BLUE CANYON TECHNOLOGIES

Spacecraft Buses, Systems & Solutions

Spacecraft Design and Enablers for Express-class Missions

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BCT Overview

BLUE CANYON
TECHNOLOGIES

- BCT was founded in 2008 by industry veterans
- Staff of highly experienced engineering, production, procurement, and support personnel
  (Over 30 spacecraft prior to BCT)
- ~60 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

Inc. 5000 #162 2016

In 2016, Inc. Magazine listed BCT as the Number 1 Fastest Growing Private Engineering Company in the United States, and #162 overall.

BCT Products

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

Reaction Wheels
NanoSats to SmallSats (ESPA and beyond)

Attitude Control Systems
Precision GN&C Systems for NanoSats to SmallSats (enclosed or distributed architecture)

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

Complete Spacecraft Avionics
Integrated avionics system (ADCS, EPS, C&DH, GPS, RF-comm)

Turnkey Spacecraft
Complete SmallSat Spacecraft Bus Solution (Integration and Test, Operations)

XACT ADCS Module

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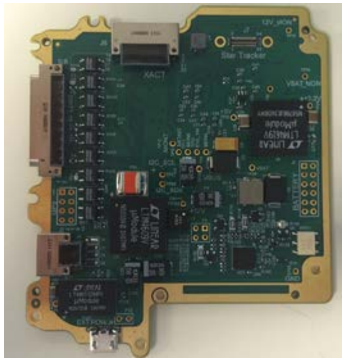
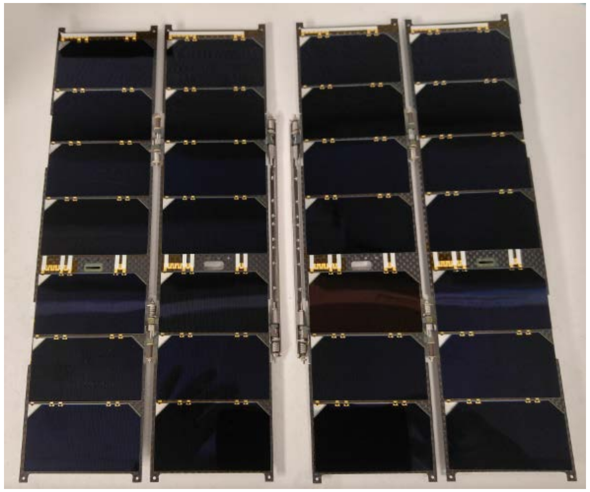
- Complete high-performance attitude control module for CubeSats and MicroSats
  - Nano Star Tracker for precise attitude determination (Integrated stray light baffle)
  - Three low-jitter reaction wheels enabling precise 3-axis control
  - Three torque rods
  - MEMS IMU
  - MEMS Magnetometer
  - Sun sensors
- Multiple pointing reference frames, such as:
  - Inertial
  - LVLH
  - Earth-fixed target
  - Solar
  - Lunar
  - Other satellites
- Pointing Accuracy:
  - 0.003 deg (1-sigma) for 2 axes
  - 0.007 deg (1-sigma) for 3rd axis

XACT ADCS module
(10x10x5 cm , 0.5U package)

