BLUE CANYON TECHNOLOGIES

# LAUNCH YOUR MISSION WITH US

Spacecraft Buses, Systems & Solutions

www.BlueCanyonTech.com

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*5330 Airport Blvd*
*Boulder, CO 80301*

# About Blue Canyon Technologies

- Founded in 2008
- Experienced team of space industry veterans
- Agile small satellites:
  - Spacecraft
    - Cubesats (3U, 6U, 12U)
    - Microsats to ~200kg
  - Components/Subsystems
    - Star Trackers
    - Reaction Wheels
    - ADCS
- Staff & Facility:
  - >100 people
  - 45,000 sq-ft
  - Additional 40,000 sq-ft beginning soon


# BCT Small Satellite Products

BLUE CANYON TECHNOLOGIES

## 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 to Microsats (enclosed or distributed architecture)

## Electrical Power Systems

Batteries, solar panels, power control and distribution

## XB Spacecraft Avionics

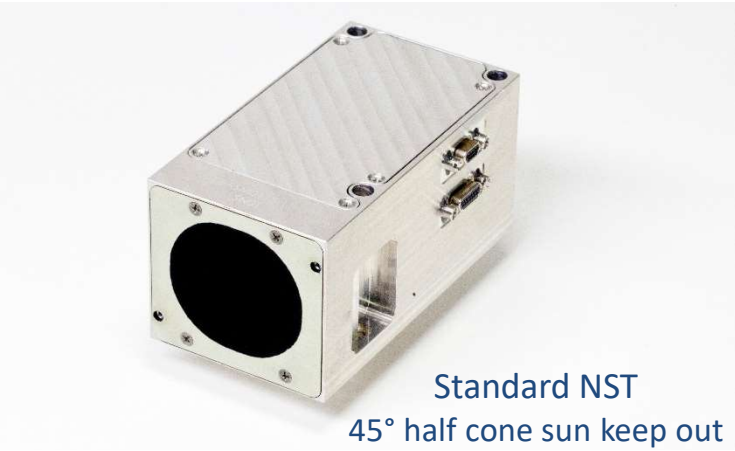
Integrated Nanosat system (ADCS, EPS, C&DH, GPS, Processors, Software Defined Radios)

## XB Spacecraft Buses

Complete Nanosat to Microsat Spacecraft Bus Solutions (Design, Manufacturing, Integration & Test, Launch, and Operations)

# Nano Star Trackers

- The Blue Canyon Technologies Nano Star Tracker is a reliable, high performance design, compatible with a variety of SmallSat 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 electronics
  - Compact packaging (CubeSat compatible)
  - Can track at 2+ deg/



Standard NST
45° half cone sun keep out

***25 Star Trackers On Orbit***

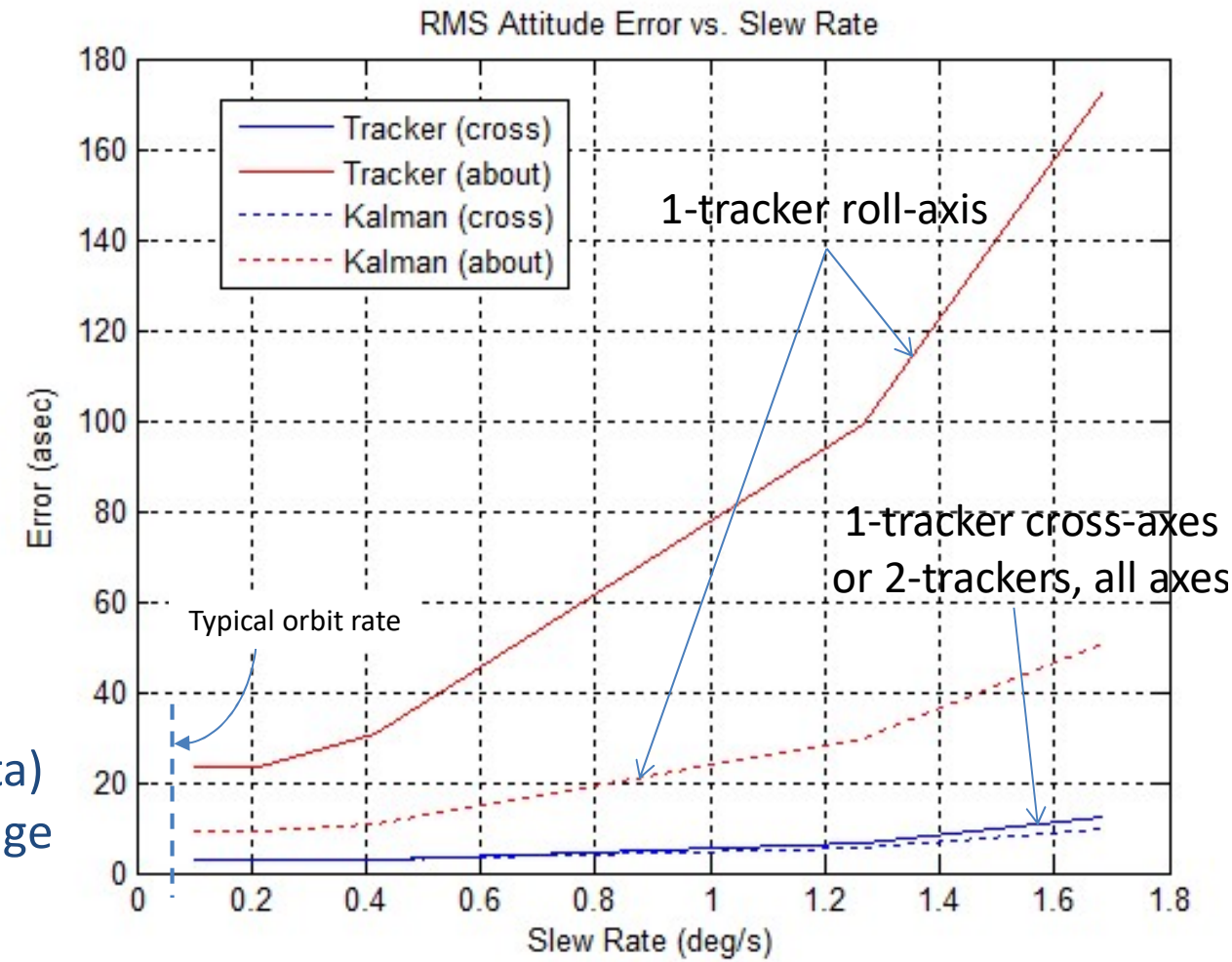
Extended Baffle NST
(+28V option, 17.5° half cone sun keep out zone)

| Nano Star Tracker Capability | |
|---|---|
| Specification | Performance |
| Attitude solution update rate | 5 Hz |
| Bore-sight accuracy | 4 arcsec (1-sigma) |
| Roll axis accuracy | 30 arcsec (1-sigma) |
| Lost in space solution time | 2 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, I2C, SPI |

# Attitude Knowledge at Various Slew Rates

- Performance estimates obtained from extensive night-sky testing
- High-precision telescope gimbal used to slew NST at various rotation rates
- Mean motion removed, resulting in NST knowledge error
- Classical 6-state MEKF Kalman filter (with IMU data) enhances attitude knowledge versus raw tracker

***Applies to all spacecraft sizes: 3U to ESPA***



# Reaction Wheels

- 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, Air Force, and Aerospace Corp experts

  - *Any size wheel* can be used with BCT attitude determination systems
    – Only table values in flight software need to change

