Characterization of the Blue Canyon Technologies Nano Star Tracker Performance

By Kevin Lo, Laura Jones, Swati Mohan
Jet Propulsion Laboratory
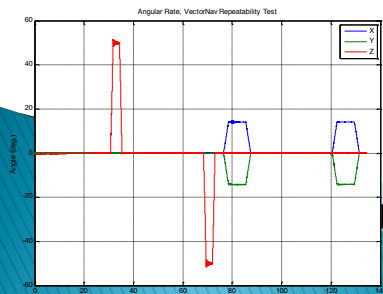California Institute of Technology
4/26/16

JPL's SmallSat Dynamics Testbed (SSDT)
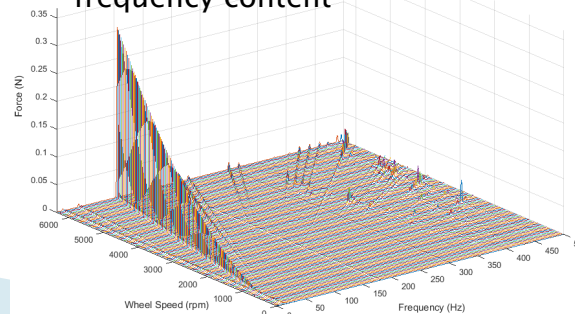
Gyro Characterization

- Angle random walk,
- Rate random walk,
- Angle white noise,
- Quantization,
- Bias repeatability,
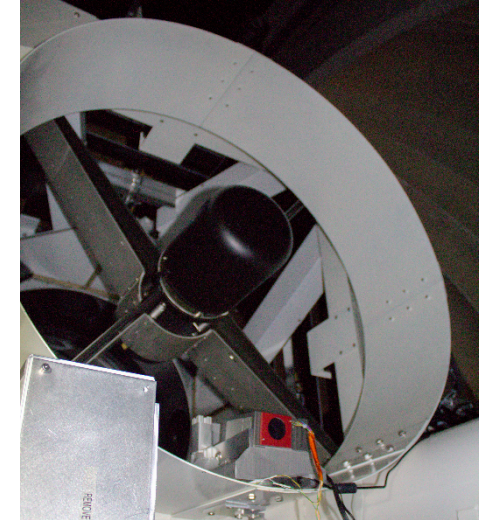- Scale factor
- Sense axis

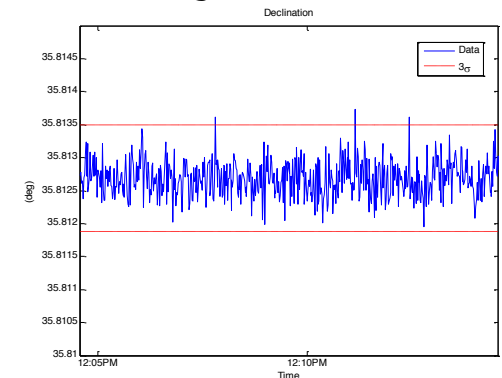## Reaction Wheel Characterization

- Force amplitudes as a function of wheel speed and frequency content
- Torque amplitudes as a function of wheel speed and frequency content
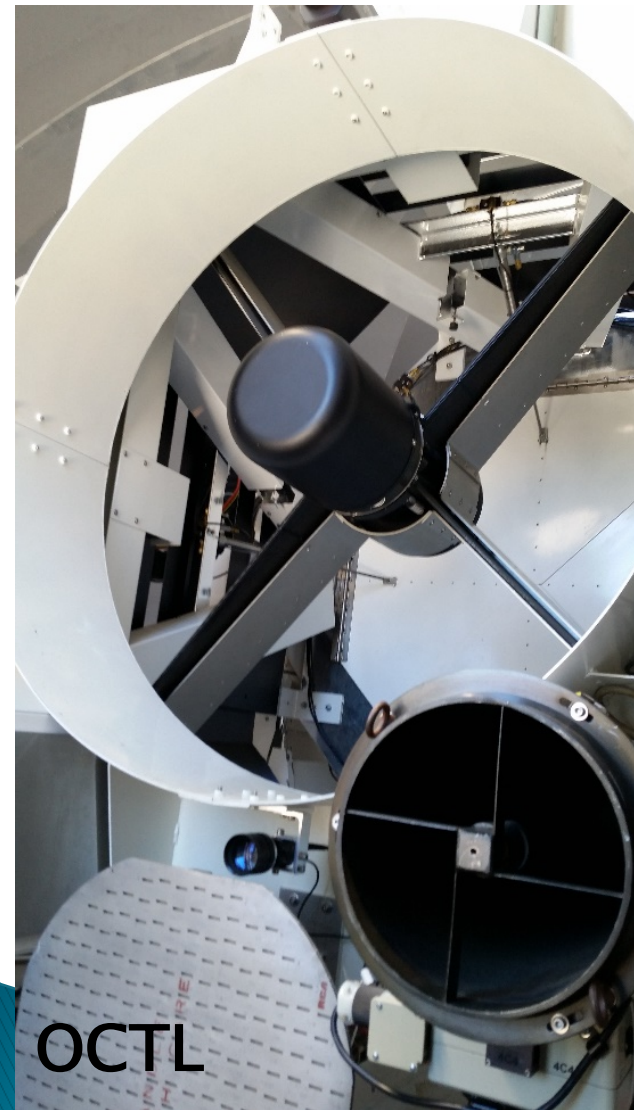