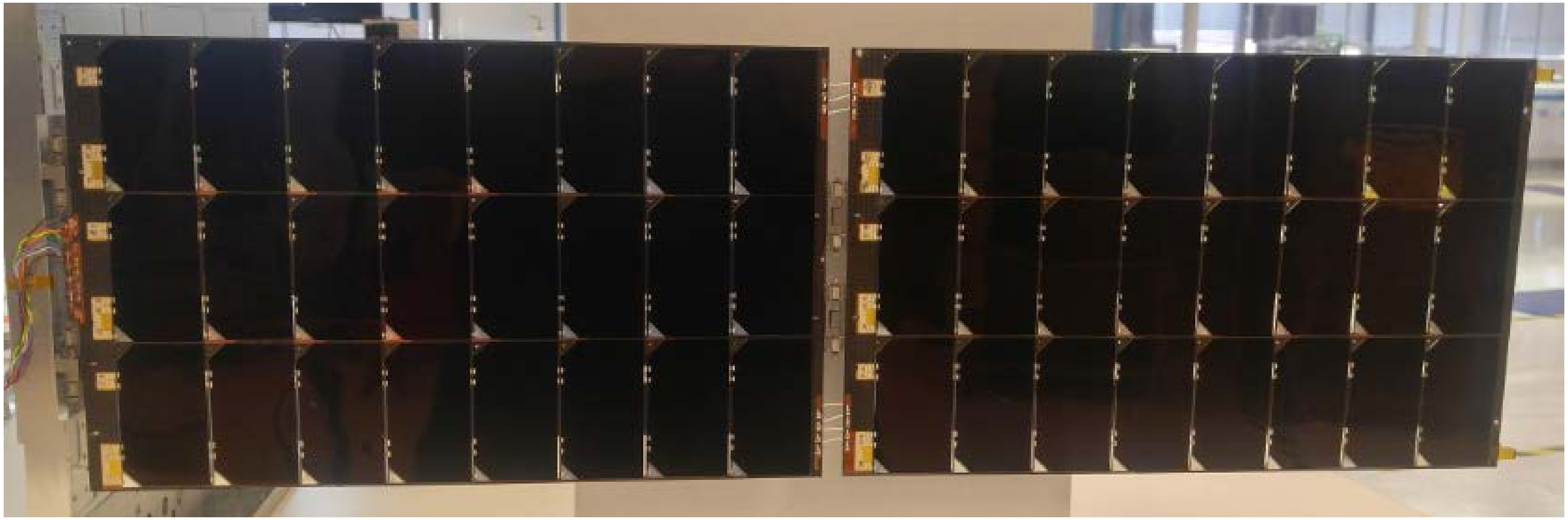
Power Subsystems

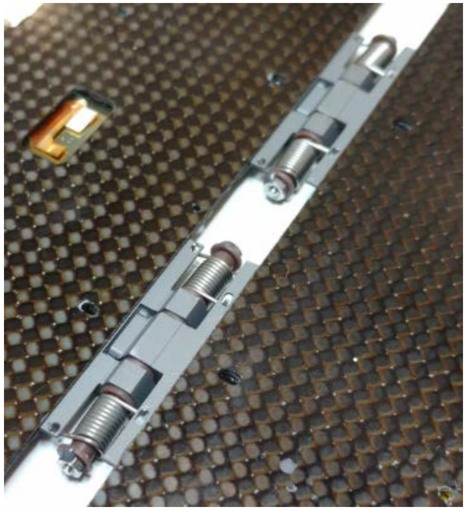
- Charge control electronics with switched regulated voltages
- Wide range of solar panel configurations
- Variety of fixed deployment angles to maximize power across all Beta angles
- Solar array drives
- Can provide 100W of power for CubeSats
- Can provide 900W of power for ESPA-class
- Li-Ion and Li-Fe-PO_4

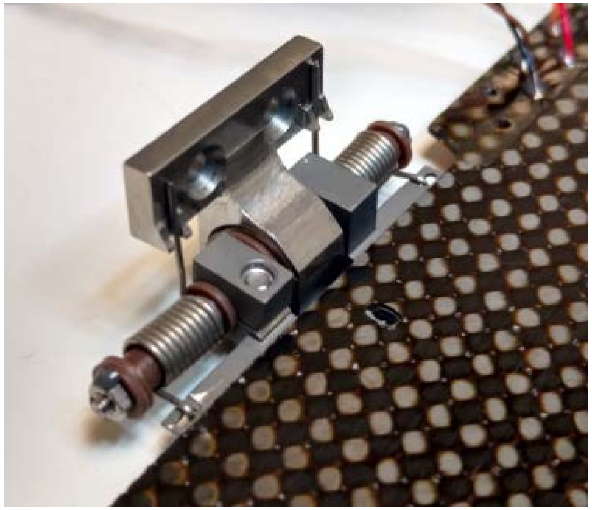




Solar Panels, Hinges, and Release Mechanisms

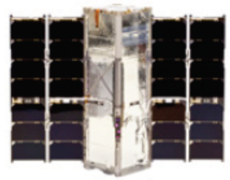


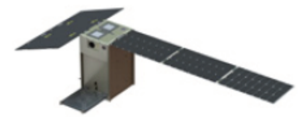




- Carbon fiber substrates
- Titanium hinges
- High-reliability release mechanisms
  - No ‘perishables’; no reloading
  - Redundant wiring
  - Built-in deployment switch indicator