***69 RWp015 On Orbit***

***3 RWp500 On Orbit***

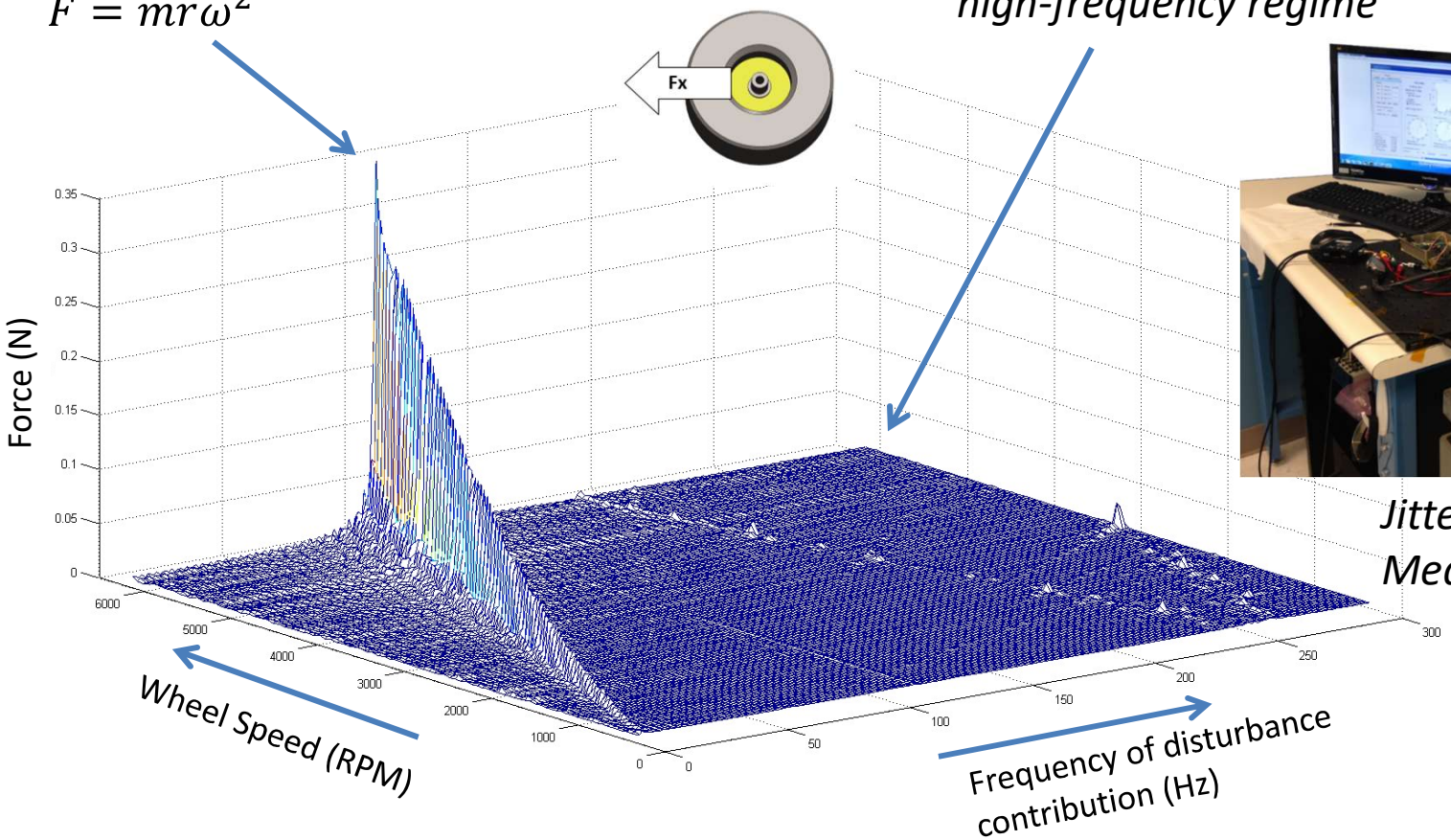
| | (MicroWheel) RWP015 | RWP050 | RWP100 | RWP500 | RW1 | RW4 | RW8 |
|---|---|---|---|---|---|---|---|
| **Momentum** | 0.015 Nms | 0.050 Nms | 0.10 Nms | 0.50 Nms | 1.5 Nms | 4.0 Nms | 8.0 Nms |
| **Max Torque** * | 0.004 Nm | 0.007 Nm | 0.007 Nm | 0.025 Nm | 0.1 Nm | 0.3 Nm | 0.3 Nm |
| **Mass** | 0.130 kg | 0.24 kg | 0.35 Kg | 0.75 kg | 1.6 kg | 3.0 kg | 4.1 kg |
| **Volume** | 42 x 42 x 19 mm | 58 x 58 x 25 mm | 70 x 70 x 25 mm | 11 x 11 x 3.8 cm | 15 x 15 x 6.5 cm | 17 x 17 x 7 cm | 19 x 19 x 9 cm |
| **Voltage** | 12 VDC | 12 VDC | 12 VDC | 28 VDC | 28 VDC | 28 VDC | 28 VDC |
| **Power @ 1/2 Momentum** | < 0.6 W | < 0.5 W | < 0.5 W | < 3.0 W | < 3.0 W | < 4.0 W | < 5.0 W |
| **Power @ Full Momentum** | < 1.0 W | < 1.0 W | < 1.0 W | < 6.0 W | < 7.0 W | < 8.0 W | < 10.0 W |
| **Design Life** | > 5 years | > 5 years | > 5 years | > 10 years | > 10 years | > 10 years | > 10 years |
| **Static Unbalance** * (Fine) | < 1.2 g-mm (0.25 g-mm) | < 1.2 g-mm (0.35 g-mm) | < 1.5 g-mm (0.5 g-mm) | < 3 g-mm (1 g-mm) | < 4 g-mm (1.8 g-mm) | < 6 g-mm (2 g-mm) | < 8 g-mm (2.8 g-mm) |
| **Dynamic Unbalance** * (Fine) | < 20 g-mm² (2.5 g-mm²) | < 20 g-mm² (2.5 g-mm²) | < 20 g-mm² (5 g-mm²) | < 25 g-mm² (10 g-mm²) | < 100 g-mm² (50 g-mm²) | < 150 g-mm² (75 g-mm²) | < 200 g-mm² (100 g-mm²) |

# Wheel Jitter Performance

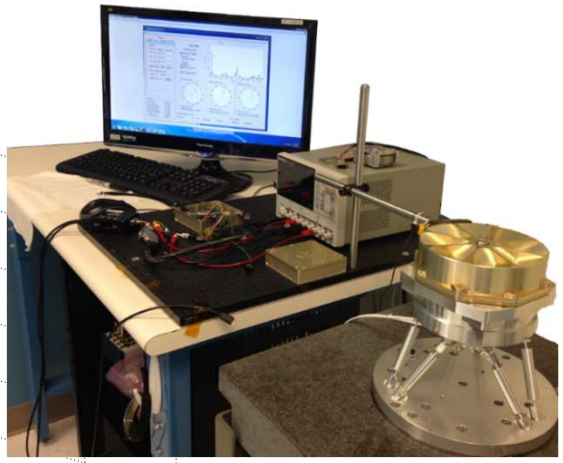
- BCT wheels are designed for long life, and extremely low jitter
- Low wheel disturbances result in low payload line-of-sight motion
- Plot is characteristic of all BCT wheel sizes

*Low residual static imbalance force*

$F = mr\omega^2$




*Extremely quiet high-frequency regime*



*Jitter Environment Measurement System*

# Wheels Produced in Batches

- Designed for high-volume manufacturing
- Often built in batches of 30 or more
- Each high-performance wheel assembled in a few hours.

# XACT / XB1 ADCS Module

- XB1 ADCS/C&DH is similar to stand-alone XACT
  - Nano Star Tracker for precise attitude determination (Integrated stray light baffle)
  - Three 15 mNms (or larger) reaction wheels enabling precise 3-axis control
  - Three torque rods
  - MEMS IMU
  - MEMS Magnetometer
  - Sun sensors

***11 Units On Orbit. Dozens more to go.***

***2 on their way to Mars!***

- Multiple pointing reference frames, such as:
  - Inertial
  - LVLH
  - Earth-fixed target
  - Solar
  - Lunar
  - Planets
  - Other spacecraft
- Highly-integrated architecture with powerful, robust processing core

*0.5U module*
*(15 mNms wheels)*

***XACT** Single tracker pointing accuracy:*
***0.003 deg, RMS, 2 axes,***
***0.007 deg, RMS, 3rd axis,***
*at <1 deg/s*

***XB1** Power module contains 2nd tracker.*
*Resulting 2-tracker pointing accuracy:*
***0.002 deg, RMS, all 3 axes,***
*at <1 deg/s*

# XACT & XACT-50

- Identical systems, except for different reaction wheel size
- Radiation tested to > 45kRad

