FlexCore – Low-Cost Attitude Determination and Control Enabling High-Performance Small Spacecraft

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BCT Overview

- BCT was founded in 2008 by industry veterans
- Staff of highly experienced engineering, production, procurement, and support personnel
  (Over 30 spacecraft prior to BCT)
- Over 35 employees, and growing
- 23,000 square feet for manufacturing, test, and mission operations center
- Recent equipment & systems automation investments
- Facility enhancements for volume manufacturing & test
- Located in Boulder, CO

BCT Products

Nano Star Trackers
High-performance, ultra-small size & power

Reaction Wheels
Nanosat, CubeSat, and Microsat sized wheels

Attitude Control Systems
Precision GN&C Systems for CubeSats and Microsats (enclosed or distributed architecture)

Electrical Power Systems
Batteries, solar panels, power control and distribution

XB1 – Spacecraft Avionics
Integrated Nanosat system (ADCS, EPS, C&DH, GPS), X-Band Transmitter

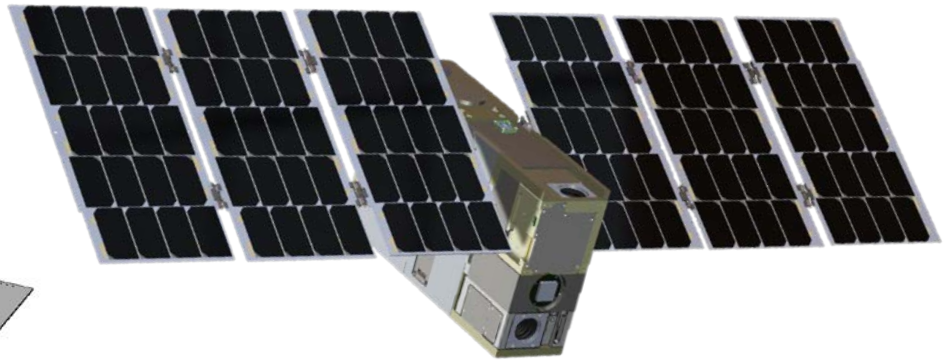
XB1 Spacecraft Bus
Complete Nanosat Spacecraft Bus Solution (Integration and Test, Launch, Operations)

Turn-key Spacecraft Solutions

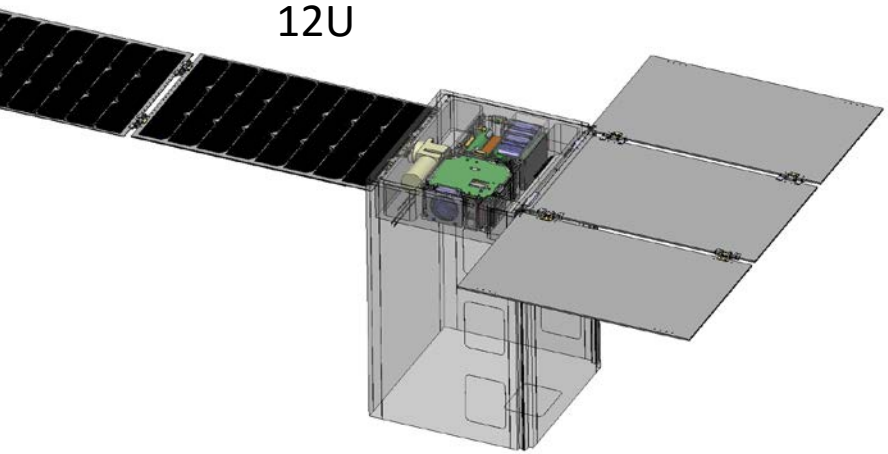
- XB-based Spacecraft Buses
  - 3U, 6U, 12U, micro-sat
  - Support LEO and GEO missions
- Integration & Test
- Launch Vehicle Integration
- Mission Operations