BCT Family of Buses






Express-class

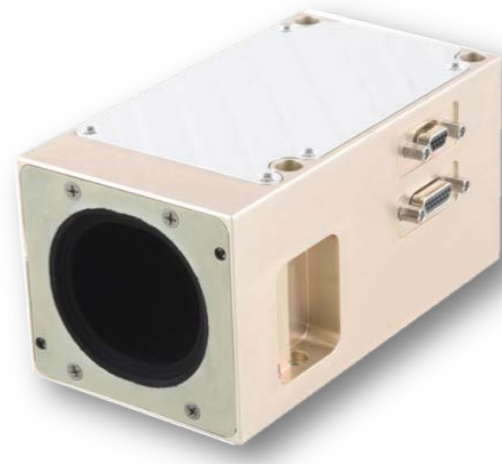
	XB3	XB6	XB12	XB Micro-Sat
Class	3U	6U	12U	Up to 70 kg
Available Payload Volume	2U	5U	11U	40 x 40 x 60 cm
Pointing Accuracy	±0.002° (1-sigma), 3 axes, 2 Trackers			
Pointing Stability	1 arc-sec over 1 sec			
Maneuver rate	10 deg/sec (typical 3U)	3 deg/sec (typical)	3 deg/sec (typical)	5 deg/sec (typical)
Orbit knowledge	4m, 0.05m/s	4m, 0.05m/s	4m, 0.05m/s	4m, 0.05m/s
Data Interfaces	Serial, LVDS, Spacewire, HDLC, I2C or SPI available			
Onboard Data Storage	16 Gbytes	16 Gbytes	16 Gbytes	16 Gbytes (1 TB option)
System Bus Voltage	9 – 23 V (battery and array dependent)	9 – 23 V (battery and array dependent)	9 – 23 V (battery and array dependent)	9 – 36 V (battery and array dependent)
Energy Storage	Standard: 25Whr, expandable	Standard: 50Whr, expandable	Standard: 75Whr, expandable	Standard: 125Whr, expandable
Solar Panels	Customer or BCT Provided (Details available per request)	Customer or BCT Provided (Details available per request)	Customer or BCT Provided (Details available per request)	Customer or BCT Provided (Up to 200W)
High Current Capability	Unregulated up to 60W	Unregulated up to 140W	Unregulated up to 140W	Sized for program specific needs
Frequency	UHF, Sband, Xband			
Uplink	CCSDS, SGLS, NSGLS			
Downlink	Up to 15 Mbps	Up to 15 Mbps	Up to 15 Mbps	150 Mbps option
Mass / Volume for Avionics	1.5 kg / 10 cm x 10 cm x 14 cm	1.5 kg / 10 cm x 10 cm x 14 cm	2.0 kg / 10 cm x 10 cm x 20 cm	25 kg / 40 cm x 40 cm x 20 cm
XACT-Bus Nominal Power	< 6.3W (Excluding RF Comm)	< 6.3W (Excluding RF Comm)	< 6.3W (Excluding RF Comm)	< 10W (Excluding RF Comm)
Orbit Altitude / Orbit Lifetime	LEO / > 5 years			