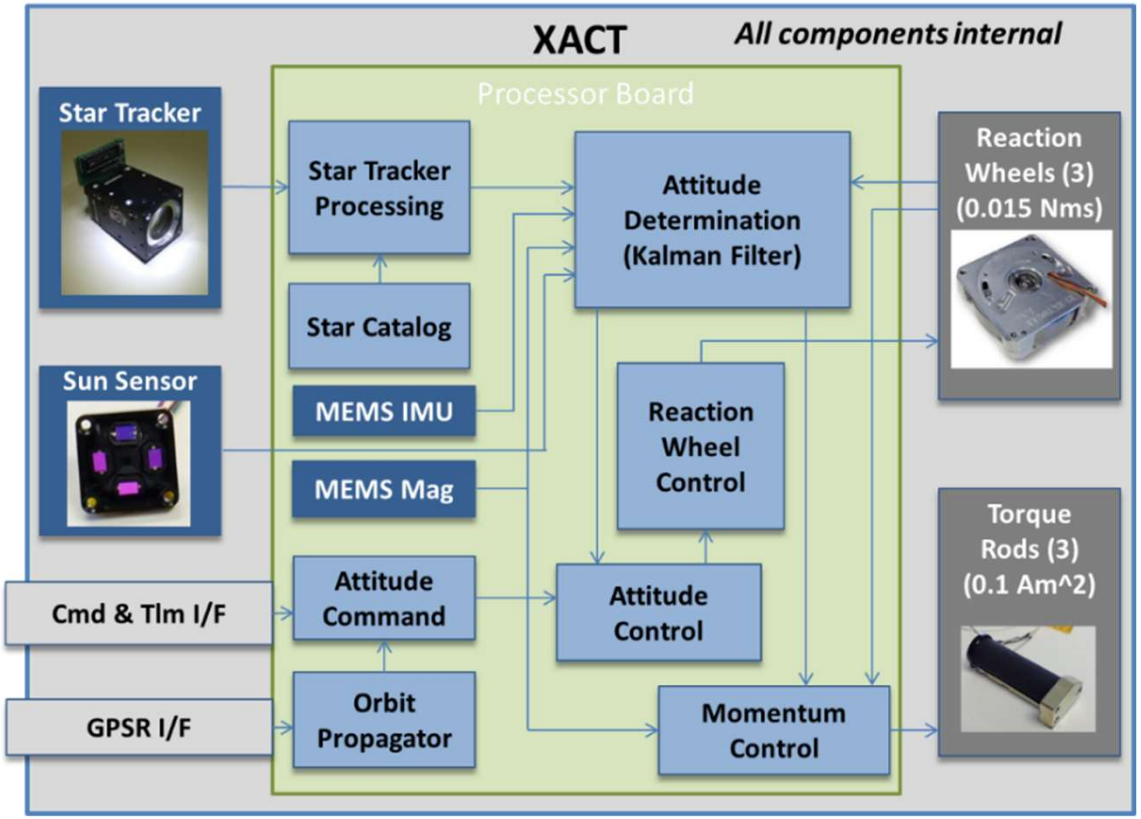
15 mNms

10 x 10 x 5 cm

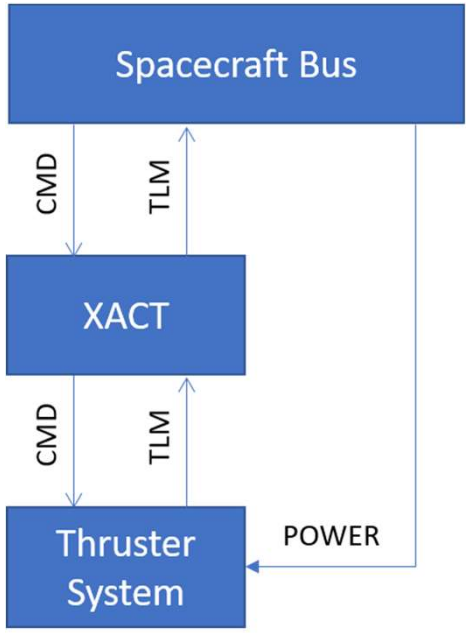
50 mNms

10 x 10 x 7.5 cm

# XACT Functional Block Diagram




Shown configured for typical LEO mission

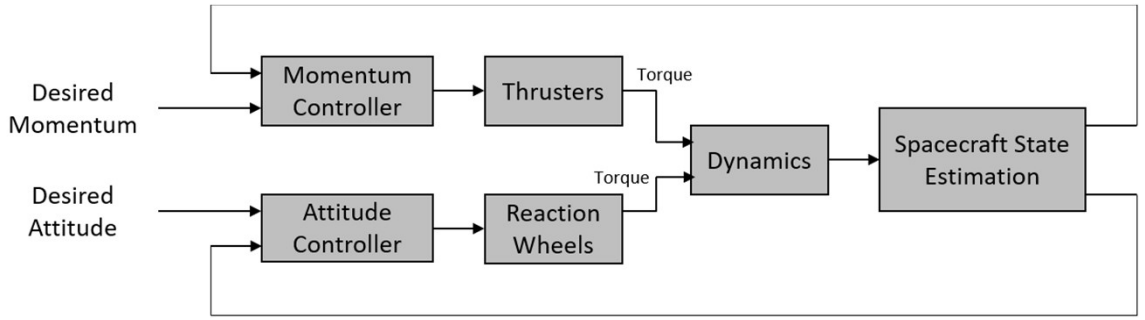



Thruster interface
(Typically for *non*-LEO)

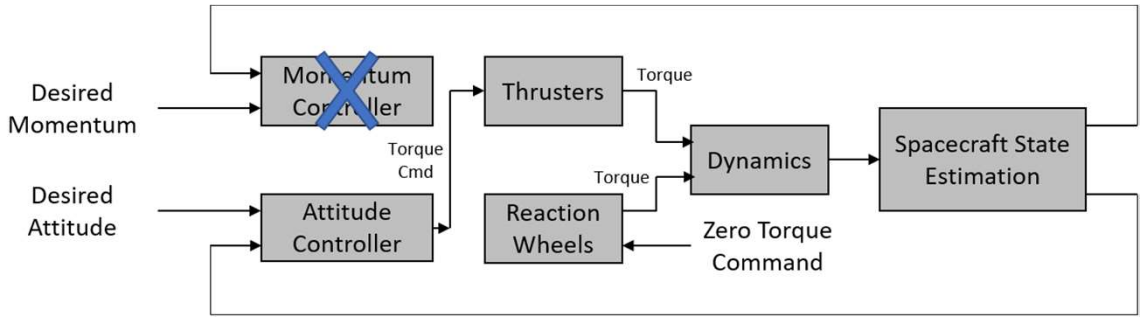
# Thruster Control

- XACT/XB1 algorithms first augmented to support propulsion/momentum control for JPL MarCO Mars mission
- XACT/XB1 is compatible with multiple propulsion systems
- Currently baselined with:
  - Cold gas
  - Ion
  - Green Prop
- Supporting multiple GEO, lunar, and deep space missions

Hybrid thruster-wheel attitude and momentum control for orbit adjustment with low-thrust systems

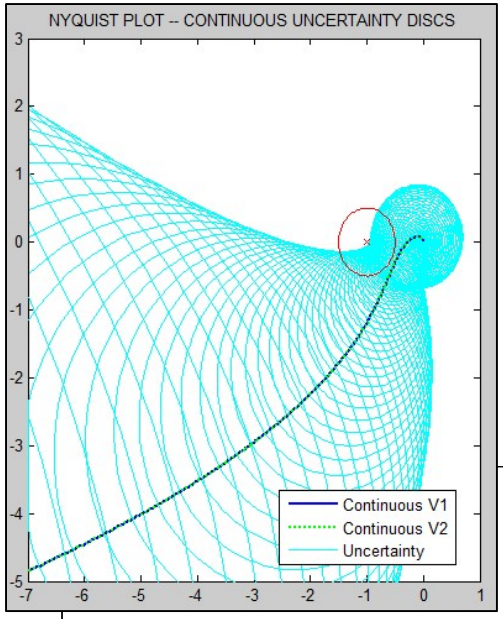


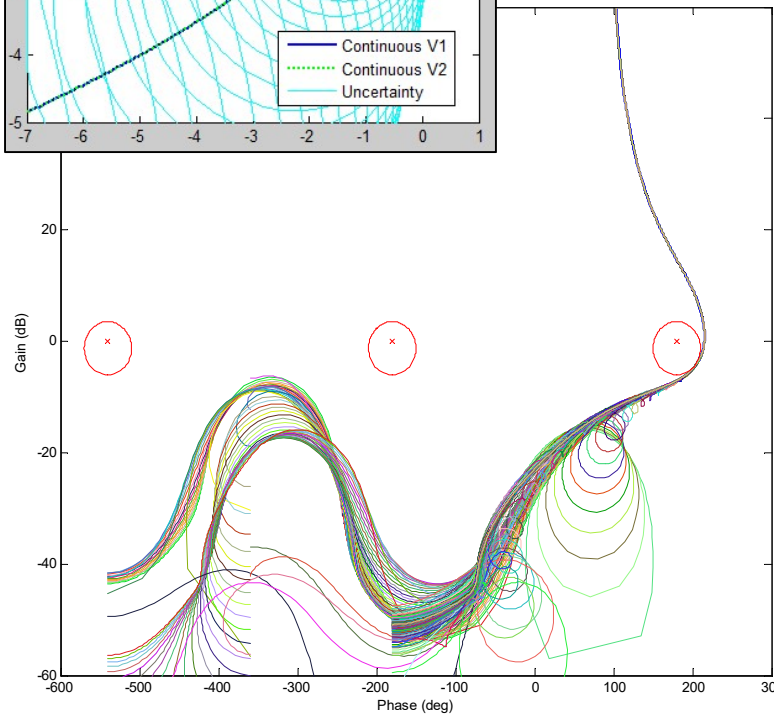

Thruster-based closed-loop attitude control for orbit adjustment with high-thrust systems



