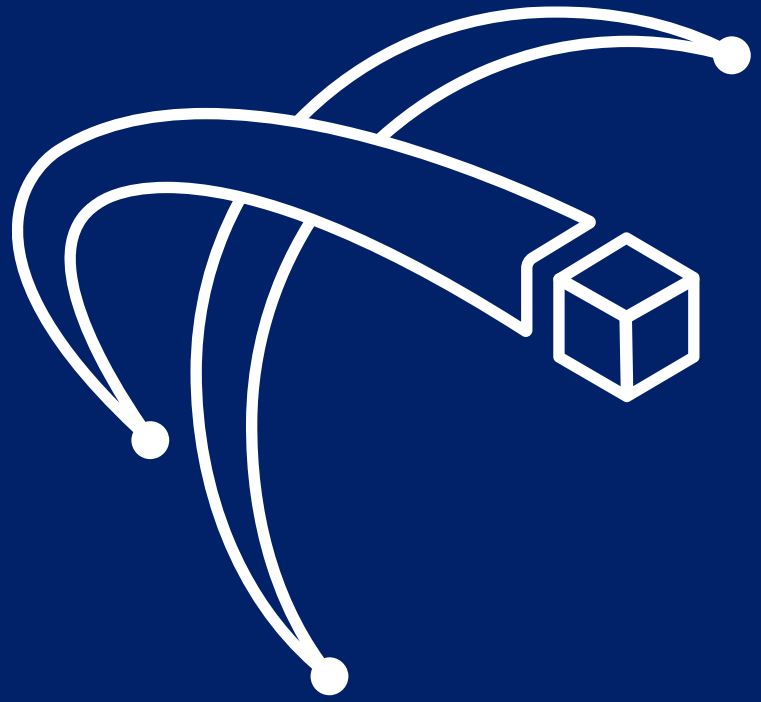
Who Are Clyde Space?



Our Missions: EO Case Studies

Emerging Technologies

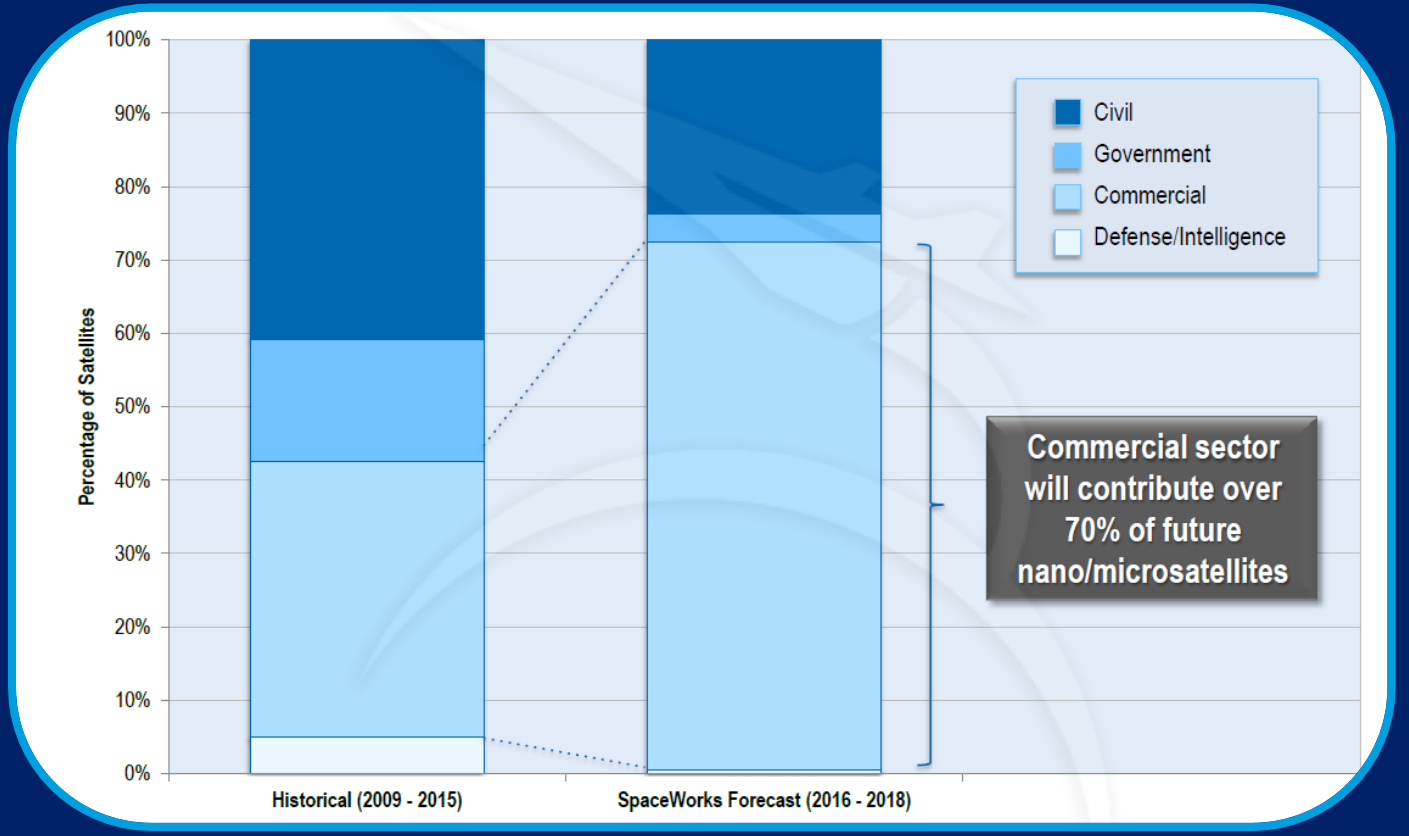
Conclusion



OUR MARKET VISION

A Changing Market Demographic

- University and scientific projects no longer the primary consumers of CubeSat platforms and technologies
- Maturity and capability of modern CubeSats now offer opportunities for successful commercial applications
- Increasing number of CubeSats for commercial customers, and increasing number of constellations