Multiple Products On Orbit

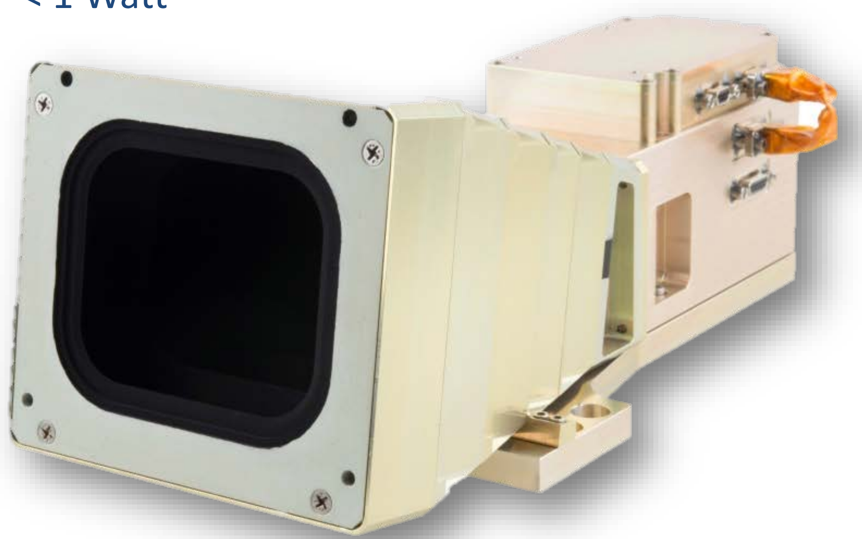
- 3U RAVAN Cubesat for JHU/APL on orbit since Nov 2016
  - APL provided the radiometer payload
  - Built and operated by BCT
  - Recently granted mission extension
  - Dual star tracker precision pointing
- 3 XACT units on-orbit (MinXSS, SHARC, IceCube)
  - MinXSS recently de-orbited after 1 year on orbit
  - Controlled spacecraft down to 180 km
- 8 star trackers and 24 wheels on 8 CYGNSS spacecraft
- Dozens more BCT XACTs and buses baselined (CubeSats to ESPA-class) in next couple years (multiple launching this year)
  - Will support a wide range of missions
  - LEO, GEO, Moon, Mars, Deep Space

Nano Star Trackers

- High performance design, compatible with a variety of cubesat and SmallSat configurations and missions.
  - Star light in – quaternion out
  - < 6 arcsec RMS, cross axis error
  - 10x12 deg FOV
  - Lost-in-space solution < 4 seconds
  - Integrated stray-light baffle (performance verified on orbit)
  - < 1 Watt



Standard NST
(45° half-cone sun keep-out angle)