# Proprietary Advanced Control Synthesis Tools

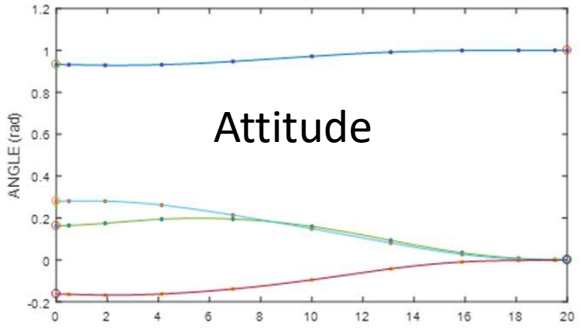
- Wide range of payload inertia and stiffness to accommodate
- BCT-proprietary optimization tools maximize performance subject to robustness constraints
  - Controllers must be robust for a user-defined set of spacecraft modal properties
  - Proprietary tool synthesizes the controller with optimal performance (per user-defined criteria) while still meeting this robustness constraint
  - Order-reduction keeps controller complexity to very reasonable levels without significant compromise
- High-performance controllers typically designed in 1-2 hours
  - Verified against high-fidelity 200 Hz time-domain multi-body simulation
  - Also verified via automated control stability analysis using parameters extracted directly from flight database
- Dozens of flight deliveries have used this toolset/process

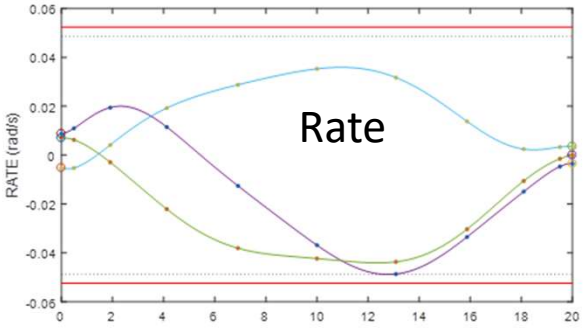


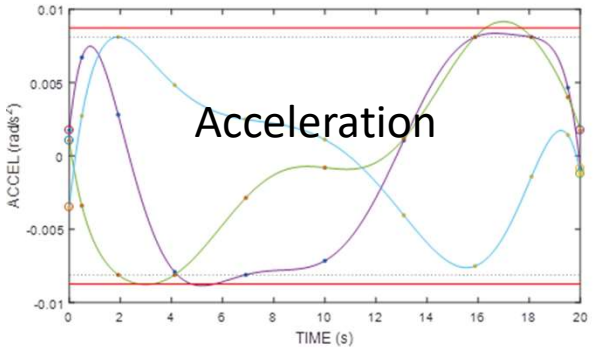



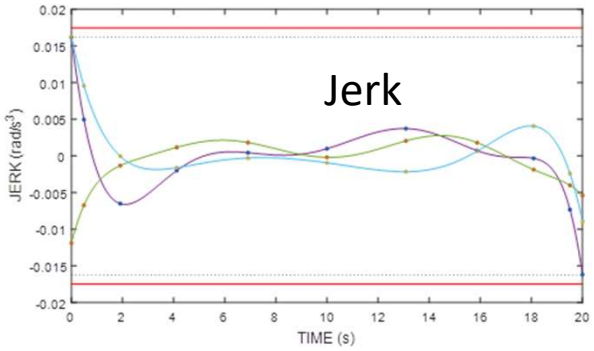
# Advanced Attitude Maneuver Optimization

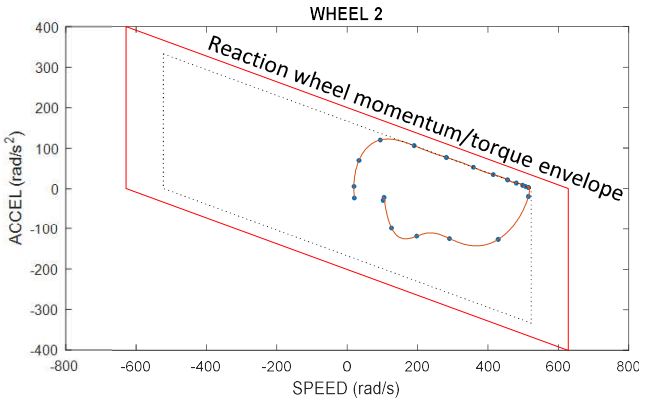
- Leverages some aspects of the increasingly popular pseudo-spectral optimal control approach
- Proprietary formulation satisfies theoretical conditions that guarantee some desirable convergence properties
- Proprietary solver infrastructure integrated with BCT flight code for maximum performance