3U

6U

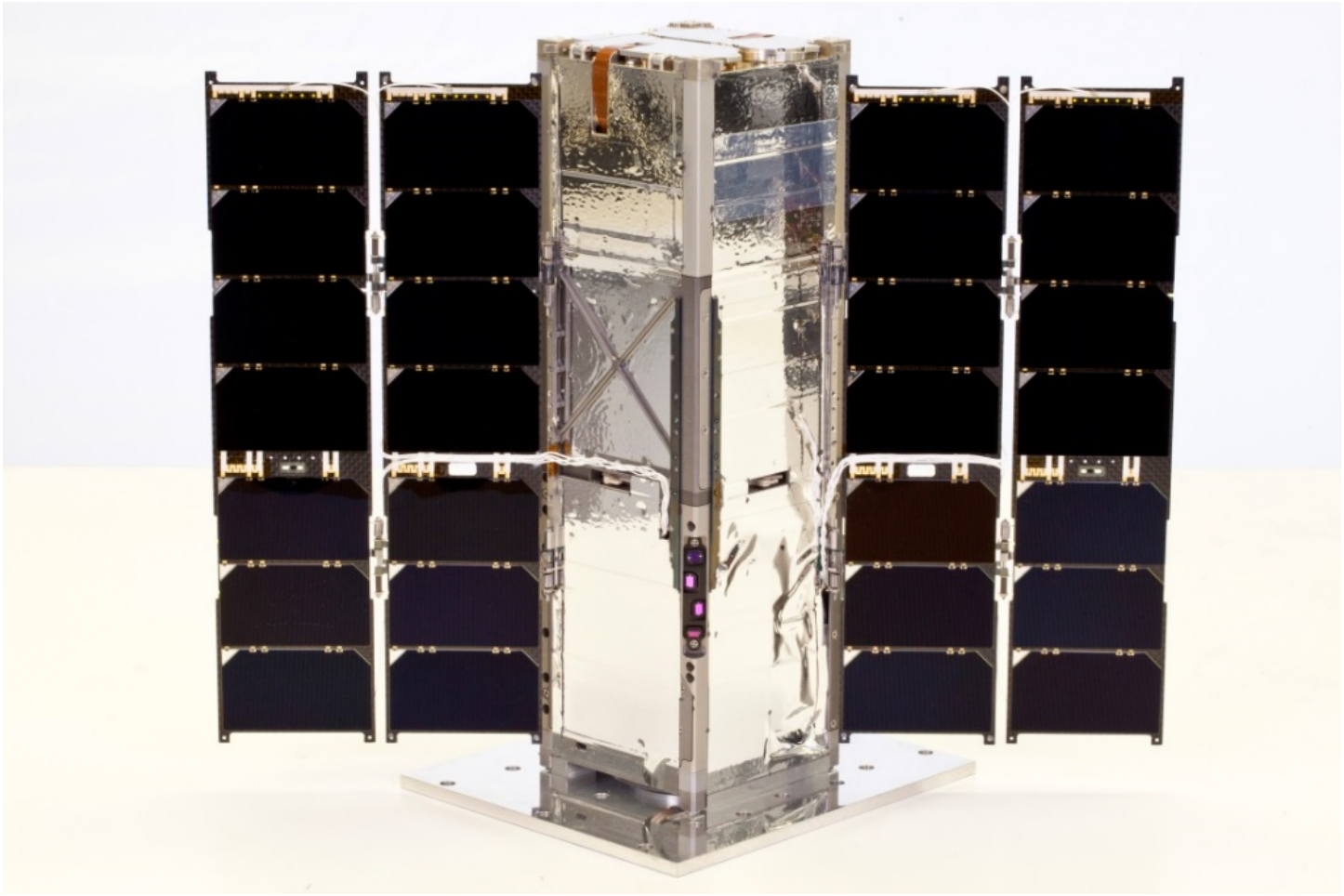


12U



First Flight of XB Spacecraft: RAVAN Launches mid Sept, 2016

- 3U spacecraft built by BCT
- Radiometer payload provided by JHU-APL



XACT ADCS Module

- Complete high-performance attitude control module
  - Nano Star Tracker for precise attitude determination (Integrated stray light baffle)
  - Three micro sized (or larger) reaction wheels enabling precise 3-axis control
  - Three torque rods
  - MEMS IMU
  - MEMS Magnetometer
  - Sun sensors
- Multiple pointing reference frames, such as:
  - Inertial
  - LVLH
  - Earth-fixed target
  - Solar
  - Lunar
- Highly-integrated architecture with powerful processing core

0.5U ADCS module

First Flight of XACT: MinXSS Deployed May 16, 2016

- University of Colorado Boulder built & operates the cubesat

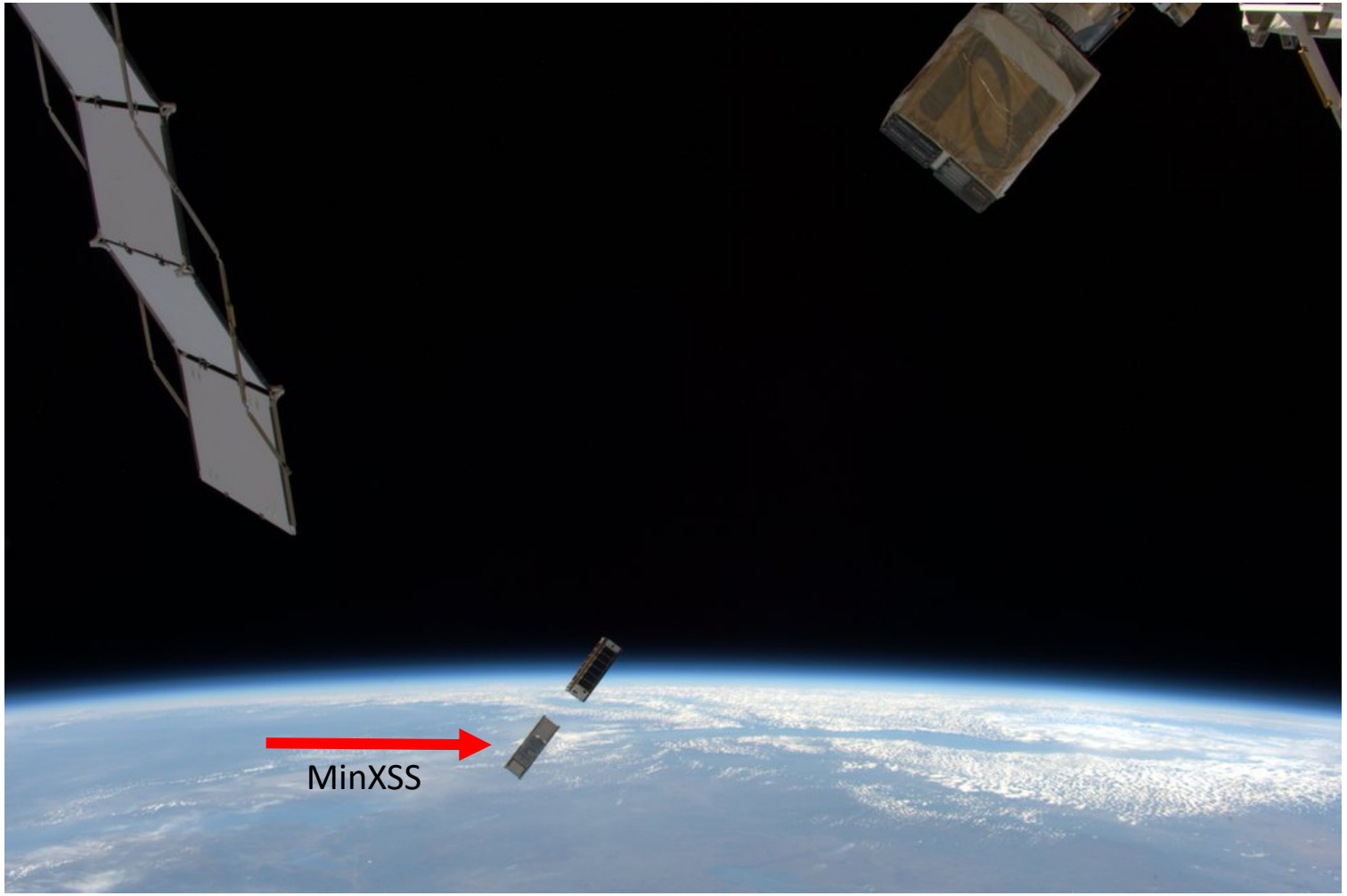
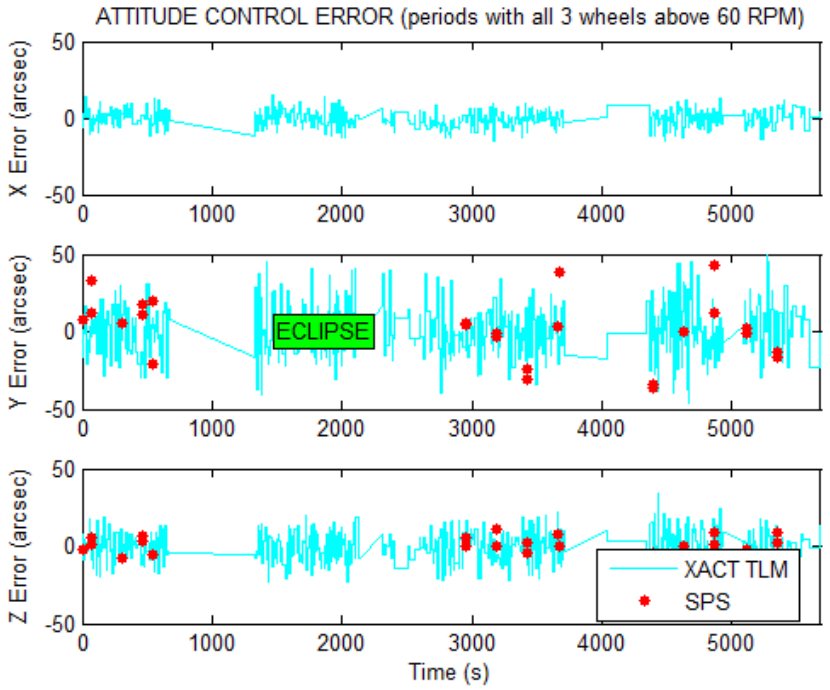