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

Attitude Knowledge at Various Slew Rates

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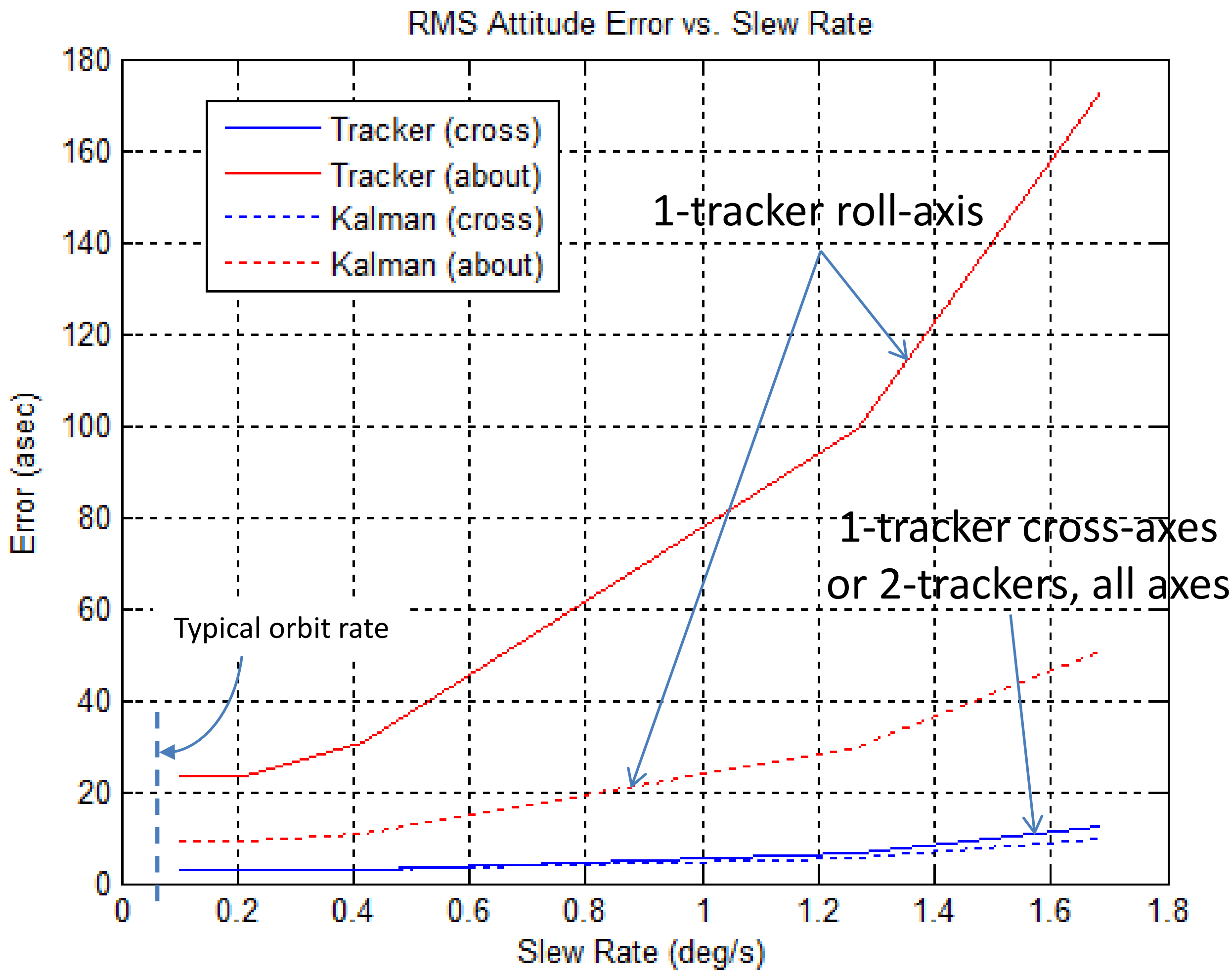
- Performance estimates obtained from extensive night-sky testing
- High-precision telescope gimbal used to slew NST at various rotation rates
- Mean motion removed, resulting in NST knowledge error
- Classical 6-state MEKF Kalman filter (with IMU data) enhances attitude knowledge versus raw tracker

Applies to all spacecraft sizes: 3U to ESPA



BCT Reaction Wheels

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Express class

RWp015 0.015 Nms | RWp050 | RWp100 | RWp500 | RW1 | RW4 | RW8 8.0 Nms

- Wheel designs reviewed by NASA and Aerospace bearing and lubricant experts
- Multiple units undergoing life-test