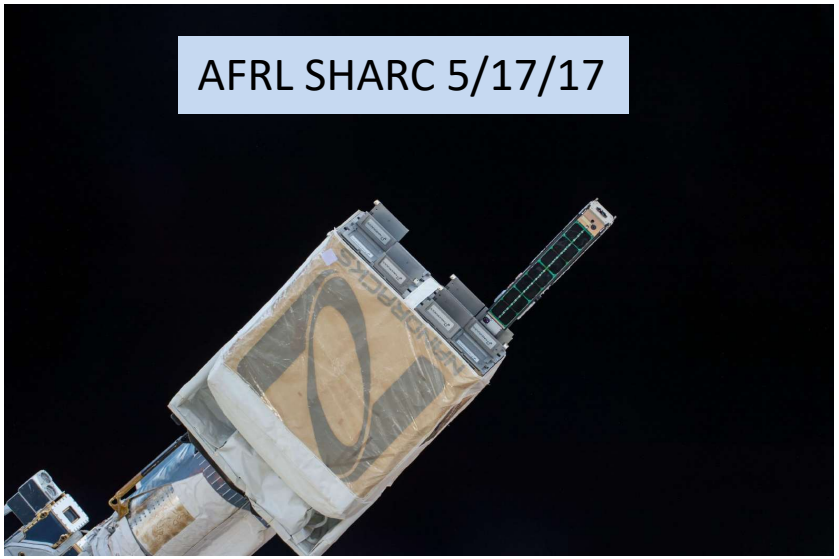




Wheel Torque vs. Speed

# Deployments of XACT S/C







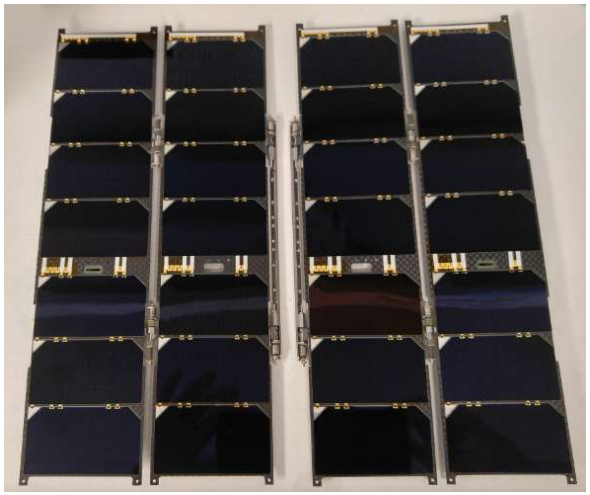
Photos: NASA, AFRL

# Lunar and Beyond

- **Lunar IceCube**
  - **Customer:** Morehead State University;
  - **Destination:** Lunar Orbit; **Objectives:** Search for water ice on Moon;
  - **BCT Providing:** XACT
- **NEA Scout**
  - **Customer:** NASA MSFC;
  - **Destination:** Interplanetary; **Objectives:** Flyby of an asteroid with solar sail propulsion;
  - **BCT Providing:** 4 RWp015. Modified XACT, Solar Panels
- **BioSentinel**
  - **Customer:** NASA Ames;
  - **Destination:** Heliocentric; **Objectives:** Detect, measure, and correlate the impact of space radiation in living organisms;
  - **BCT Providing:** XACT
- **Lunar Flashlight**
  - **Customer:** NASA JPL;
  - **Destination:** Lunar Orbit; **Objectives:** Map lunar south pole for volatiles;
  - **BCT Providing:** XACT-50, Solar Panels
- **CuSP**
  - **Customer:** Southwest Research Institute;
  - **Destination:** Interplanetary; **Objectives:** Heliophysics;
  - **BCT Providing:** XACT
- **EQUULEUS**
  - **Customer:** University of Tokyo and JAXA;
  - **Destination:** Earth-Moon, L2; **Objectives:** Trajectory control experiment in cis-lunar region, Imaging of earth's plasmasphere, Lunar impact flash observation, measurement of dust environment in cis-lunar region;
  - **BCT Providing:** XACT-50
- **OMOTENASHI**
  - **Customer:** AeroAstro;
  - **Destination:** Lunar surface; **Objectives:** Demonstration of a nano-lander;
  - **BCT Providing:** XACT
- **ArgoMoon**
  - **Customer:** Argotec;
  - **Destination:** Earth (6 months); **Objectives:** Take historically significant photography of the EM-1 mission;
  - **BCT Providing:** XACT
- **LunaH-Map**
  - **Customer:** Arizona State University;
  - **Destination:** Lunar orbit; **Objectives:** Mapping of hydrogen around Lunar South Pole;
  - **BCT Providing:** XB1
- **Earth Escape Explorer (CU-E3)**
  - **Customer:** University of Colorado Boulder;
  - **Destination:** Deep space; **Objectives:** Demonstrate deep space communications from a 6U CubeSat as part of the NASA CubeQuest Challenge;
  - **BCT Providing:** XB1
- **MarCO**
  - **Customer:** NASA/JPL;
  - **Destination:** Mars; **Objectives:** Data relay for INSIGHT lander during entry, descent, and landing phase;
  - **BCT Providing:** XACT

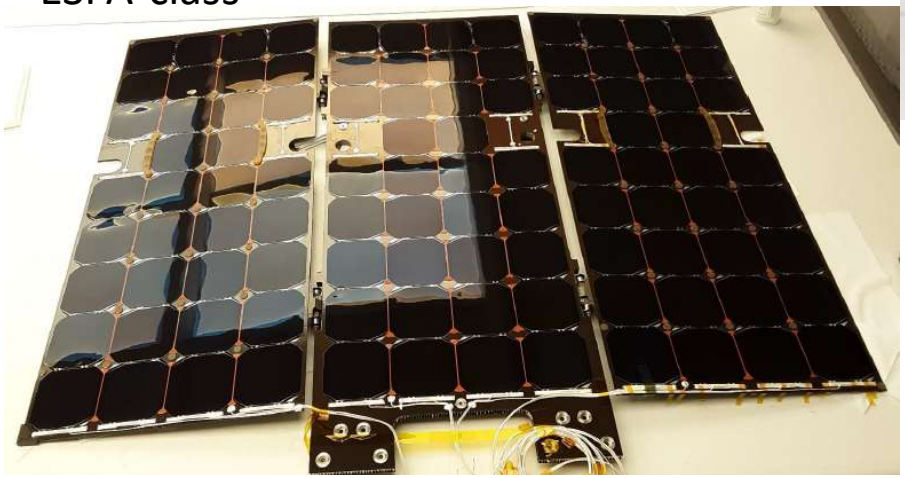
# Power Subsystems

- Charge control electronics with switched regulated voltages
- Wide range of solar panel configurations
- Variety of fixed deployment angles to maximize power across all Beta angles
- Micro-stepping SA drives
- Can provide 120W of power for CubeSats
- Can provide 400W of power for ESPA-class
- Li-Ion and Li-Fe-$PO_4$ batteries (75 - 600 W-hr)

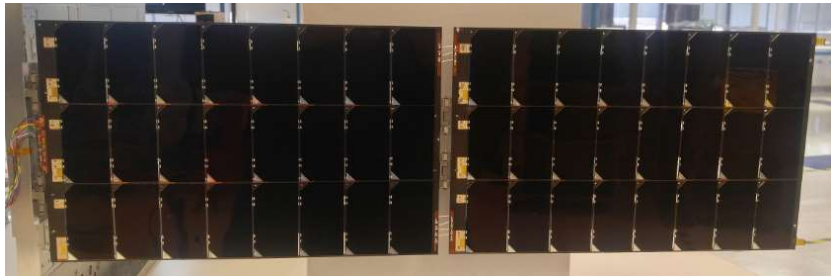


3U

ESPA-class



6U & 12U



# XB1 Avionics

## XACT-Bus 1U Integrated CubeSat System

- Highest-available pointing performance from *Dual* Micro-Star Trackers
- Bus functionality for GN&C, EPS, Thermal, C&DH, SSR, option for RF Comm
- Interfaces and control provided for Payload, Propulsion, and Solar Arrays
- Supports configurations up to 27U
- Supports user-hosted software via API function calls

- 1/2U ADCS/C&DH module and 1/2U Power module combine to form XB1

| | XB1 Parameter | Value/Notes |
|---|---|---|
| GN&C | Pointing Accuracy | ±0.002° (1-sigma), 3 axes, 2 Trackers |
| | Pointing Stability | 1 arc-sec/sec |
| | Maneuver rate | 10 deg/sec (typical 3U CubeSat) |
| | Orbit knowledge | 4m, 0.05m/s |
| CDH | Data Interfaces | Serial: LVDS, I2C, or SPI available |
| | Onboard Data Processing | Configurable via user loadable software |
| | Telemetry Acquisition | 6 12bit Analog, 6 discrete inputs |
| | Commands | Real-time, stored, macro |
| | Onboard Data Storage | 32 Gbytes |
| EPS | System Bus Voltage | 10 – 20 V (battery and array dependent) |
| | Energy Storage | Standard: 25Whr, expandable |
| | Solar Panels | Customer or BCT Provided Solar Panels (Details available per request) |
| | High Current Capability | Unregulated up to 60W |
| | Payload Power Feeds | QTY 6 (12, 5, 3.3V or Bus voltage) |

# Turn-key Spacecraft

- 3U to ESPA-class
- Full service: Design to Operations
- ~ 30 missions
- ~ 60 spacecraft