Source: SpaceWorks Nano/Microsatellite Market Forecast 2016

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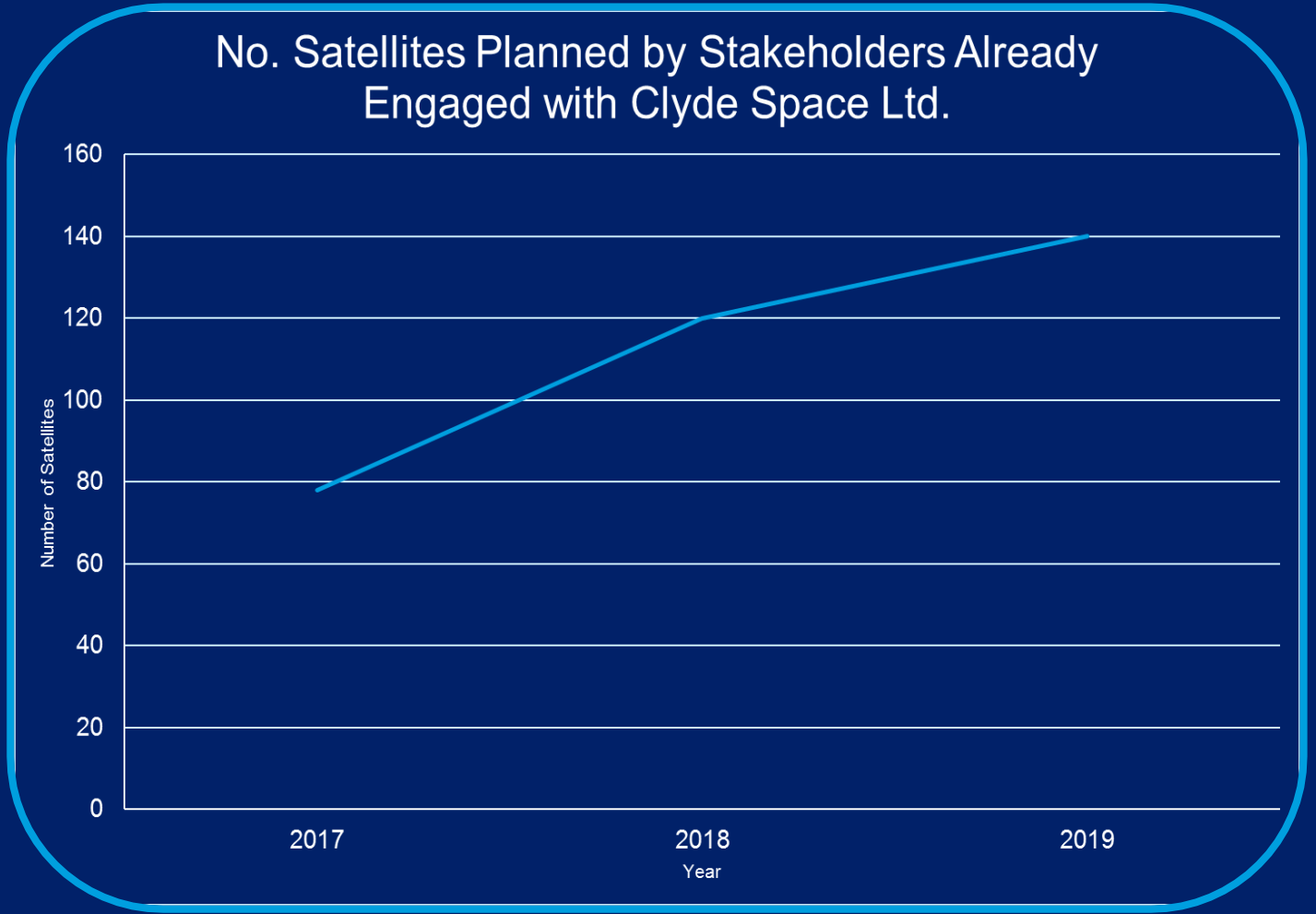


A Positive Feedback Loop

Commercial Customers:

New capabilities enable novel applications, requiring constellations

Volume orders demand mass manufacturing processes

CubeSat Hardware Manufacturers:

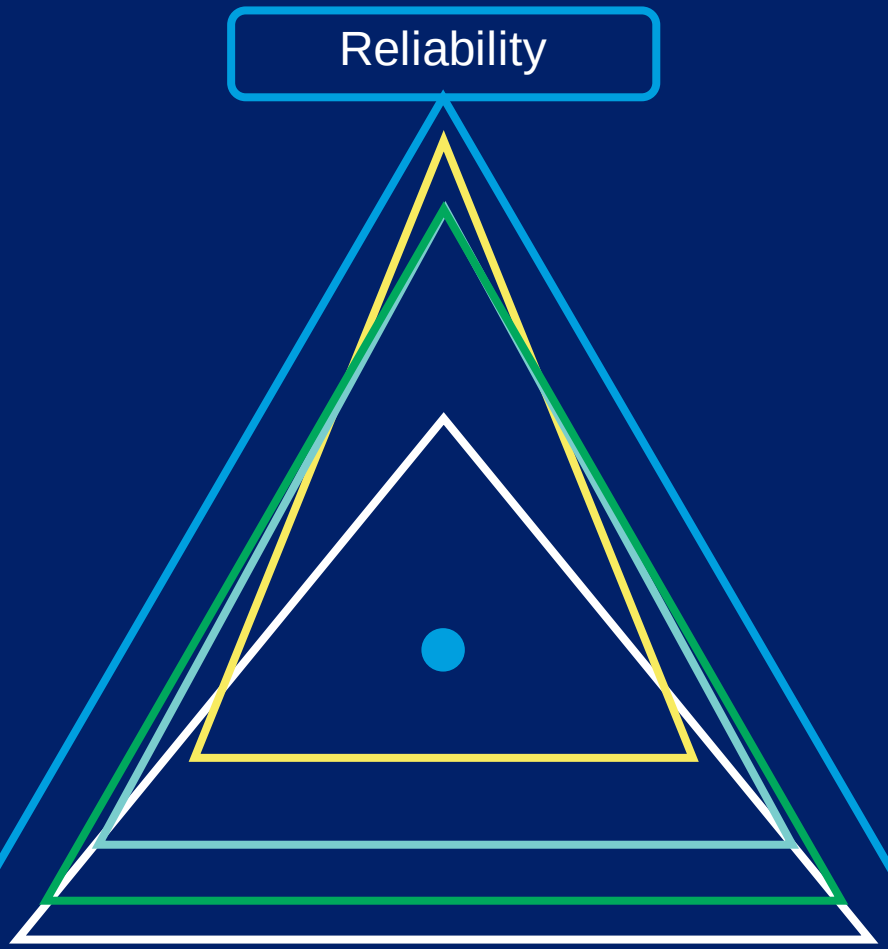
Volume manufacturing of reliable products

Volume manufacturing drives down costs

Civil & Academia:
Low cost enables more technology demonstration missions

New and miniaturised technologies unlock new capabilities

“Pick Two”?