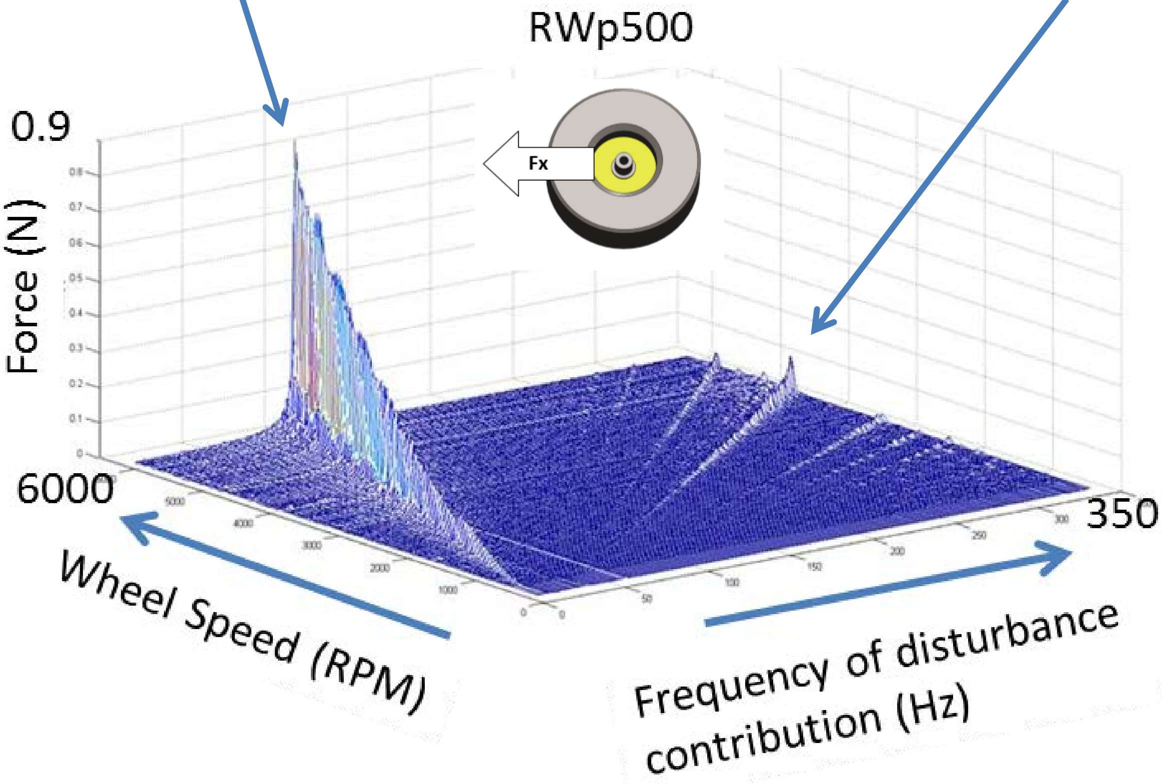
- High re-use of attitude determination for all spacecraft sizes
  - Star tracker
  - IMU
  - Processor
  - Algorithms
- Simply plug in larger actuators for larger spacecraft and update flight software table parameters

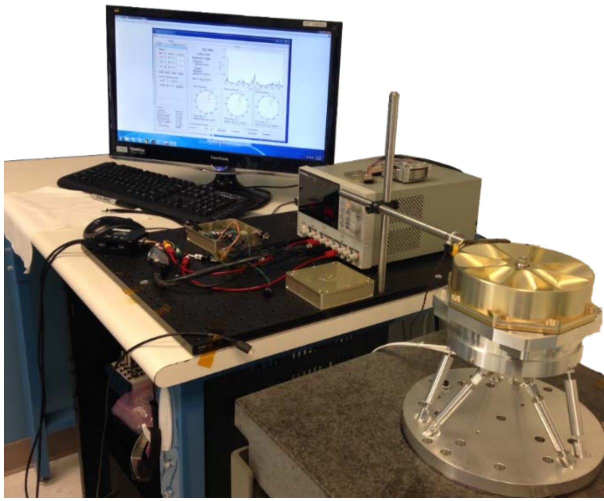
Wheel Jitter Performance

- Built-in patent-pending vibration isolation and damping results in very low jitter
- Low wheel disturbances enable wide range of missions
- Plot is characteristic of all BCT wheel sizes