# 3U Cubesats

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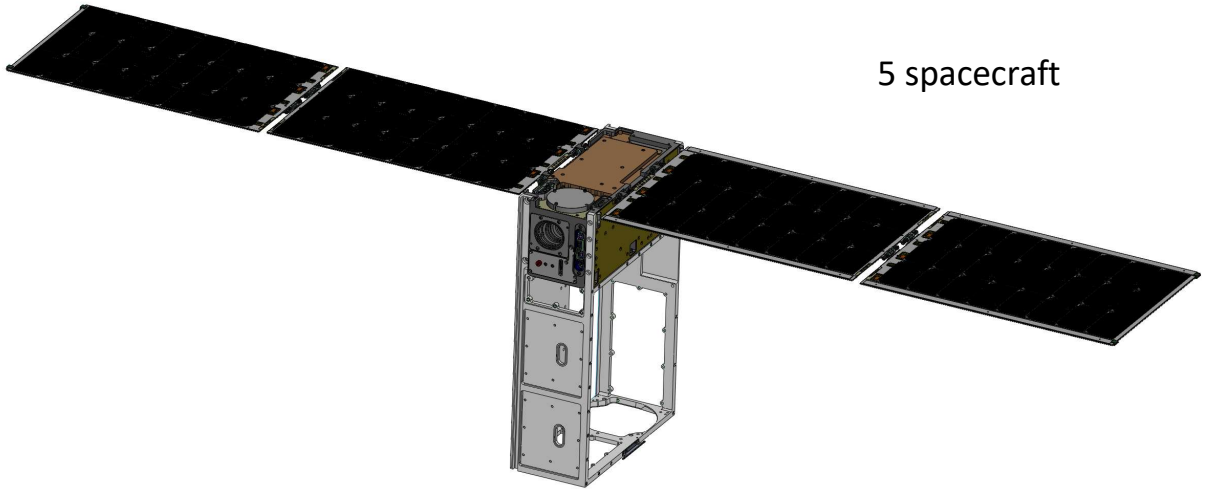
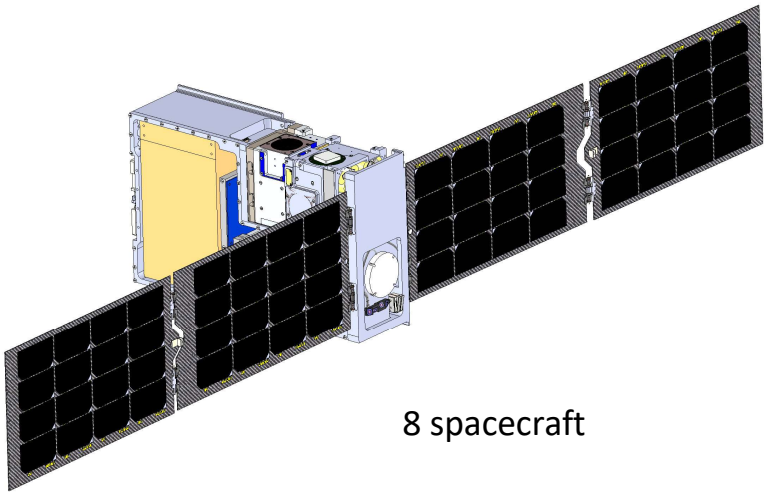
RAVAN

TROPICS

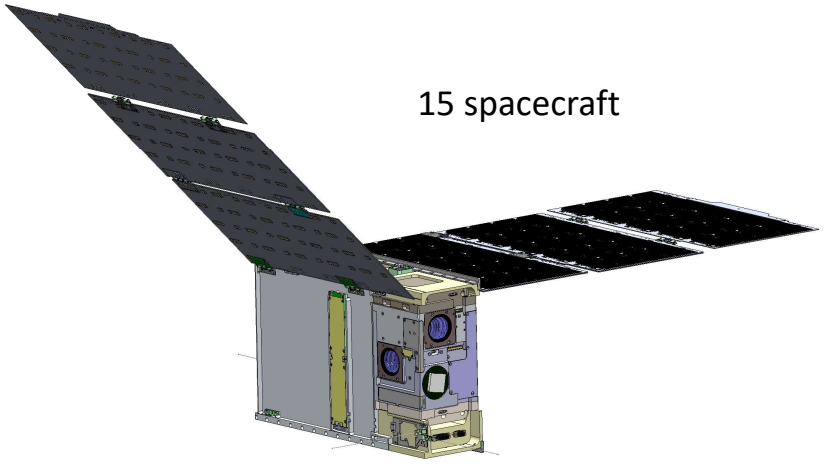
# 6U Spacecraft Configurations



5 spacecraft



8 spacecraft



15 spacecraft

# TEMPEST-D & CubeRRT

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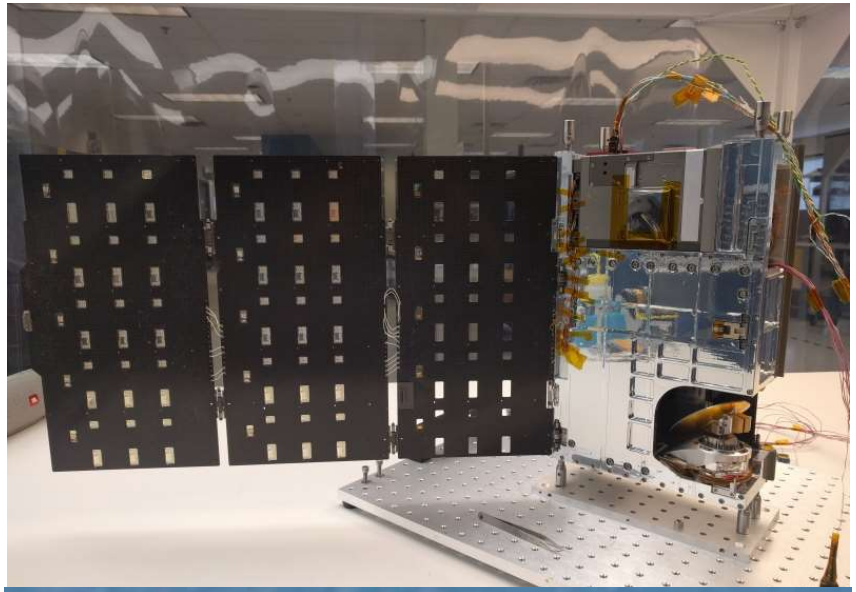

# 12U GEO ASCENT CubeSat

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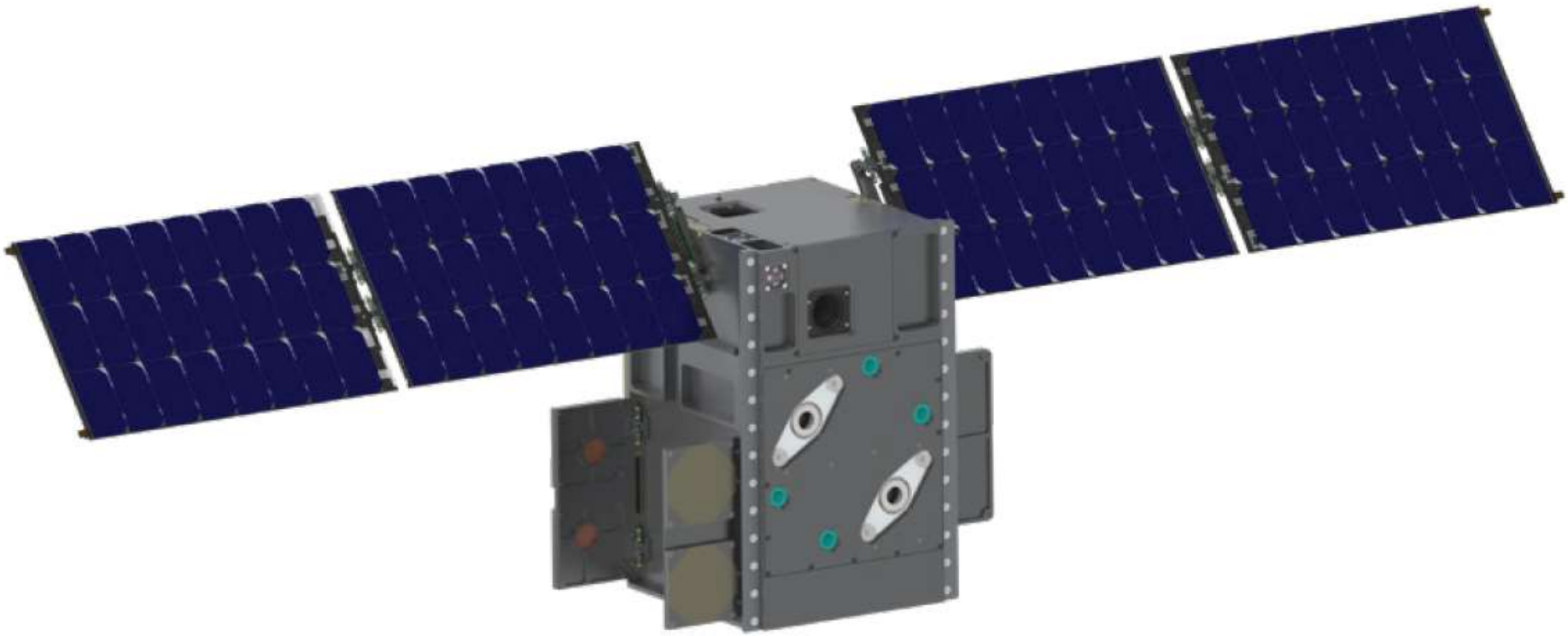
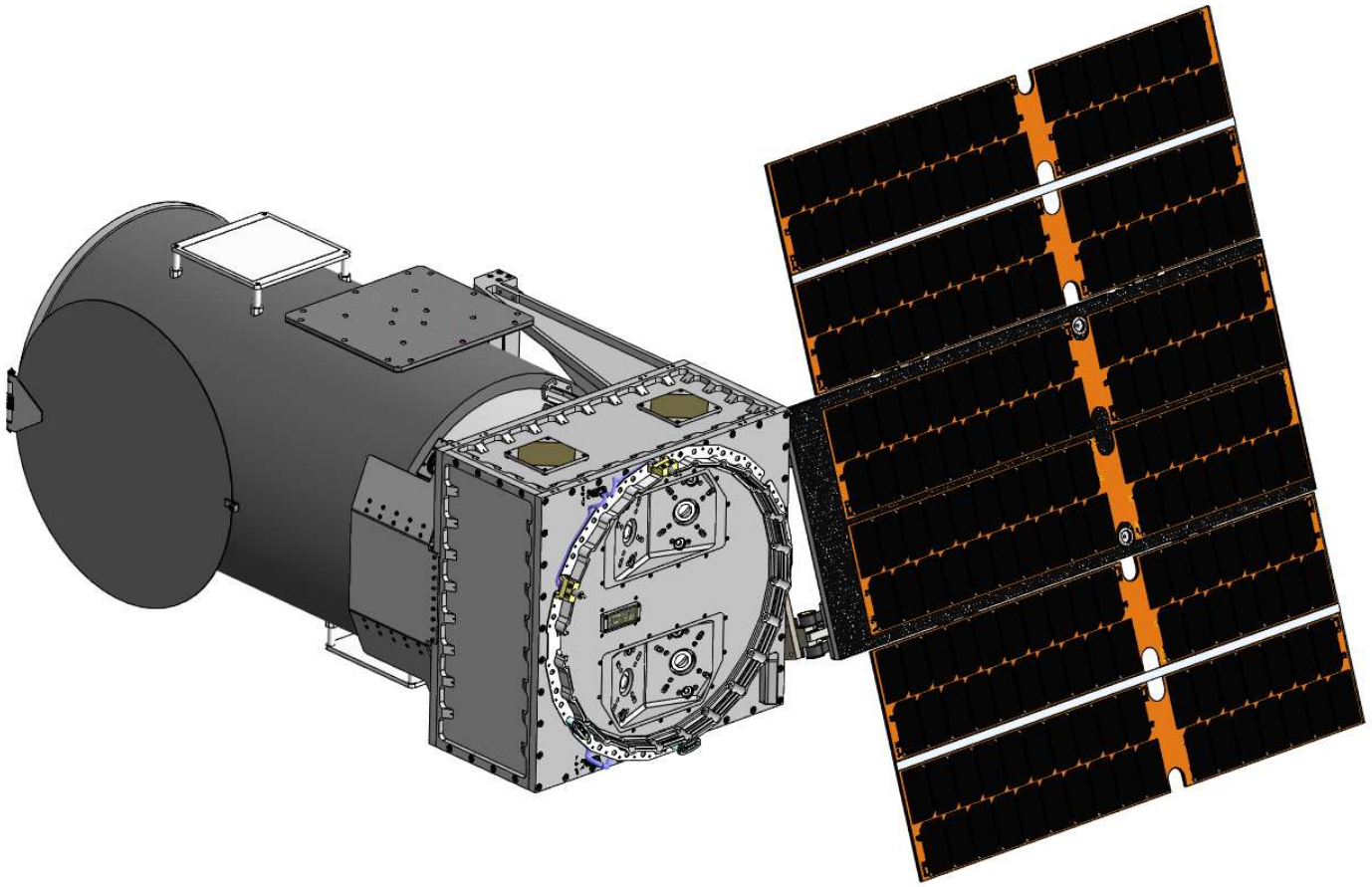