Traditional CubeSat Perception

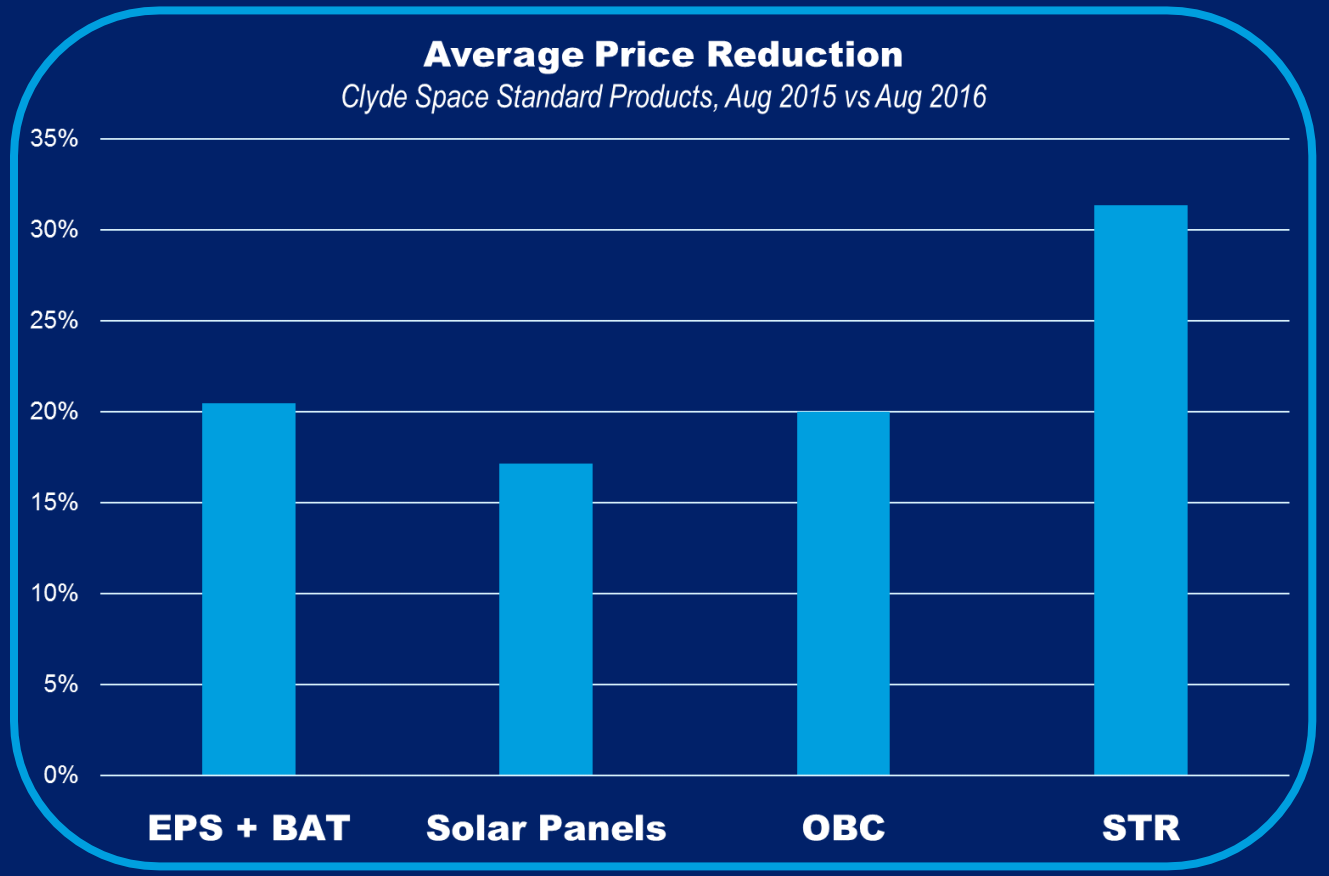
Traditional Space Perception

Clyde Space (Previous)

Clyde Space (Now)