Low residual static imbalance force
$F = mr\omega^2$

Extremely quiet
high-frequency regime

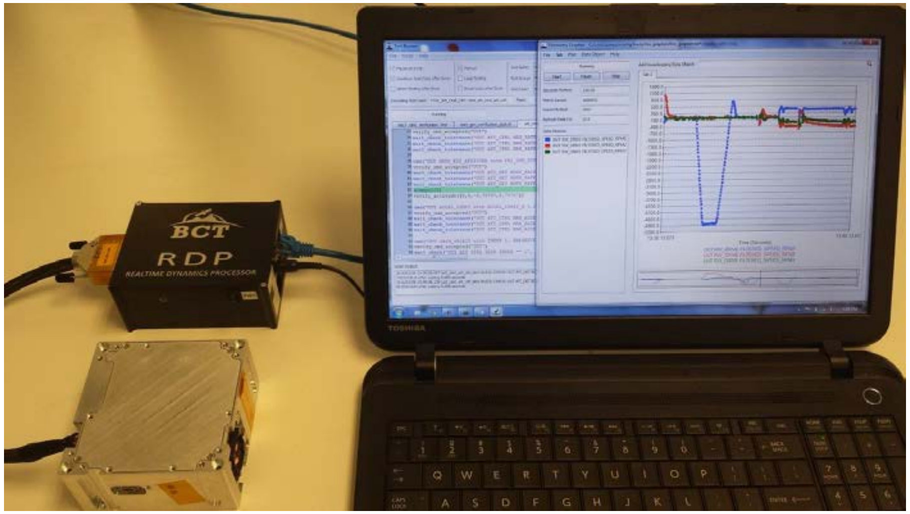




Jitter Environment Measurement System (JEMS)

Software Re-use Across All Products

- Highly-table driven software supports near-100% code re-use across all spacecraft.
- Common core for all Blue Canyon Technologies software products.
- 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.
- Automated code generation and build process substantially reduces effort over traditional methods.
- Thorough testing performed using automated, scripted procedures
- HWIL "test as you fly" capability



Recently Awarded ‘Express’ Bus

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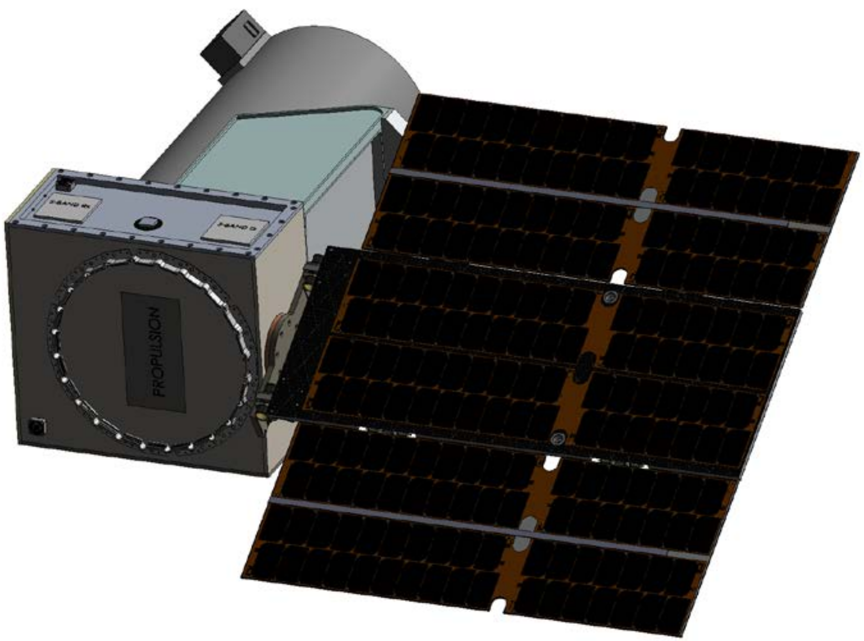
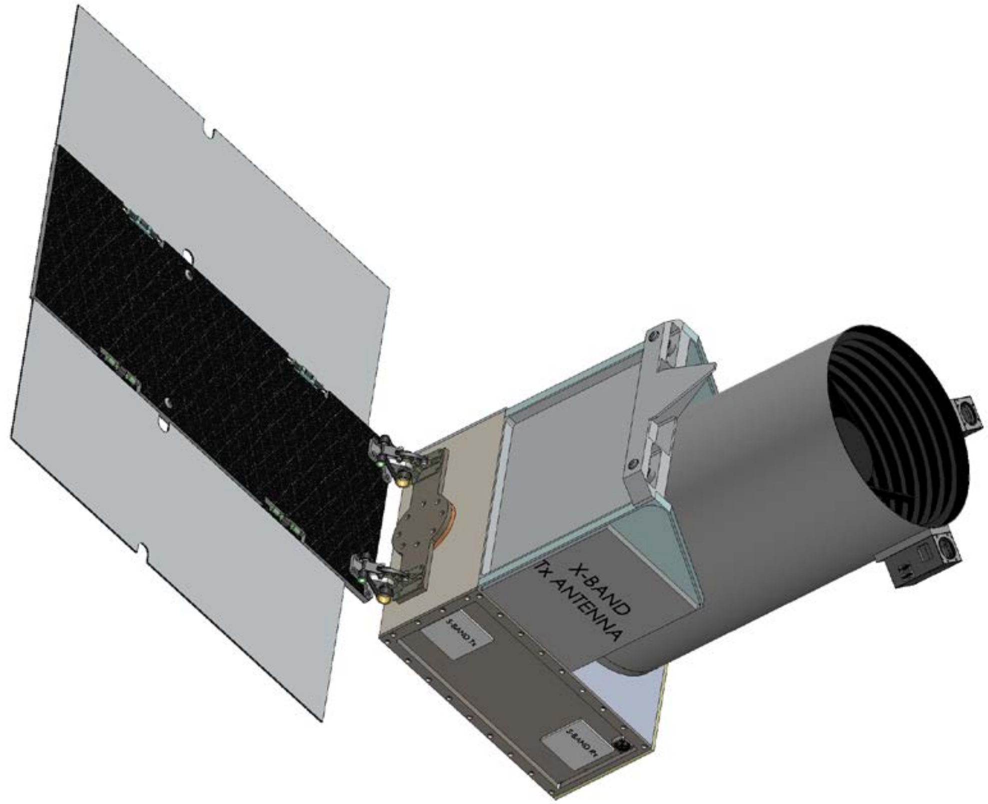
- 70-kg class
- Unclassified Government mission
- Optical payload
- Up to 35-cm aperture
- High agility
- Will fly at GEO