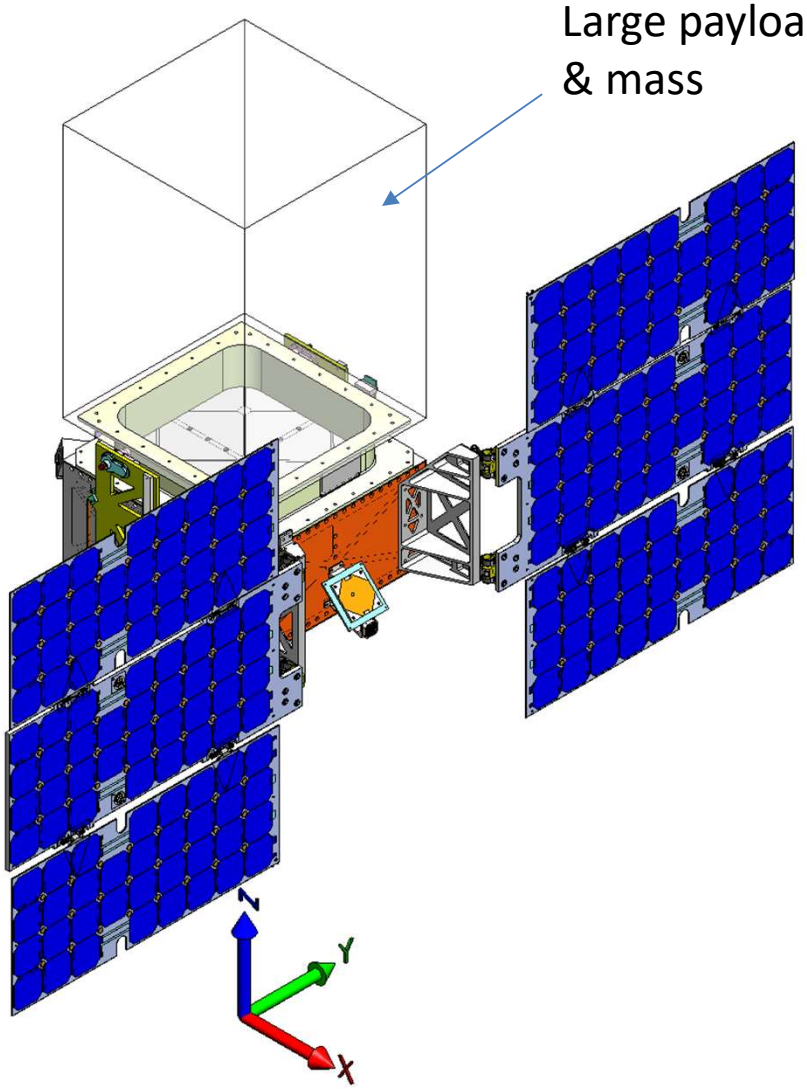
# S5 – GEO SSA Mission for AFRL

70kg MicroSat

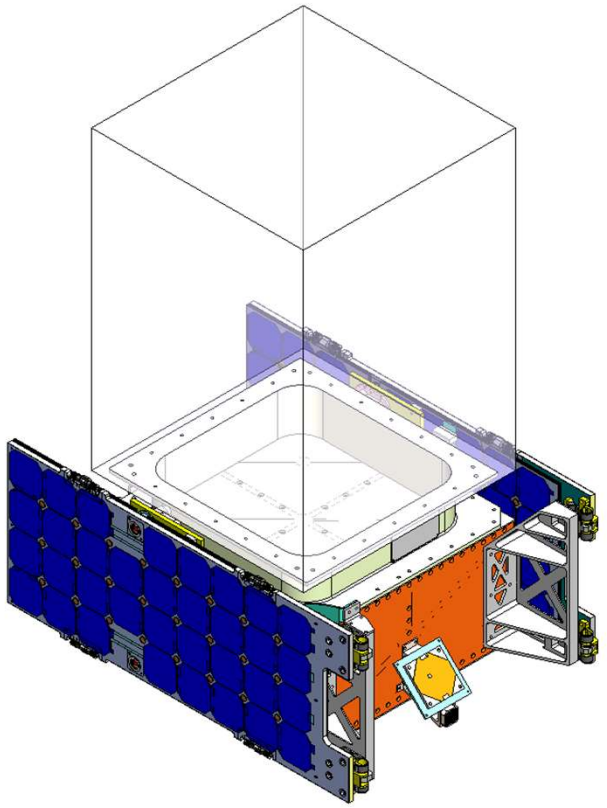


# ESPA Spacecraft

Large payload volume & mass




170kg ESPA



# Software Development

- Highly-capable software supports near-100% code re-use across all spacecraft.
- Capability-rich software goes far beyond most cubesats and microsats.
- Over 90% of flight software is auto-coded using Matlab/Simulink.
- One of the most advanced spacecraft auto-code systems in the industry.
- Developed by highly-experienced GN&C and software personnel.
- One master Matlab/Simulink simulation is common core for all Blue Canyon Technologies software products.