Photo: Time Peake, NASA

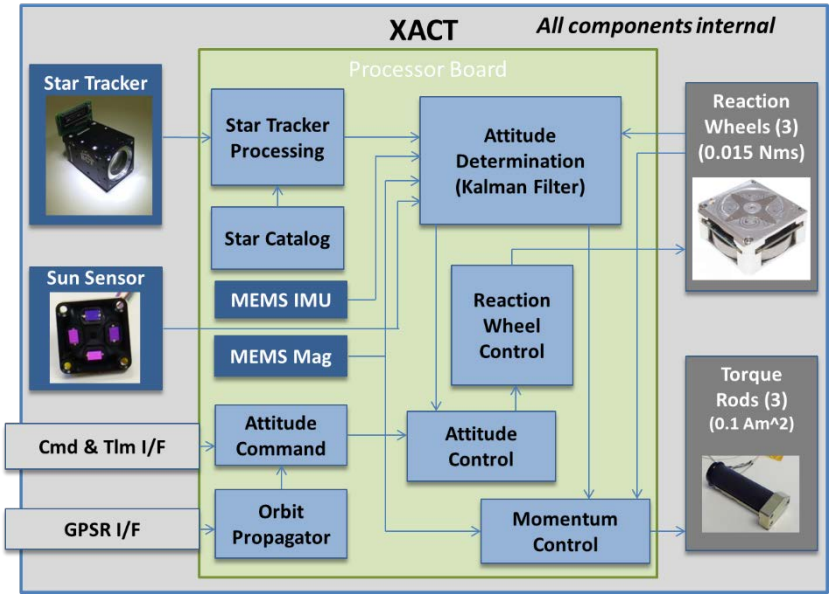
XACT Points 3U MinXSS Platform with High Accuracy

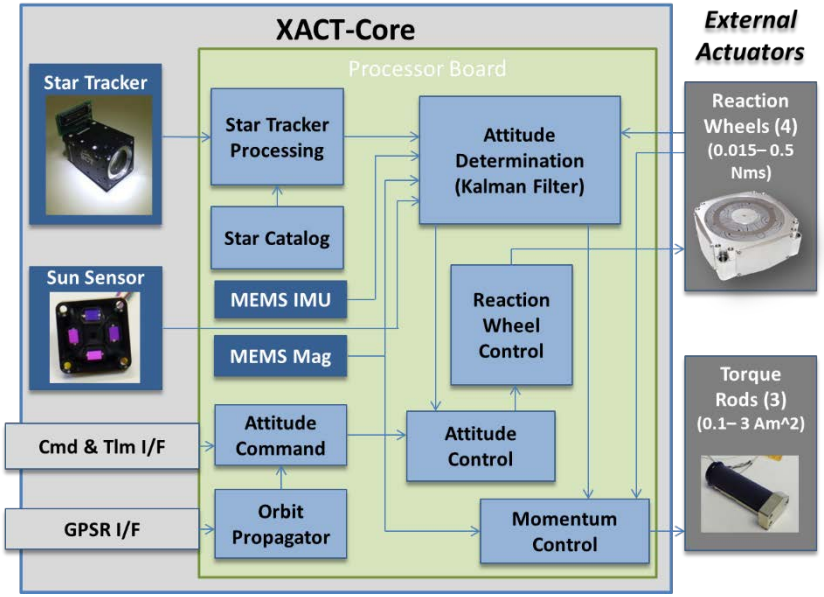
- Two independent measures of attitude control error
  - XACT telemetry based on star tracker, high-fidelity sun model
  - MinXSS fine Sun Point Sensor (SPS) with 2 asec dark noise
- X axis shows 5 asec performance across tracker boresight (BCT specification is 11 asec)
- Y axis shows 16-20 asec performance, mostly about-tracker boresight (BCT specification is 25 asec)
- Z axis shows 7-9 asec performance
  - Very low inertia makes this axis more sensitive to torque disturbances
  - Axis also has an about-tracker-boresight component
  - Long-term SPS data shows 7 asec performance over many days