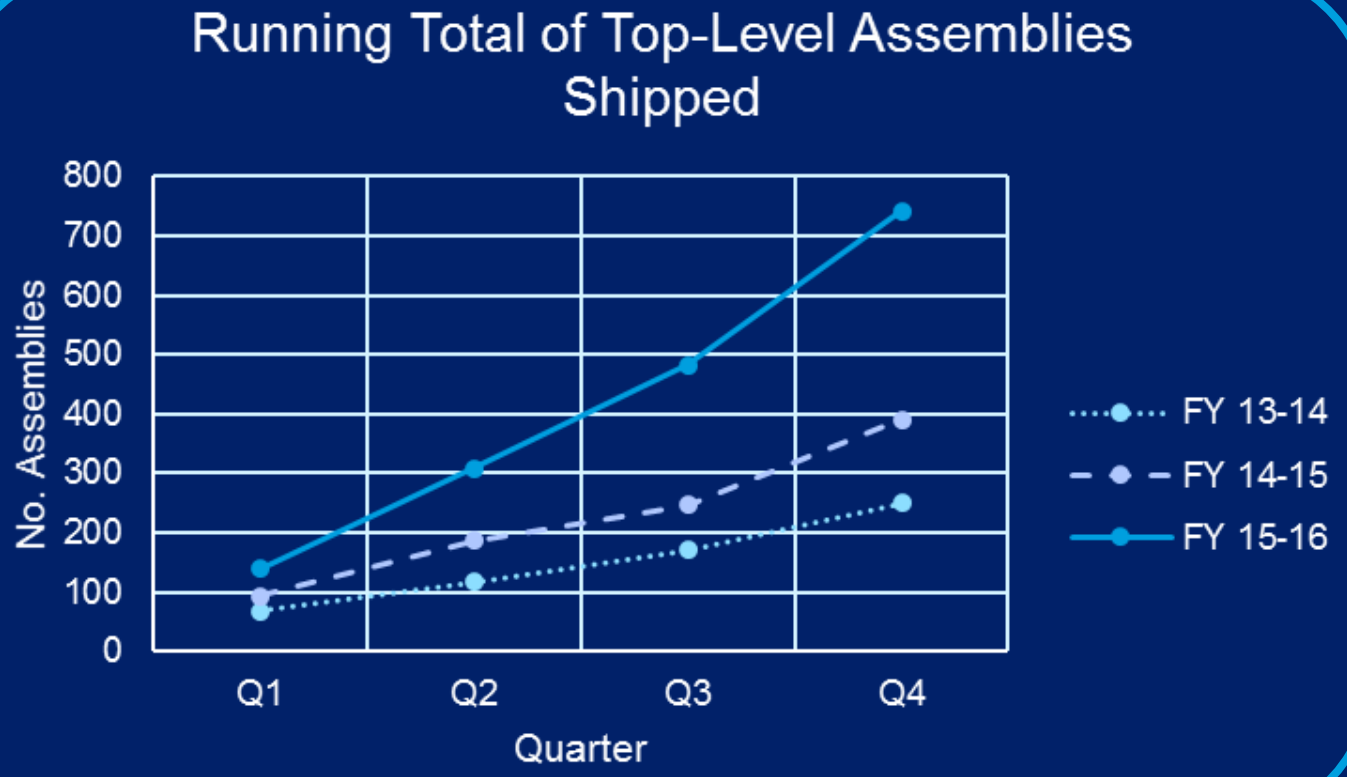
Seeing Results

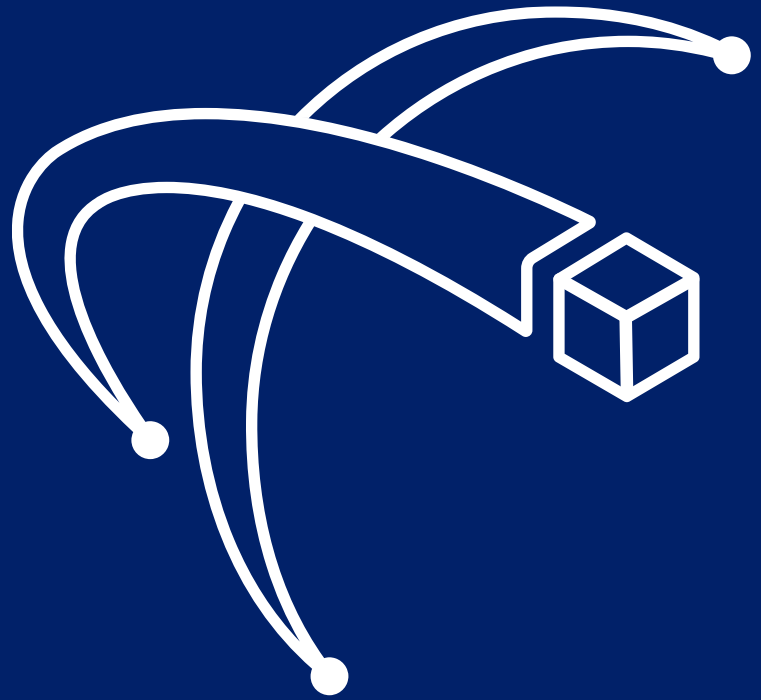
- Standard product pricing reduced by ~20% on average since same time last year
- Despite staff increase ~40% over same period



Seeing Results

- Number of units shipped per quarter tripled since introduction of new processes
- Top-level assemblies: composed of 1.99 individual subsystem units on average





WHO ARE CLYDE SPACE

Introduction to Clyde Space

One of the UK's leading space companies:

- Prime contractor UKube-1
- Space Leadership Council
- IPSP & IPP Projects
- Award winning

ISO 9001:2008 accredited Quality Management

Global leader in CubeSats, with hardware on c40% of CubeSat missions

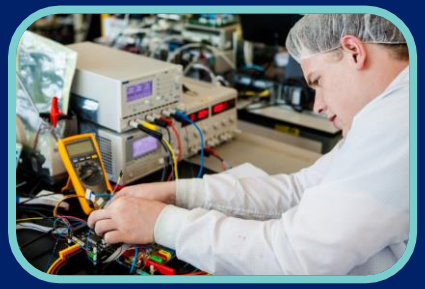
Regarded as having more hardware in space than any other small satellite provider

Broad space capability:

- Subsystems
- Platforms
- End-to-end missions
- Constellation design and implementation

Over 10 years experience in spacecraft subsystems

THE QUEEN'S AWARDS FOR ENTERPRISE: INNOVATION 2017

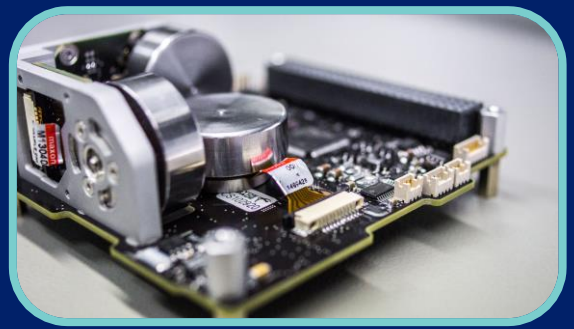


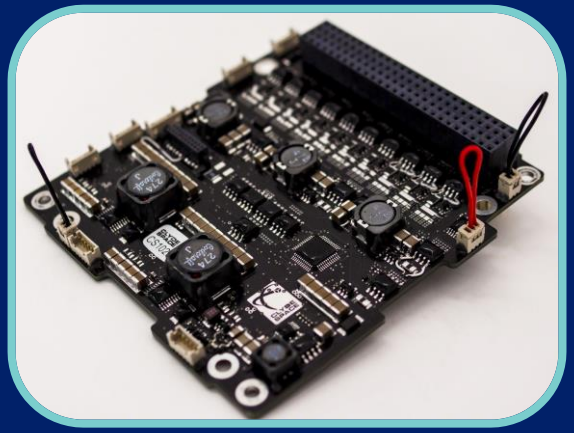
World's leading supplier of small spacecraft power systems

COTS Subsystems

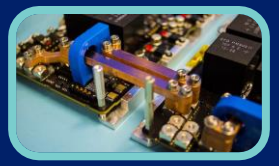
- **Hundreds of units supplied:** world's most popular CubeSat Power System Components
- **Power Systems:** EPS, Batteries, Deployable Solar Panels
- **Attitude Control:** Processing units and algorithms, reaction wheels, thrusters
- **On-Board Computers**
- **Structures**
- **Partners:** Comms, software, sensors

Systems available for CubeSats, Nanosatellites, and larger Small Satellites





Bespoke Subsystems



PCDU Systems

- Clyde Space founded by former head of power systems at SSTL
  - Strong heritage of power system development
- 2-3kW, 100A SA Input SmallGEO and 500W, 15A SmallSat power systems available
  - Standardised designs with heritage, configurable to your mission
- Fully bespoke systems also available

Solar Panels

- We have produced nearly 1000 solar panels over the past ten years
- Over 50 years of combined flight heritage
- No known failures
- Solar panel manufacturing process recently audited by ESA ahead of contract award
- Primarily use Spectrolab UTJ cells, but familiar with other cell types including Azur Space and Emcore.
- Al honeycomb cores, Al or carbon fibre skins
  - Have also used hybrid PCB on Al approach, and PCB-only for CubeSats