Express Bus Features

- Supports payload mass up to 50 kg
- ~200 W array power
- 300 W-hr battery
- Up to three precision star trackers
- Up to four low-jitter reaction wheels
- High-rate downlink
- Flexible payload electrical interfaces
- High rate, and high volume data storage I/O
- Supports LEO & GEO operations

Enablers for Express-class

- Re-use of CubeSat technology
  - CubeSats have shown that good things *can* come in very small packages
  - ‘Wetted appetites’ for those who have larger payloads
  - Re-use of flight-proven, high-performance CubeSat hardware and software keeps costs low
    - Same software (primarily table changes)
    - Same components (some simply scaled up)
  - More cost-effective to scale up, than to scale down

- Launch/rideshare opportunities
  - Multiple LEO rides
  - PODS to GEO

Benefits of Express-class

- Out of the 'box' (i.e. no canister)
  - Don't need to carry around "unnecessary" mass of a canister
- Larger Payload SWaP compared to CubeSats
  - Much more breathing room
- Easier to support high-rate comms
  - Area and/or volume for high-gain antennas
  - Optical comm
- Perception (i.e. "It's not a CubeSat")

Challenges for Express-class (1 of 2)

- Out of the ‘box’ (double-edged sword)
  - “A man’s got to know his limitations” – Dirty Harry
    - With CubeSats, you know your limitations (i.e. canister size)
    - If the payload doesn’t fit or it takes too much power, it doesn’t go (even so, however, 3U grew to 6U which grew to 12U)
    - Canister sizes force people to ‘live within their means’
    - Keeps cost and schedule constrained
  - ‘Box-less’ freedom of the Express class will inevitably lead to desire for customization, which may lead to cost and schedule growth
  - Premier challenge will be to fight the endless ‘what if’s
    - “What if we make it 3 cm wider on this side?”
    - “What if we make it 5 kg heavier?”

Challenges for Express-class (2 of 2)

- More substantial hold-down/release mechanisms
  - Can't rely on canister to hold everything in
- Additional analyses/tests to support launch without a canister
- PODS interface (GEO ride) requires mounting on side, rather than on end (LEO ride)

Conclusions

- Express-class will fill an important void in the spacecraft size progression, between CubeSats and ESPA
- Will offer much more flexibility for Payloads, without substantially higher costs than CubeSats
- Non-canister ‘freedom’ will require vigilance to not allow cost and schedule creep, due to customization