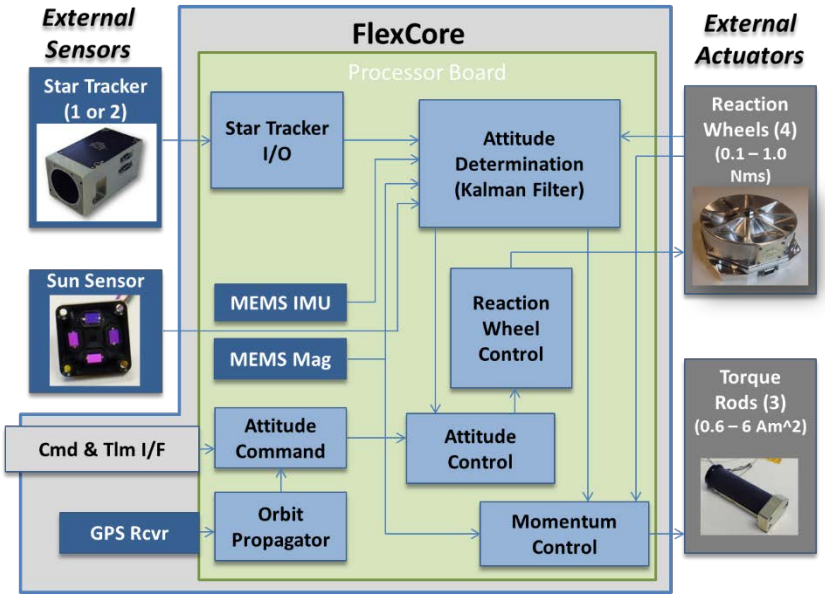
Body Axis	RMS Error (asec)	
	Per XACT	*Per SPS*
X	5.3	n/a
Y	15.8	20.1
Z	9.4	6.8



Comparison of XACT & FlexCore



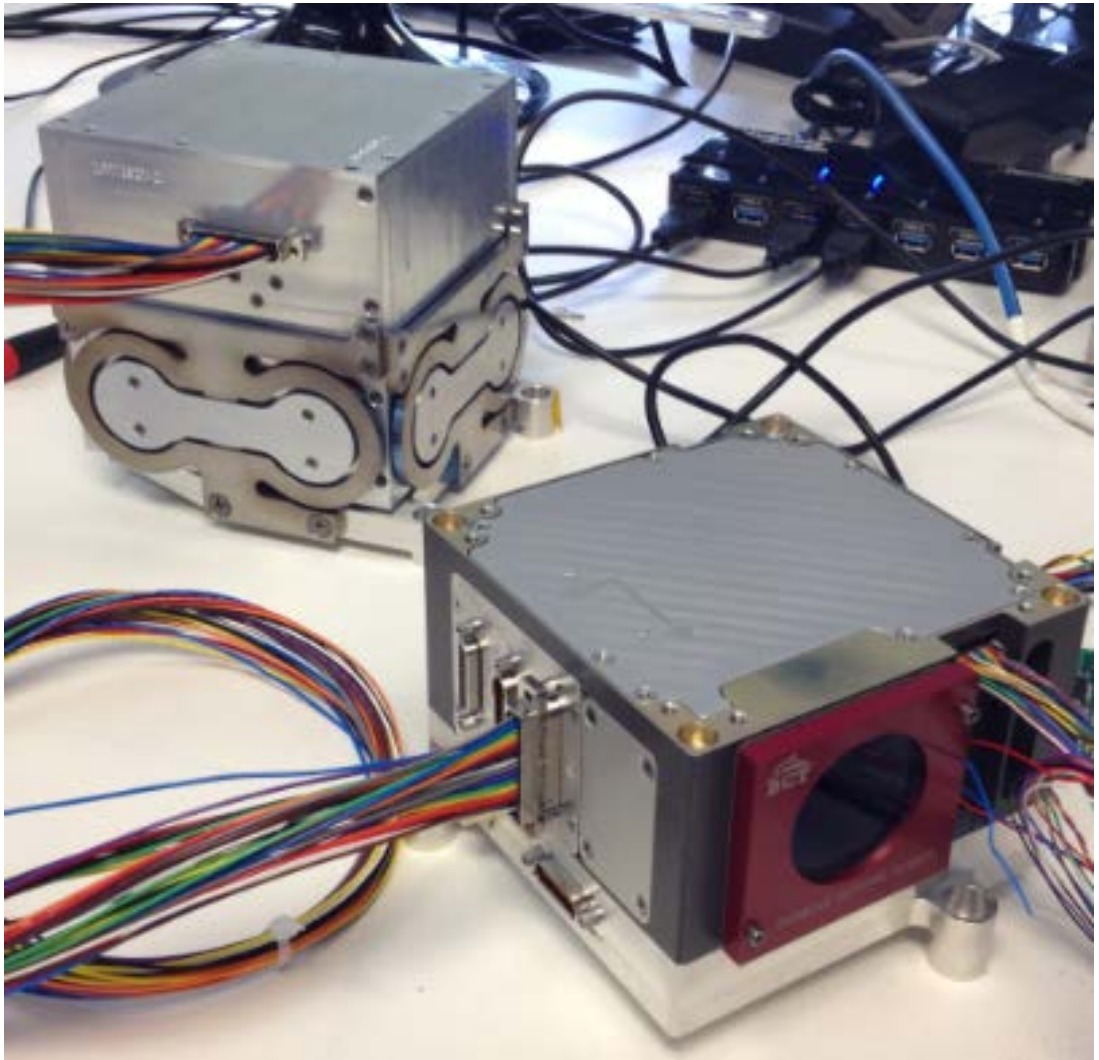




Dual-tracker FlexCore should provide 0.002-deg pointing control on all three axes

XACT-Core Hardware

XACT with RWp100 wheels

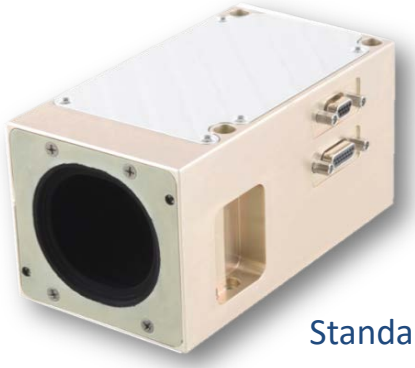


FlexCore Hardware

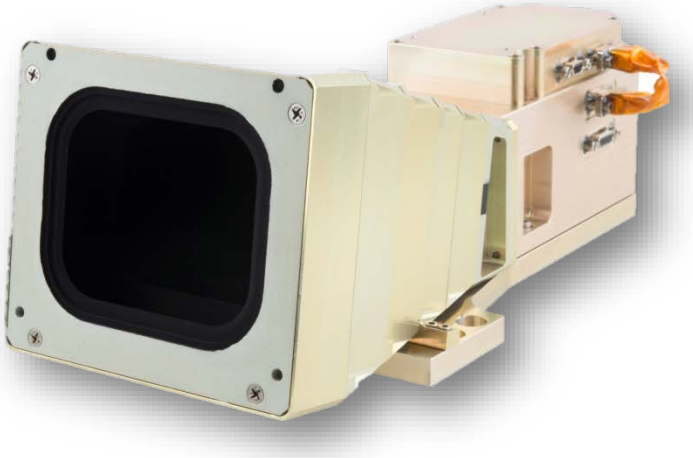
- Core XACT technology used with larger BCT wheels and torque rods to support ESPA-class spacecraft