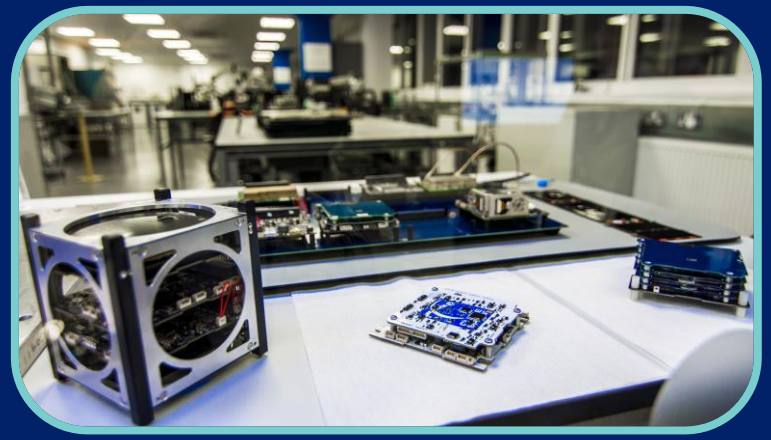
Batteries, ADCS, and other systems also available

CubeSat Platforms & Turn-Key Missions

- Currently producing 6 spacecraft per month
- Reference designs from 1U – 12U allow for rapid development
- Customised platform designs tailored to mission requirements
- COTS subsystems = low cost

Volume manufacturing approach enables cost-effective production of large-scale constellations

- First 3U platform UKube-1 featured SIX different payloads
- Clyde-Built Spacecraft continue to reside amongst the most advanced examples



Delivering Quality

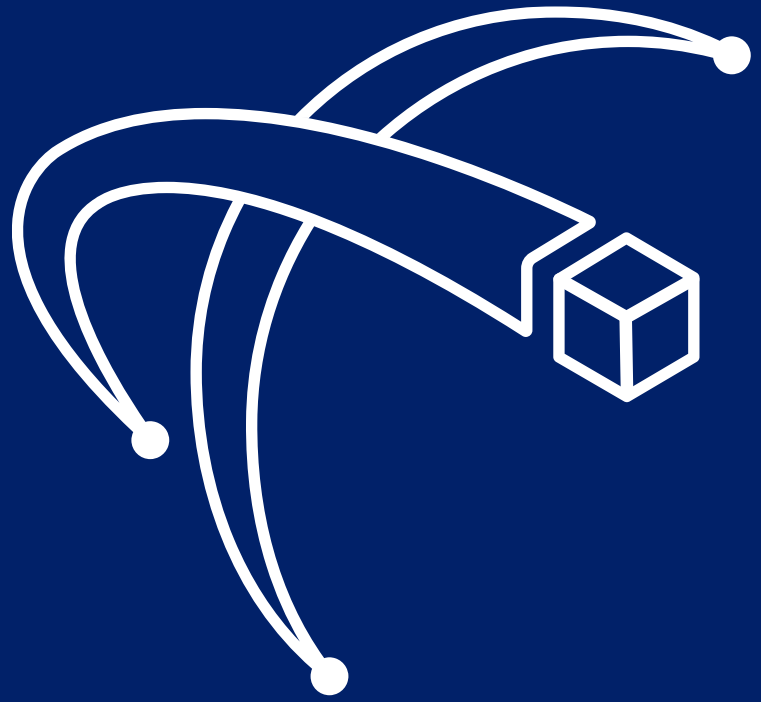
We have a high quality skills base within engineering and manufacturing

ESA qualified assembly technicians and inspectors perform and inspect conventional and surface-mount solder assembly, repair and modification operations in conformance with ECSS-Q-ST-70-08, ECSS-Q-ST-70-28 and ECSS-Q-ST-70-38.

bsi. ISO 9001 Quality Management

ISO9001:2008 accredited Quality Management System that is based on ECSS guidelines

Scalable approach to Quality: tailored implementation of ECSS for CubeSats, but inherent capability to work to full ECSS or NASA requirements when necessary.



OUR MISSIONS

Other CubeSat Missions

UKube-1 – *Tech Demo Platform*

- Complex 6-payload 3U CubeSat for UK Space Agency
- Successfully launched 8th July 2014, currently operational

Outernet – *Communication Platform*

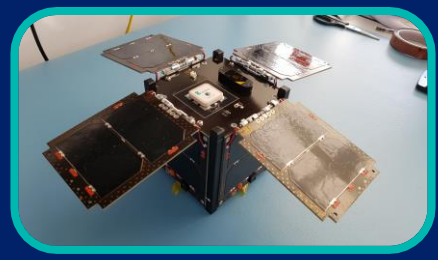
- 3x 1U CubeSats + 1x 3U for the Outernet project
- Funded through UK Space Agency's International Partnerships in Space Programme (IPSP)

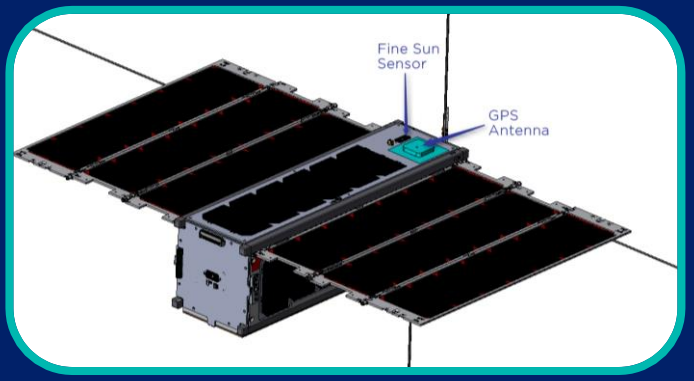
Project DaVinci

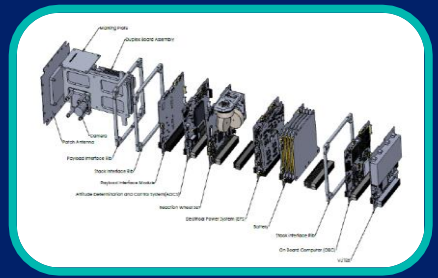
- 1x 3U CubeSat for US STEM outreach programme