Star Tracker Characterization

- Noise equivalent angle,
- Low frequency error,
- Acceleration/velocity limits on tracking

Test Facility: Table Mountain Observatory

OCTL

0.6m Tel.

Parameter	Optical Communication Telescope (OCTL)	Table Mount Observatory 0.6m Telescope
Mount	Azimuth–Elevation	Equatorial
Error	3.1 arcseconds	0.5 arcseconds
Max. Slew Rate	Az: 19 deg/s El: 10 deg/s	1 deg/s
Tests Conducted with this Facility	• Rate and Acceleration Limits	• Noise Equivalent Angle (NEA) • Low Frequency Error (LFE)
Test Dates	• August 31st, 2015 • 10 PM to 4 AM	• August 26st, 2015 • 10 PM to 4 AM

- Mounted star tracker to secondary mirror assembly of facility telescope
  - Did not directly measure hardware mounting errors
- Pointed the facility telescope in profiles designed to evaluate specific components of star tracker error
  - Large inertias and capable slewing platform enabled tests unavailable to the broader community

Test Article: BCT's Nano Star Tracker

Boresight has a 10° cant that is taken into account in the mechanical interface to approximately align the facility telescope boresight and the star tracker boresight.
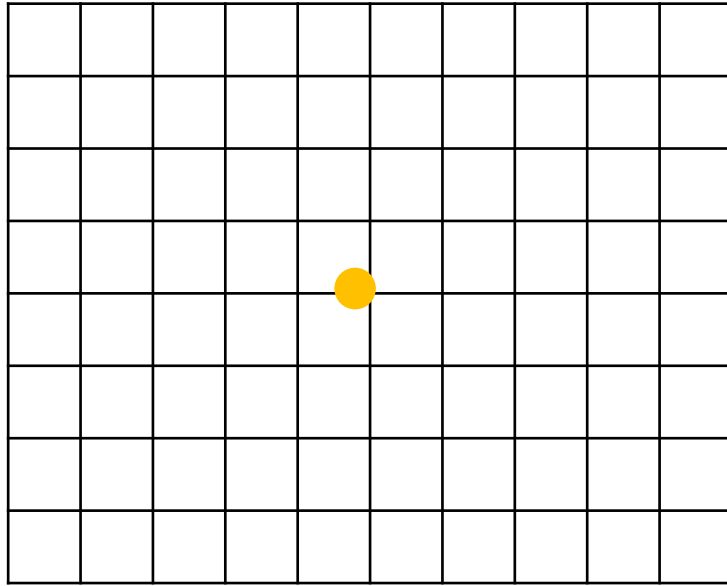
10cm