Nano Star Trackers

- High performance design, compatible with a variety of cubesat and nanosat configurations and missions. Features include:
  - Tracks stars down to 7.5 magnitude
  - On-board star catalog (>23,000 stars) and lost-in-space star ID
  - Easy-to-integrate digital interface
  - Compact packaging (CubeSat compatible)



Standard NST



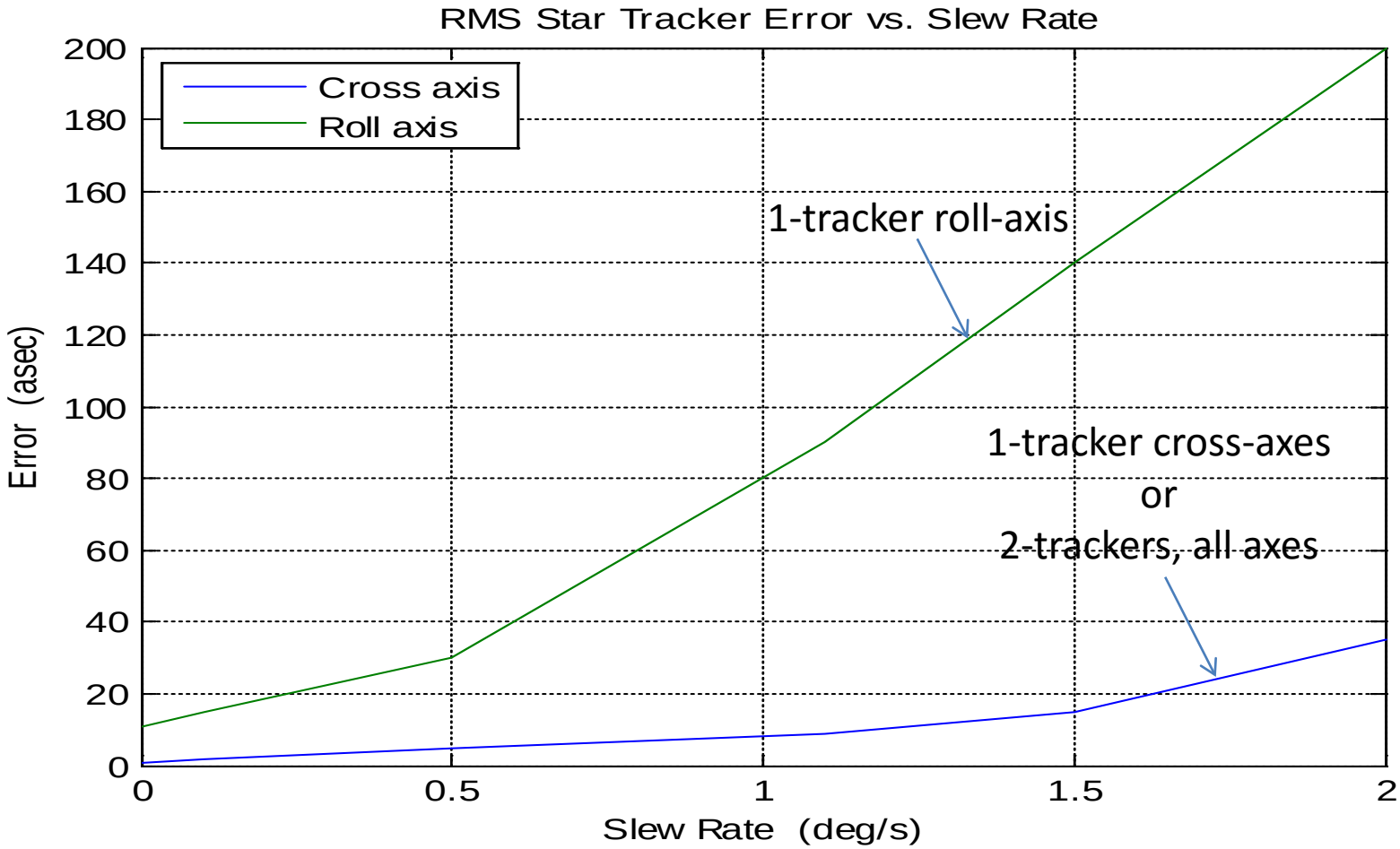
Extended Baffle NST

(+28V option, 17.5° half cone sun keep out zone)

Nano Star Tracker Capability	
Specification	Performance
Attitude solution update rate	5 Hz
Bore-sight accuracy	6 arcsec (1-sigma)
Roll axis accuracy	40 arcsec (1-sigma)
Lost in space solution time	4 seconds
Field of view	10 x 12 degrees
Spacecraft lifetime	3 Years (LEO)
Sky coverage	>99% sky coverage
Mass	0.35 kg (with baffle)
Volume	10 x 6.73 x 5 cm (with baffle)
Nominal power consumption	0.75W
Peak power	≤1.0W
Idle mode	0.5W
Operating voltage	5 +/- 0.1V
Data interface (optional drive electronics)	RS-422 (can support I2C and SPI)