Kepler Communications

- 2x 3U CubeSats for high-power communications mission







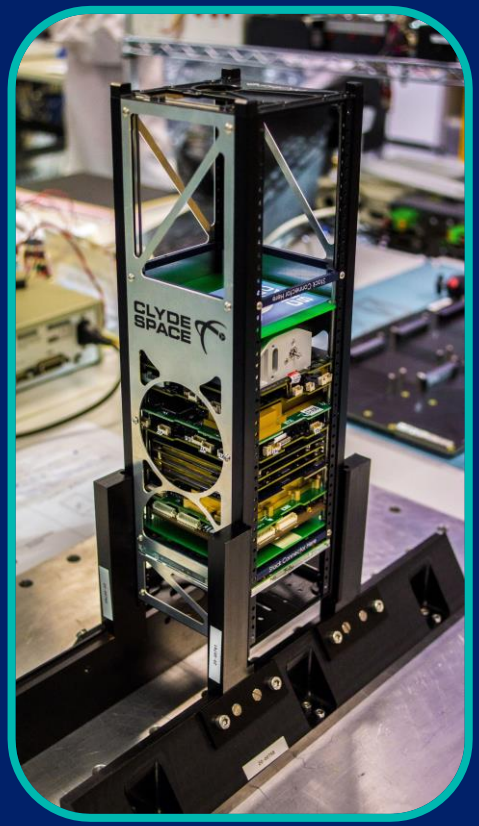
UK SPACE AGENCY

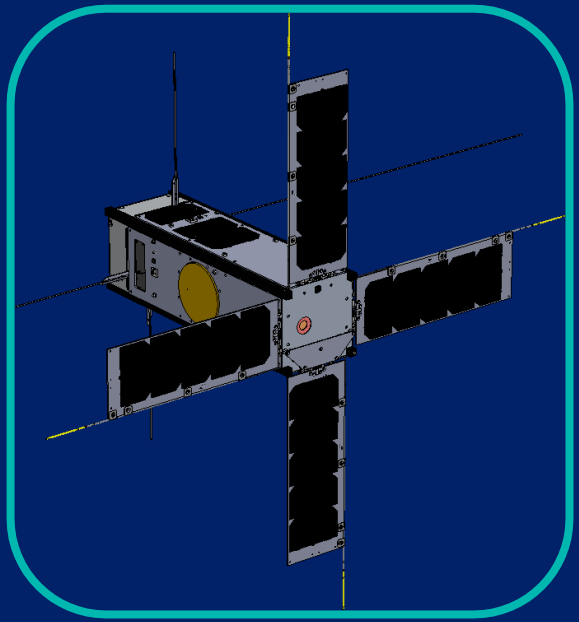
OUTERNET
HUMANITY'S PUBLIC LIBRARY

KEPLER

PICASSO

- **3U CubeSat designed, integrated, tested, and operated by Clyde Space**
- **Remote and in-situ measurements of Earth's atmosphere**
- **ESA-grade science return**
  - VISION: miniaturised hyperspectral imager





PICASSO will be launched towards the end of 2017

SeaHawk

- Delivering 2x 3U CubeSats with HawkEye payload as a technology demonstrator
- SOCON: Sustained Ocean Colour Observation from Nanosatellites
- Project Partners:
  - University of North Carolina Wilmington
  - Cloudland Instruments
  - Clyde Space
  - NASA Goddard Space Flight Center
  - Hawk Institute for Space Science
  - UK Astronomy Technology Centre
- Funded by Gordon and Betty Moore Foundation

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NASA GODDARD SPACE FLIGHT CENTER

Cloudland Instruments

GORDON AND BETTY MOORE FOUNDATION

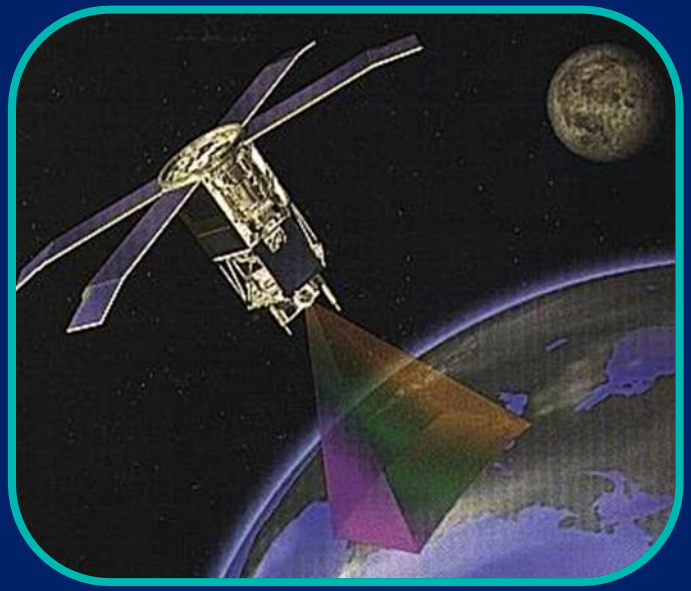
UNCW Physics and Physical Oceanography

Science & Technology Facilities Council
UK Astronomy Technology Centre

SeaWIFS – Sea-Viewing WIde Field-of-View Sensor

- SeaHawk will provide both a replacement *for* and an improvement *of* previously benchmark OCM standard sensor.

- 8 observation bands (range: 402-885nm)
- Equator Crossing Noon +20 min, descending
- Orbital Period 99 minutes
- Swath Width 2,801 km LAC/HRPT (58.3 degrees)
- Swath Width 1,502 km GAC (45 degrees)
- Sensor resolution: 1km/pixel
- Real-Time Data Rate 665 kbps
- Revisit Time 1 day
- Digitization 10 bits
- Mass: 390kg
- Development time: >10 years
- Cost: 14.1M USD



SeaHawk Take-Over Aims

- To observe in similar spectral bands as SeaWiFs.
- To achieve equivalent or better SNR performance
- To improve sensor resolution.
- Eventually achieving greater coverage and refresh rate.
- Provide Global Reference Data-set for Ocean Colour Science.
- All at substantially lower cost than SeaWiFs!