17.5cm

14.5cm
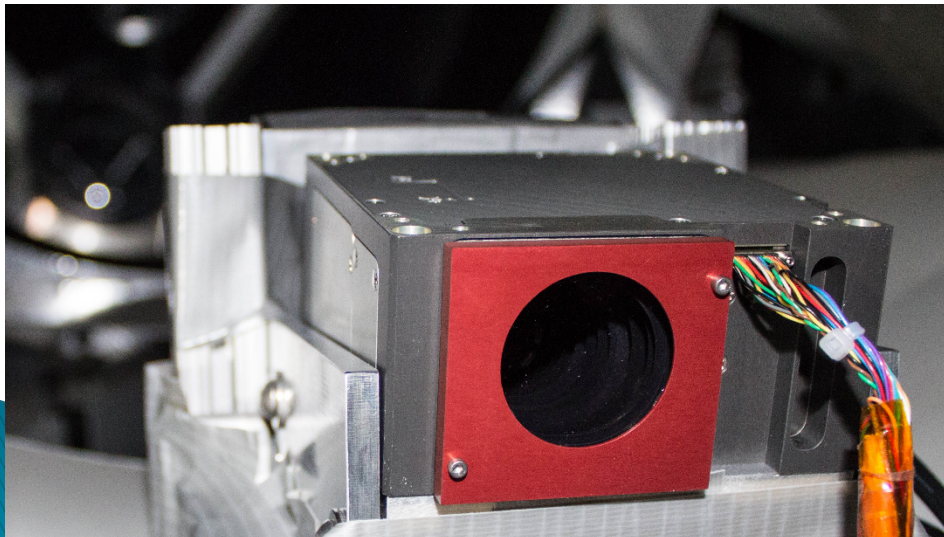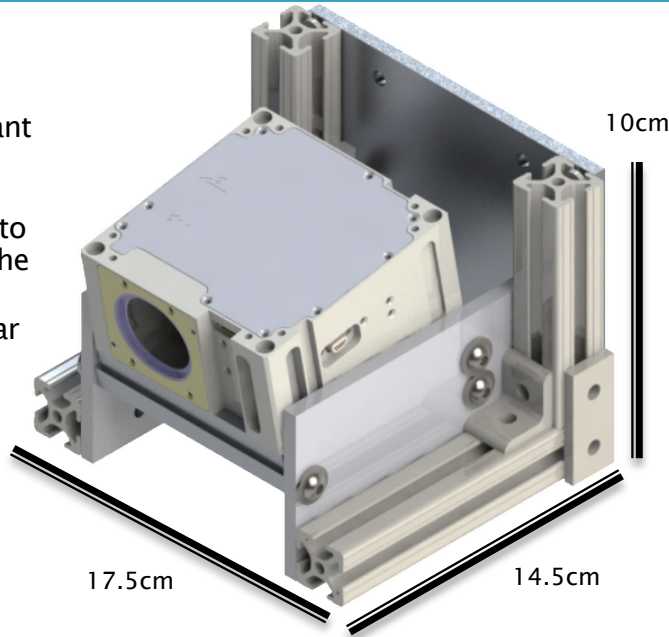
Removed SRU Cover before Tests

Vendor	Blue Canyon Technologies
Configuration	Nano Star Tracker, Embedded in XACT unit
Year of Purchase	2014
Software Version Build Date	3IMG1063D August 26, 2015
Attitude Solution Update Rate	5 Hz
Field of View	10° x 12°
Keep Out Zone	+/− 45°
Interfacing Software	BCT MATLAB GUI
Vendor−Specified Boresight Accuracy	6 arcseconds (1−σ)
Vendor−Specified Roll Axis Accuracy	40 arcseconds (1−σ)
Catalog Epoch	2016.5 (Julian Date)
Nominal Stars Tracked	30 to 50 Stars

- Unit owned by JPL's SmallSat Dynamics Testbed
- Testing was performed independently by the SSDT over the course of a year, with software updates from BCT installed over that duration
  - Results were discussed with vendor

Star Tracker Error Types

SRU Error

Noise Equivalent Angle (NEA)

- Stare at a field with a bright star on a pixel
- Track the star to compensate for Earth's rotation and maintain the star on a single pixel
- Obtain the noise in the measurement over time
- The standard deviation of the error is the NEA

Low Frequency Error (LFE)

- Optical calibration residual errors
- Point tracker towards local zenith
- Detect star movement across FOV of the SRU camera through the rotation of the Earth
- Obtain noise in the measurement over time
- The standard deviation of the error is a roll up of the NEA and LFE.