Results of Night Sky Testing

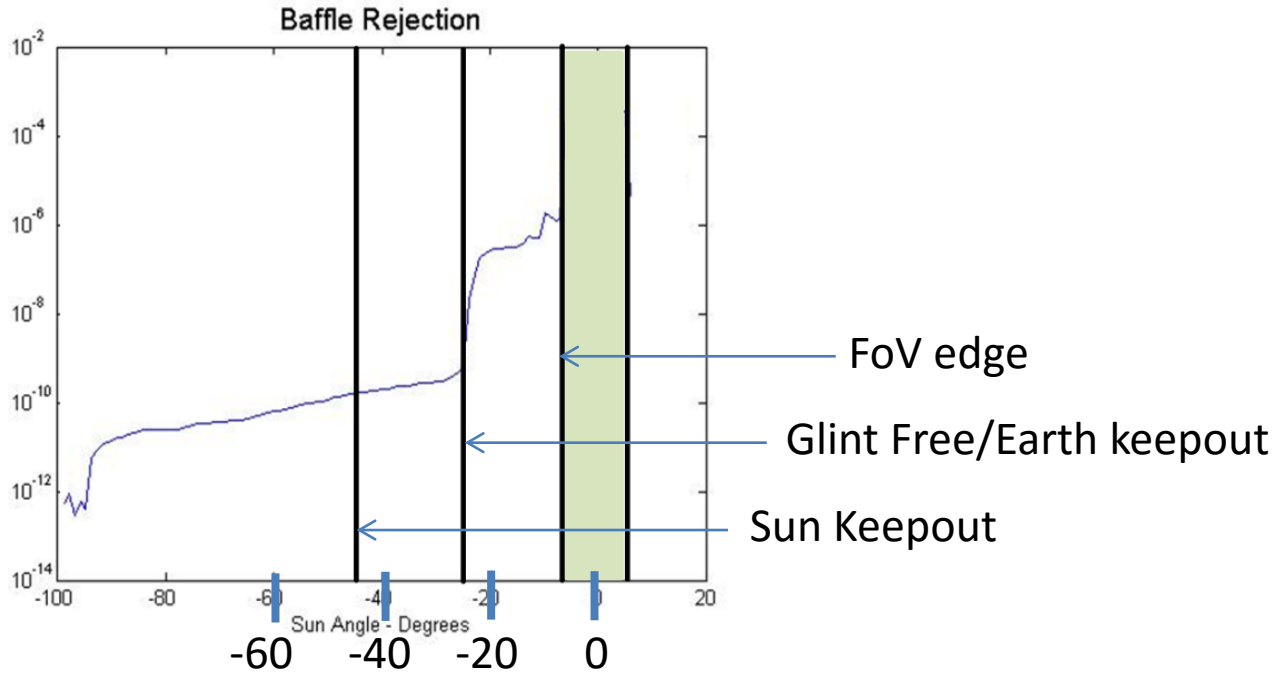
- High-precision telescope gimbal used to slew NST at various rotation rates
- Mean motion removed, resulting in NST knowledge error



Stray Light Baffle Performance

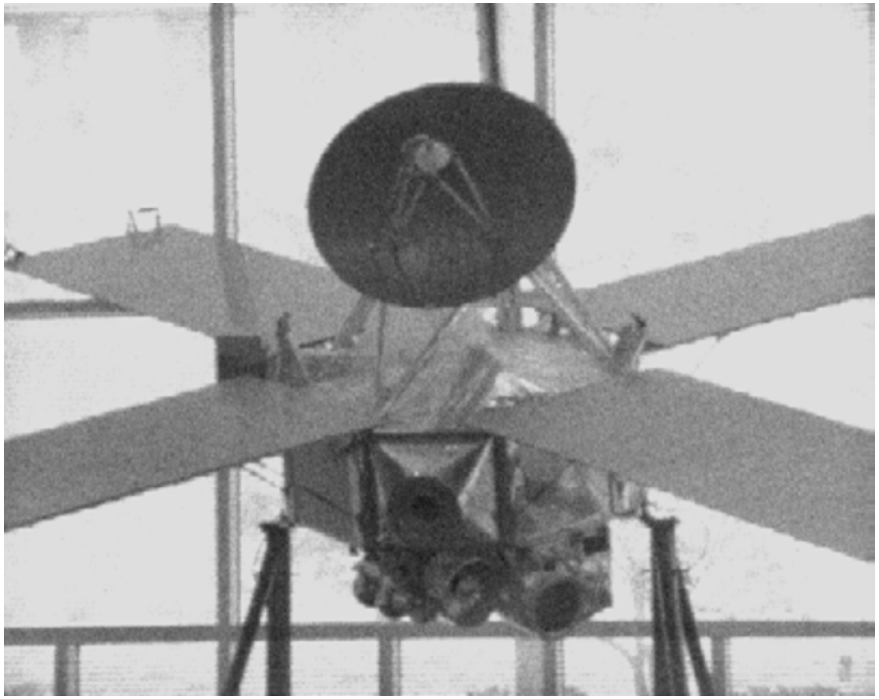
- Stray light baffle allows operation within <45 deg of sun, and 25 deg of earth.
- Performance was verified using a heliostat at CU LASP
- Results matched analytical model extremely well

Results of heliostat testing at CU LASP



Tracker Photo-mode

- User can command Photo mode using selectable gains and integration times.
- Can store and downlink full frame images



Spacecraft display in daylight.
(Lobby of CU LASP)
Short integration time.

“Star Wagon” at night.
Long integration time.