Comparison

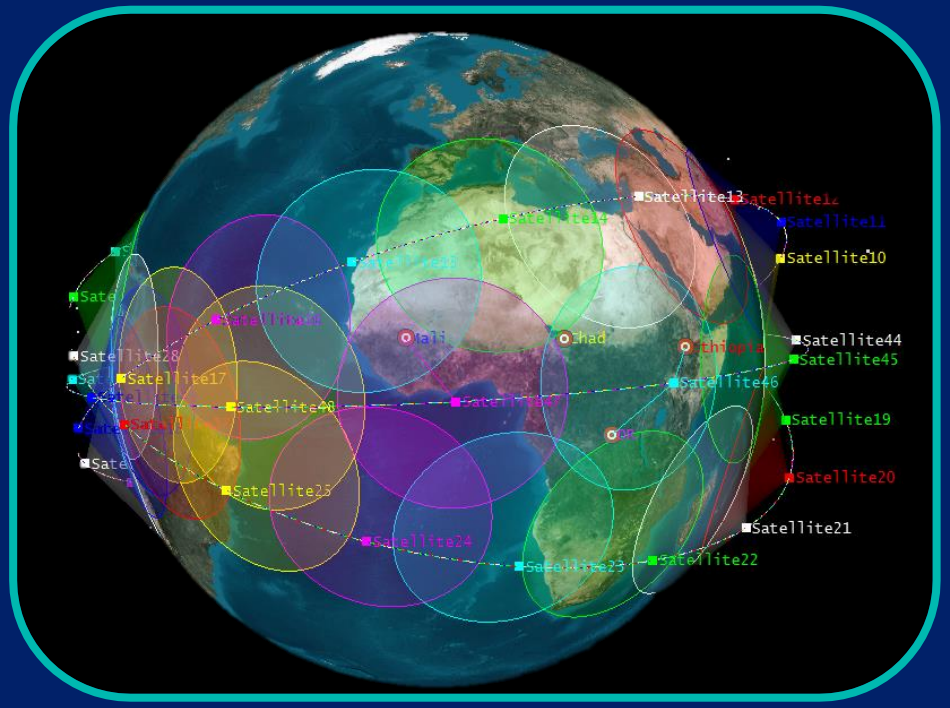
	NASA SeaWiFs	SeaHawk	Comparison
Development Time	> 10 years	2 years	20%
Cost	$14.1M	$1.675M	12%
Mass	390kg	4kg	1%
Sensor Resolution	1km / pixel (Oceanographic)	150m – 75m / pixel (Coastal or Oceanographic)	7 – 15 times better

Moore's Law in space:

smaller, faster, cheaper – *better performance*

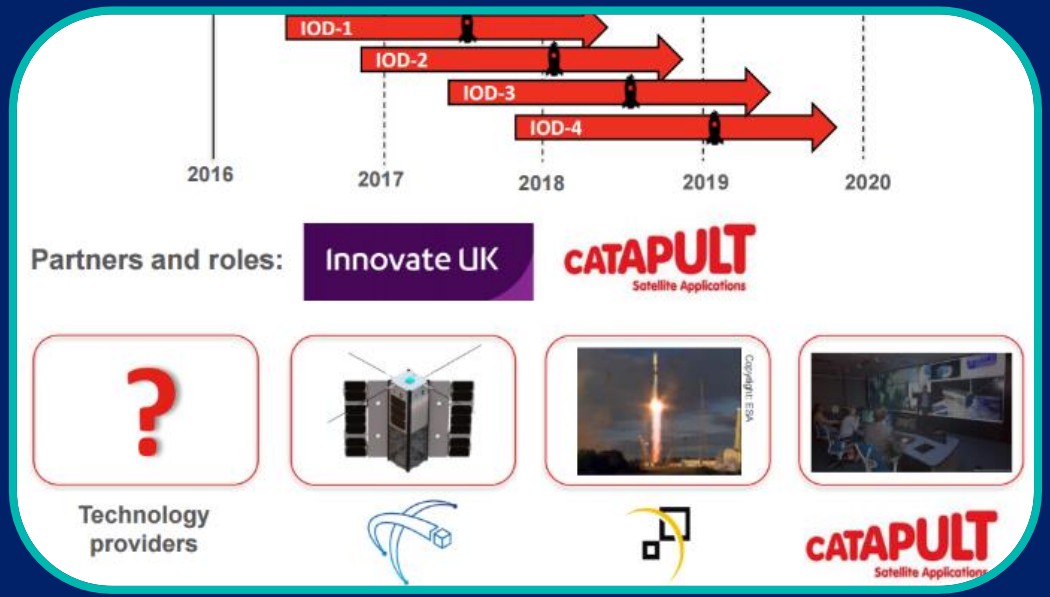
Example Costellation Performance

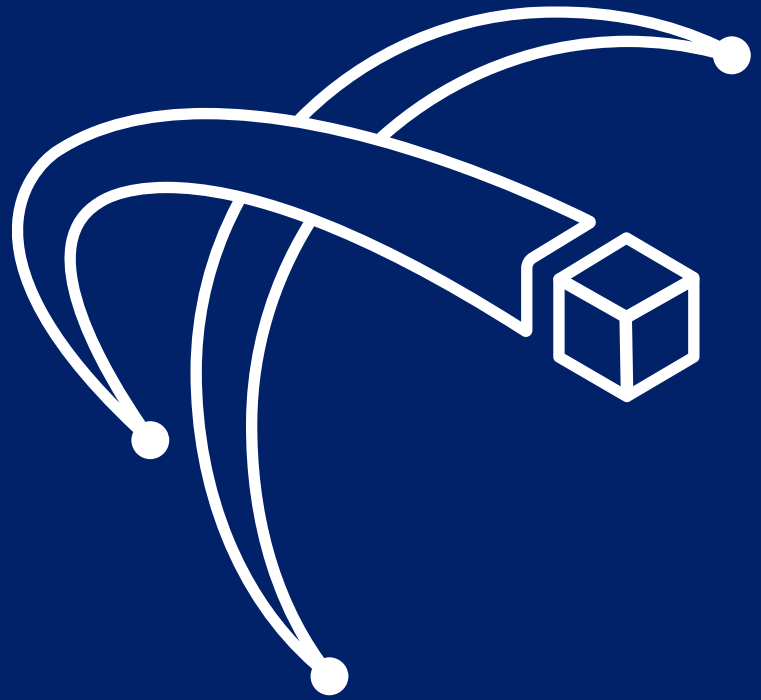
Typical Performance	Single CubeSat	Three-Plane CubeSat Constellation
# of CubeSats	1	48
Maximum Revisit Time	~ 12 Hours	~ 5 Minutes
Target Visibility	~ 1 Hour	>50 Hours



Catapult IOD Pilot Programme

- 4x 3U CubeSats for Satellite Applications Catapult
- 4 different payloads, 1 platform design
- Payloads sourced from industry & academia across the UK
- Funded by Satellite Applications Catapult, and continuing spirit of UKube-1