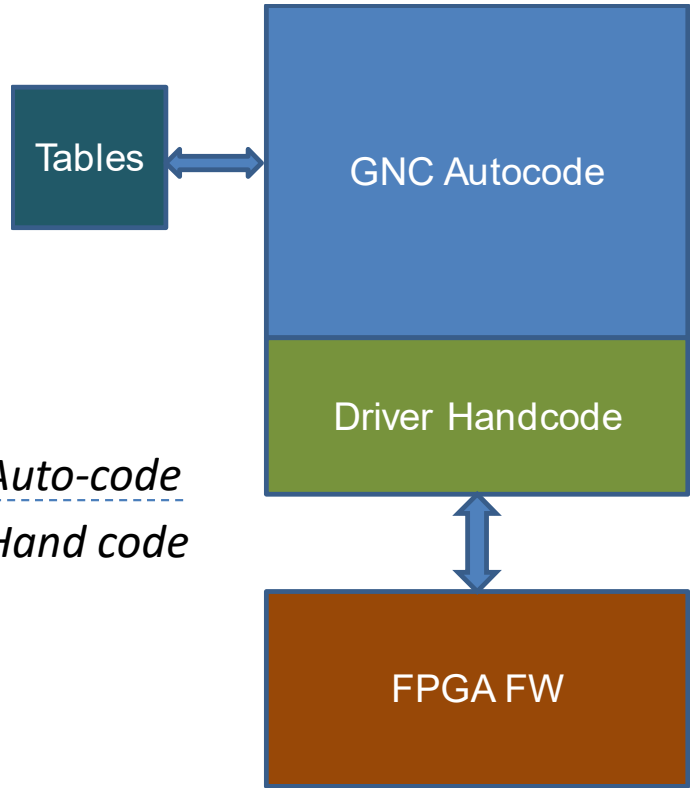
# Standard Flight Software Features

- Commands (real-time, stored, macro sequences)
- Telemetry (multiple selectable maps)
- Fault Protection & Autonomy (table-driven programmability)
- Table Management
- Time Keeping
- Attitude Orientation Command
- Attitude Determination & Control
- Orbit Propagation
- High-precision reference vectors
- Wheel Control, including high-speed servo loop
- Momentum Control (magnet and/or thruster)
- Thruster Control
- Solar Array Drive Control

*Auto-code*

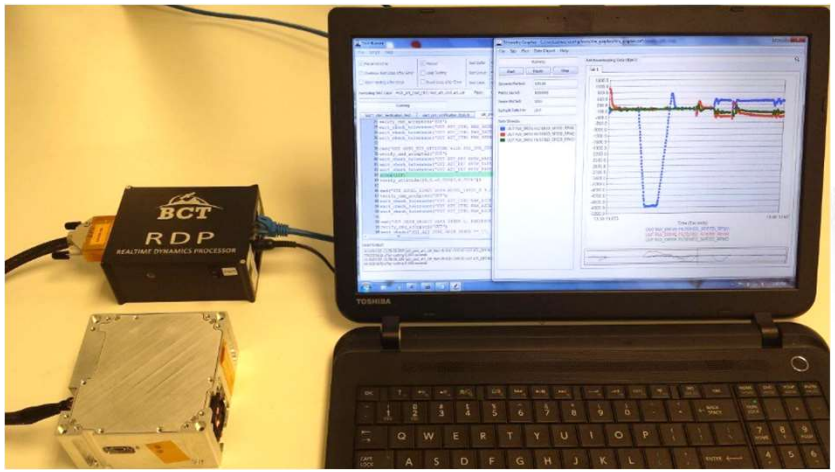
*Hand code*

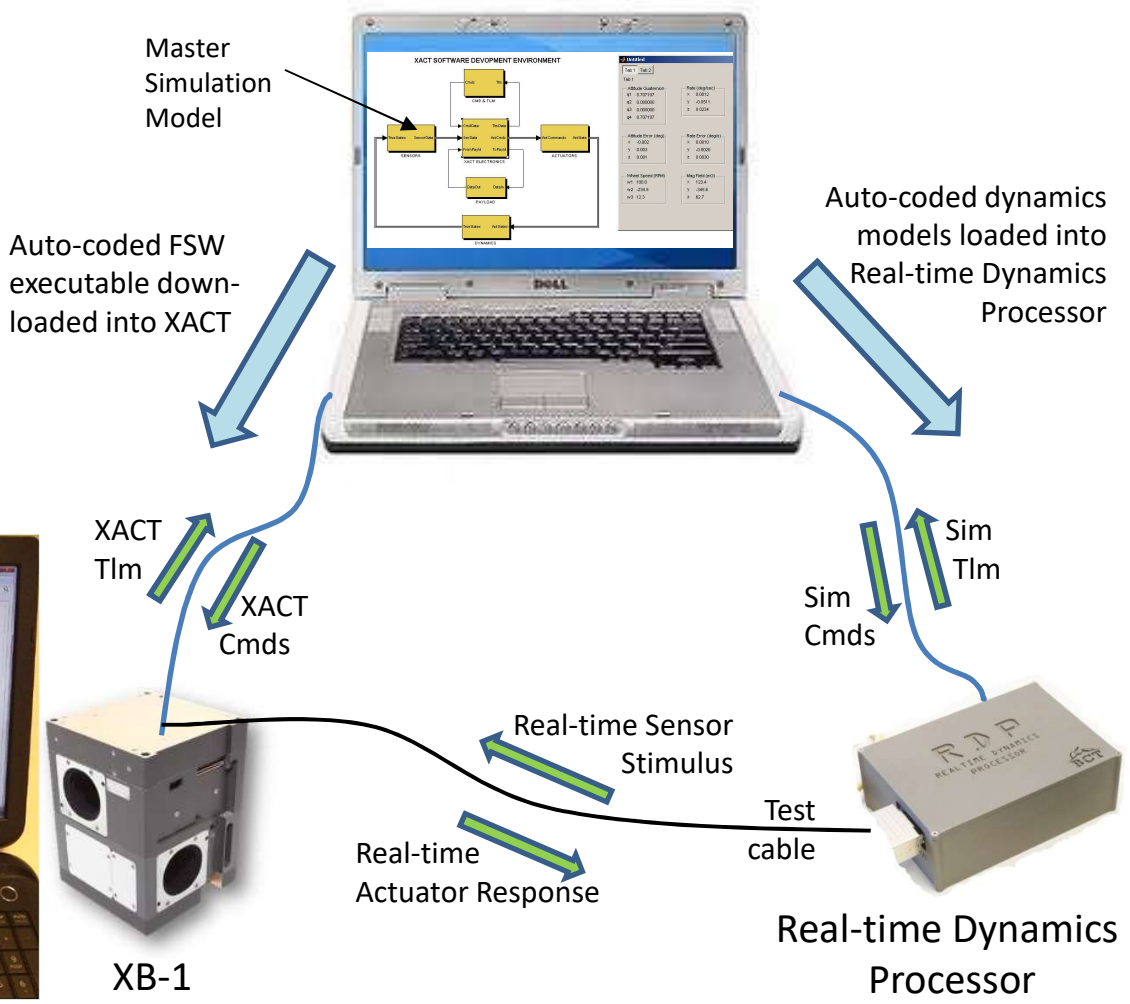
- Multi-rate system with Linux and Real-time services
- Hardware I/O drivers
- SD card management
- Radio device operation
- Payload interfaces (custom processing as necessary)



# Automated Real-time Test Capability

- Real-time Dynamics Processor (RDP) supports closed-loop testing
- System provides true “test-as-you-fly” capability
- Auto-coded from same master simulation as flight software
- Can be configured for any initial orbit and attitude conditions



# Mission Operations Software

- Features
  - Provides scripts, C&T, and tools used throughout system test & operations
  - Supports multiple missions and constellations
  - Supports multiple ground stations and radios
  - Automated and accessible
- Scheduling
  - Quickly and easily schedule tasks
  - Autonomously schedule repeating tasks
  - Autonomous constraint and resource de-confliction
- Automated Execution
  - Task execution without the need of a full time operations team
  - Automated notification of warnings and errors
- Monitoring and Visualization
  - Access to telemetry anytime, anywhere, and from any device
  - Automated analysis and quick access to s/c attitude, position, and health
- Customer Delivery
  - Customizable packages of payload and telemetry data for delivery to customer