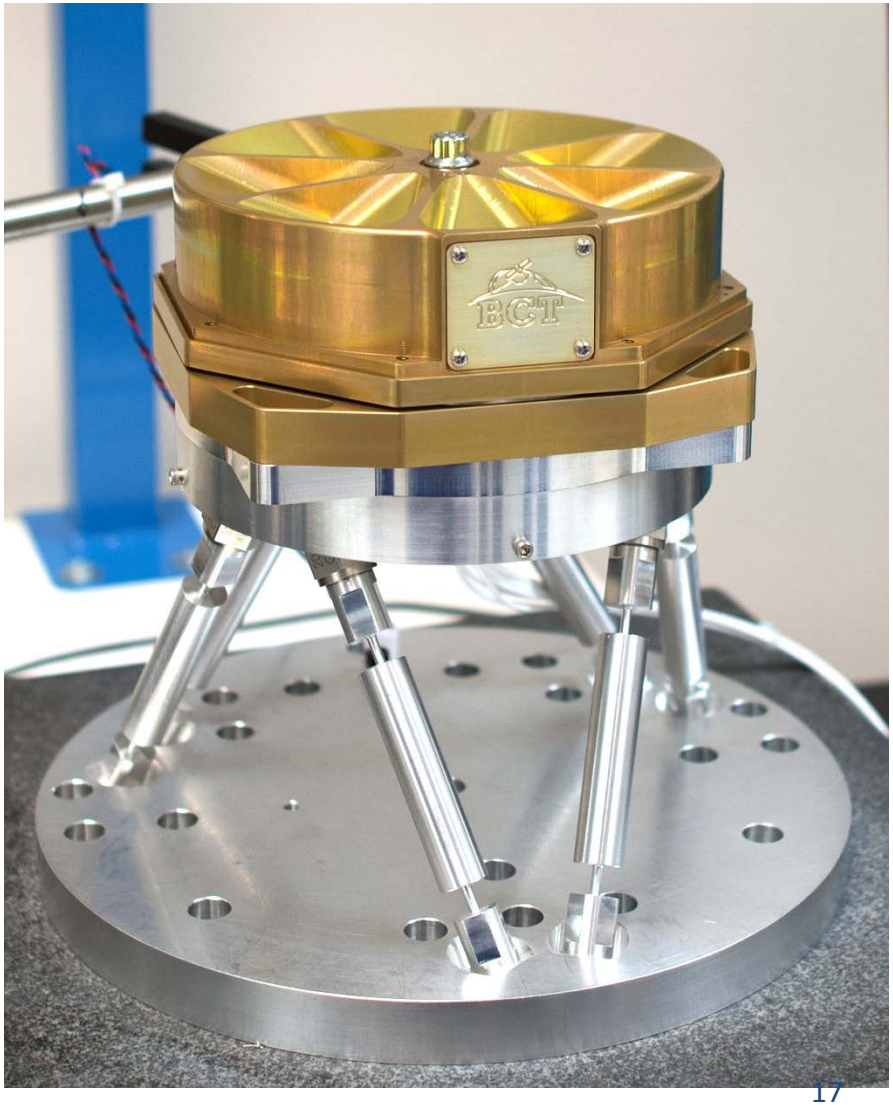
Multiple Reaction Wheels Sizes Support Range of S/C Inertias

- BCT Reaction Wheels provide an efficient, high performance solution for spacecraft attitude control
- Available in a range of sizes, providing a wide combination of torque and momentum storage
- Control electronics can be included internally to the reaction wheel, or a separate unit
- Designs reviewed by NASA bearing and lubricant experts

							In Development		*Future Products*		
Model #		**RWp015**	**RWp050**	**RWp100**	**RWp500**	**RW1**	***RW4***	***RW8***	***RW12***	***RW25***	***RW50***
Spec Torque	***Nm***	0.006	0.007	0.007	0.025	0.04	0.06	0.08	0.1	0.1	0.25
Max Momentum	***Nms***	0.015	0.050	0.100	0.500	1.5	4	8	12	25	50
Diameter	***cm***	4.3	5.8	7.0	11	15	16	17	19	21	25
Height	***cm***	1.8	2.3	2.5	3.8	7	9	9	11	11	12
RWA Total Mass	***kg***	0.115	0.24	0.35	0.85	1.5	3.1	3.3	4.9	6.9	9.3
Max Power	***Watts***	5.5	9	9	23	46	48	50	53	53	127
Nominal Power	***Watts***	0.5	0.5	0.5	3	5	5	5	7	7	9

Wheel Disturbance Measurements

- Jitter Environment Measurement System (JEMS)
- Measures static and dynamic imbalance
- Produces waterfall plots of all disturbances