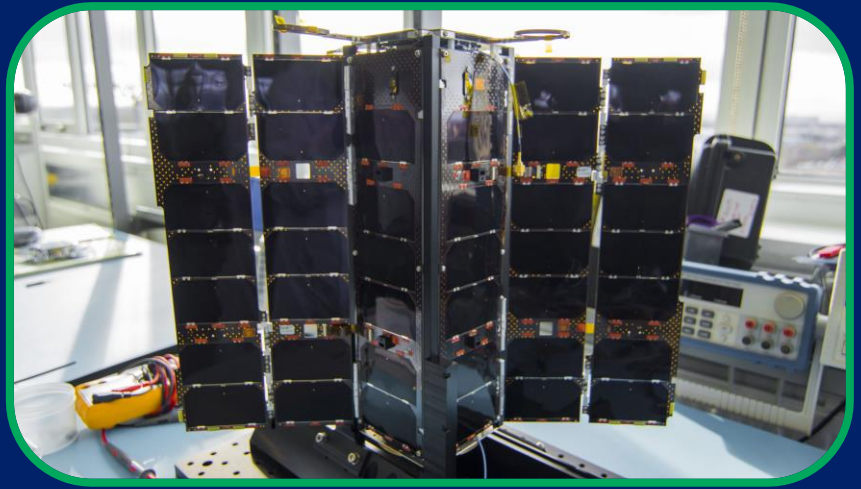




EMERGING TECHNOLOGIES

Power Generation

- Small size of CubeSats has traditionally limited available power – and thereby mission capability
- Deployable panels allow increased area and power generation
- Deployable panel technology continuing to advance: triple-deployables enabling 50W peak power generation from a 3U launching later in 2017



50+ sets of Clyde Space double-deployed panels currently on orbit with zero deployment failures

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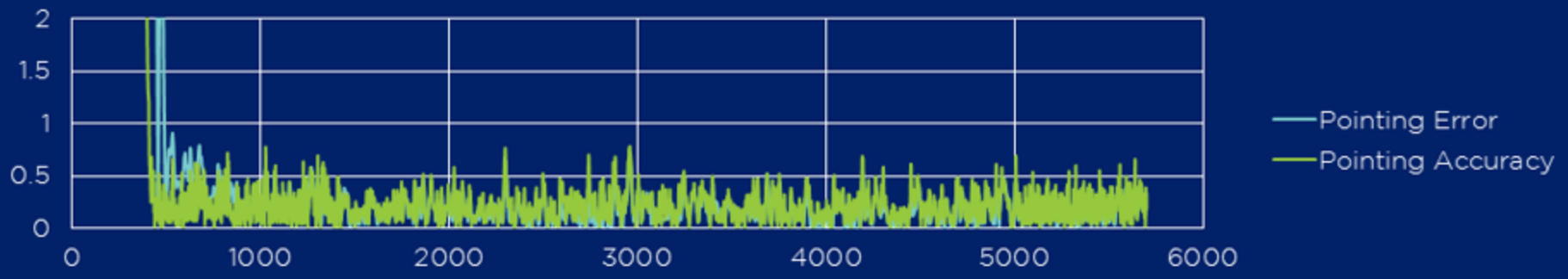
- Deployable panel technology continuing to advance: triple-deployables enabling 50W peak power generation from a 3U launching later in 2017

Clyde Space triple-deployed panels launching 2017

Larger CubeSats

- Power generation: larger area = larger solar panels
- Core spacecraft avionics unchanged: extra volume for batteries (power) and/or larger instruments
- 6U, 12U, 27Us in development

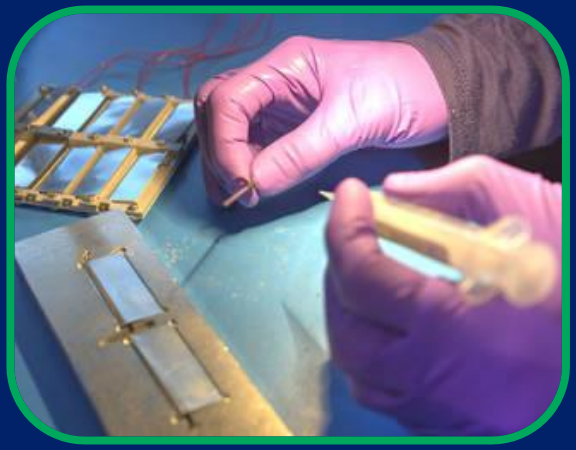
Attitude & Orbit Control



- Pointing Control
  - Active area of development: sub-degree accuracy currently achievable
  - Advanced control modes now possible including ground target tracking
- Propulsion
  - Large number of companies working on CubeSat propulsion technologies, for applications from simple orbit maintenance to formation flying and orbit raising

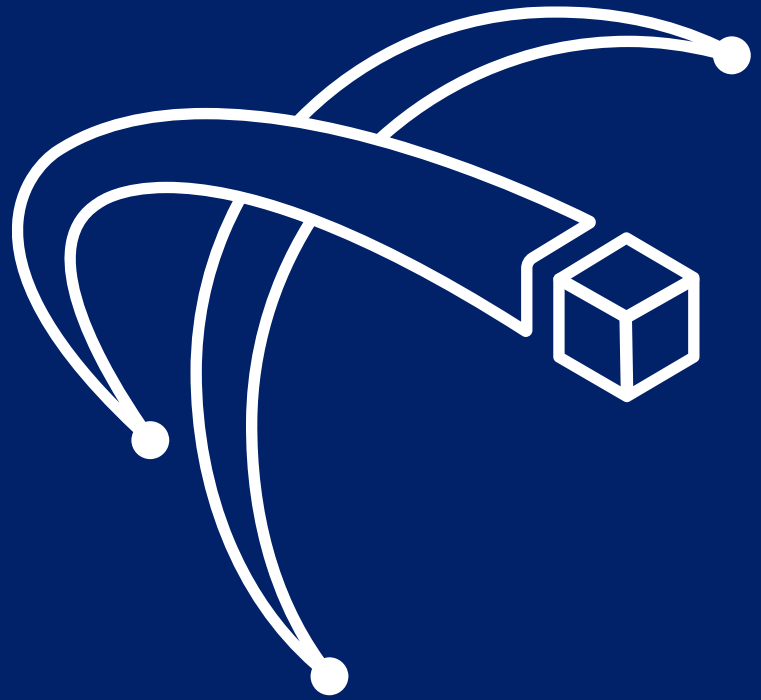
Other Technologies

- Thermal control
  - Passive and active thermal control options being investigated
- Deployable technologies
  - Wide variety of deployable technologies being developed for CubeSats
- Constellations
  - Low cost of CubeSat missions driving development of commercial EO constellations



Louvres for thermal control aboard NASA 6U Dellingr. Credit: NASA/W. Hrybyk

Lemur-2 CubeSats in Clyde Space cleanroom. Credit: Spire



CONCLUSION

Conclusion

- Nano/microsatellite market is becoming dominated by commercial constellations
  - Drives demand for high volumes, and reliability
- Clyde Space has already invested heavily and adapted in anticipation
  - Existing high quality now augmented with high volume capability
- Volume production drives down mission cost!
- Moore’s Law and technology miniaturisation driving increase in CubeSat capability year-on-year

Any Questions?

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