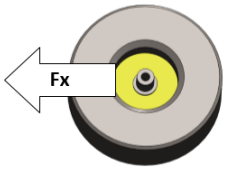


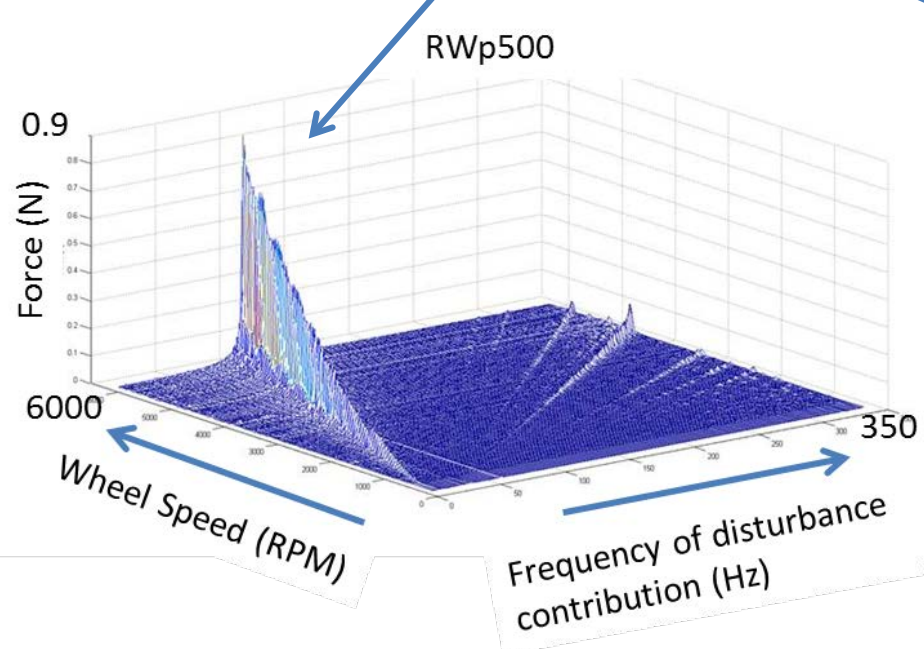
Wheel Jitter Performance

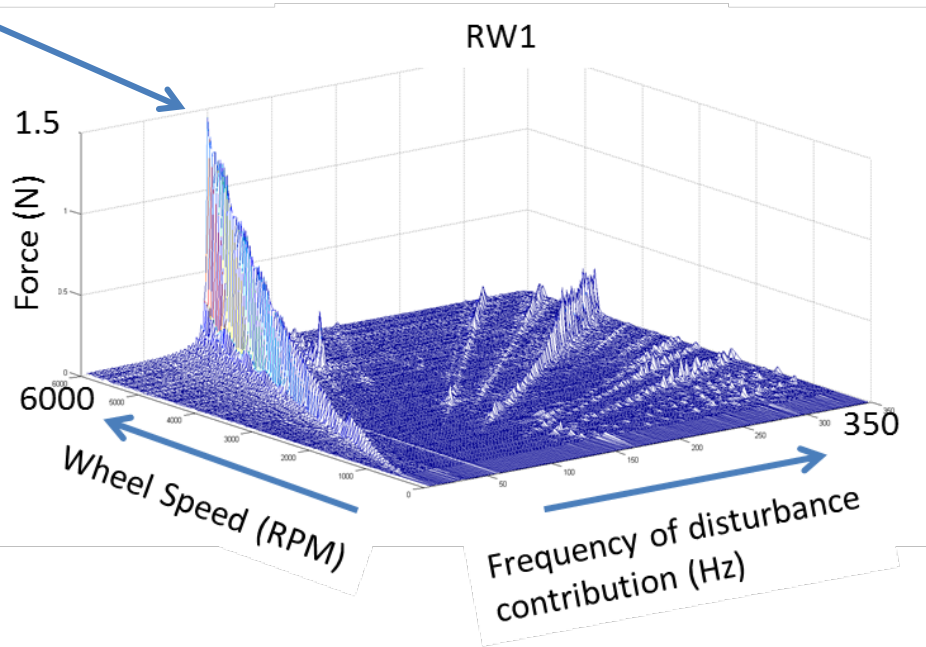
- BCT wheels are designed for long life, and extremely low jitter
- Low wheel disturbances result in low payload line-of-sight motion

Low residual static imbalance force

$F = mr\omega^2$





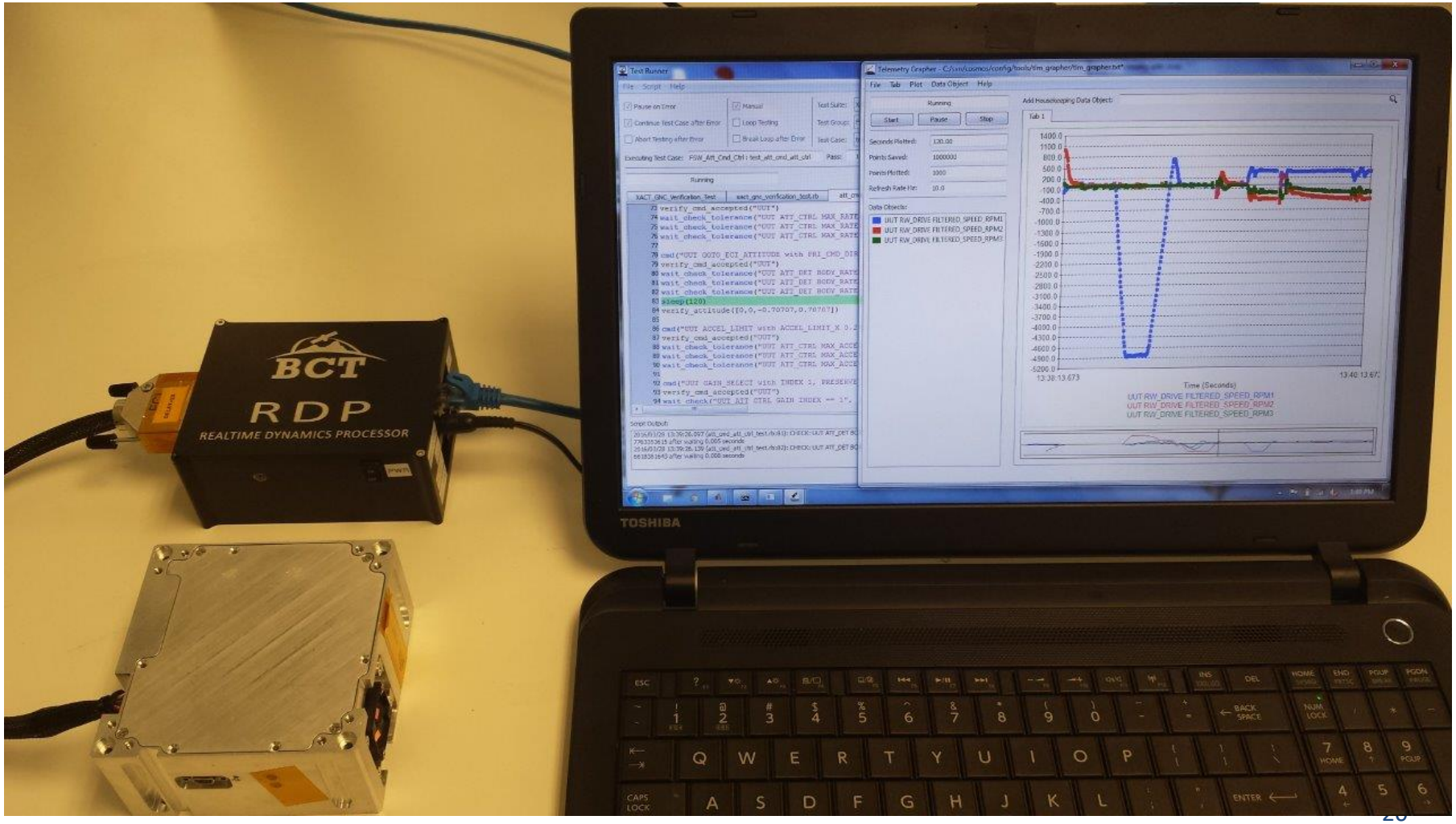


Software Development

- BCT uses proven method for software development, which is extremely efficient, robust, and supports near-100% code re-use across all spacecraft.
- Developed by highly-experienced GN&C and software personnel, having worked over 20 spacecraft programs at a variety of companies, prior to BCT.
- Capability-rich software goes far beyond most cubesats and microsats, and is *on-par with tier-1 spacecraft*.
- Over 90% of flight software is auto-coded using Matlab/Simulink.
- One of the most advanced spacecraft auto-code systems in the industry.
- Common core for all Blue Canyon Technologies software products.
- Automated code generation and build process substantially reduces effort over traditional methods.

Fully automated, scripted, closed-loop testing

- "Test as you fly" capability



Future Improvements

- Fold in results of NASA Tipping Point Technology effort (Hyper-XACT)
  - Improved pointing performance
  - Improve radiation tolerance
- Include C&DH & EPS (similar to XB1) to make FlexB1

FlexCore Summary

- Highly configurable ADCS: from CubeSat to ESPA
- High performance
- Highly experienced team

- We're hiring

bluecanyontech.com