High Frequency Error (HFE)

- Errors due to stars moving across pixel edges

SRU Error

Star Tracker Error Types

SRU Error

Noise Equivalent Angle (NEA)

- Stare at a field with a bright star on a pixel
- Track the star to compensate for Earth's rotation and maintain the star on a single pixel
- Obtain the noise in the measurement over time
- The standard deviation of the error is the NEA
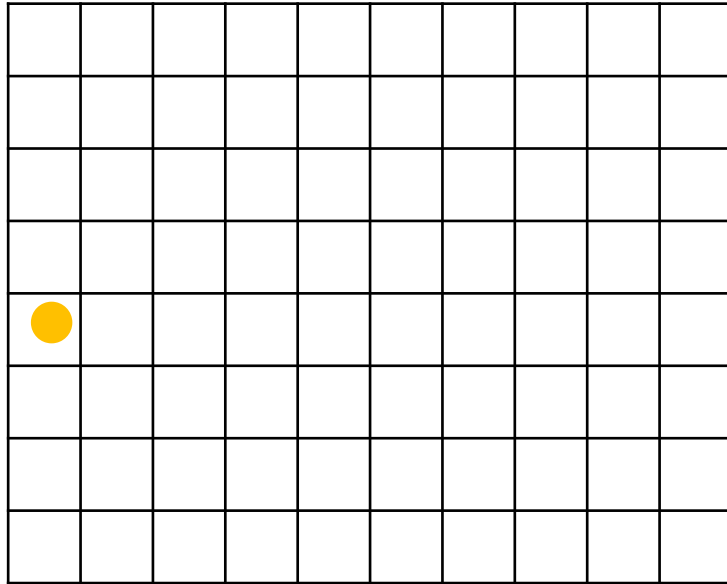
Low Frequency Error (LFE)

- Optical calibration residual errors
- Point tracker towards local zenith
- Detect star movement across FOV of the SRU camera through the rotation of the Earth
- Obtain noise in the measurement over time
- The standard deviation of the error is a roll up of the NEA and LFE.

High Frequency Error (HFE)

- Errors due to stars moving across pixel edges

SRU Error

Star Tracker Error Types

SRU Error

Noise Equivalent Angle (NEA)

- Stare at a field with a bright star on a pixel
- Track the star to compensate for Earth's rotation and maintain the star on a single pixel
- Obtain the noise in the measurement over time
- The standard deviation of the error is the NEA
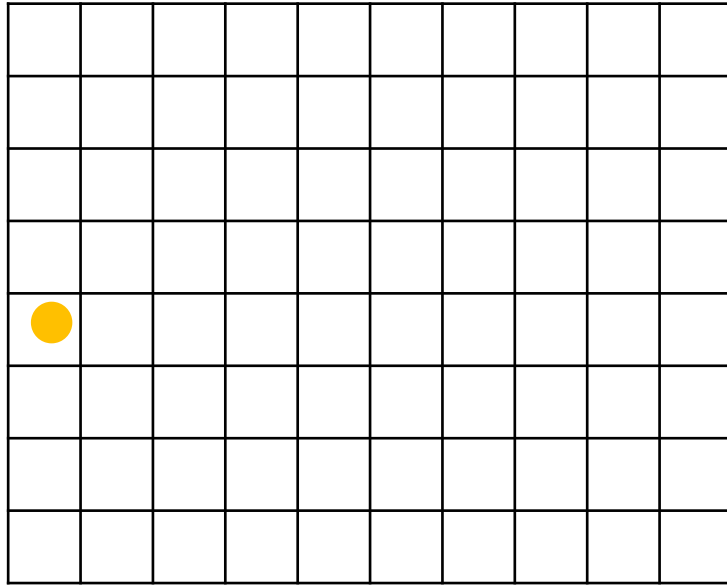
Low Frequency Error (LFE)

- Optical calibration residual errors
- Point tracker towards local zenith
- Detect star movement across FOV of the SRU camera through the rotation of the Earth
- Obtain noise in the measurement over time
- The standard deviation of the error is a roll up of the NEA and LFE.

High Frequency Error (HFE)

- Errors due to stars moving across pixel edges

SRU Error

Noise Equivalent Angle Performance

Conditions of Test	
Target	Bright star on a pixel
Duration of Each Test	10 – 15 minutes
Pointing Conditions	Inertially pointed, Elevation angle > 60°
Number of Tests	6 tests
Date of Tests	August 26, 2015
Facility	0.6m Telescope
Data used for Analysis	SRU Declination

NEA Results (1σ)		
Test 2	1.3452 arcseconds	19 Stars Tracked
Test 3	3.5073 arcseconds	20 Stars Tracked
Test 4	1.2873 arcseconds	8 Stars Tracked
Test 5	1.3054 arcseconds	8 Stars Tracked
Test 9	0.9704 arcseconds	12 Stars Tracked
Test 10	4.3556 arcseconds	16 Stars Tracked
Test Mean	**2.1285 arcseconds**	**13 Stars Average**

Test 9
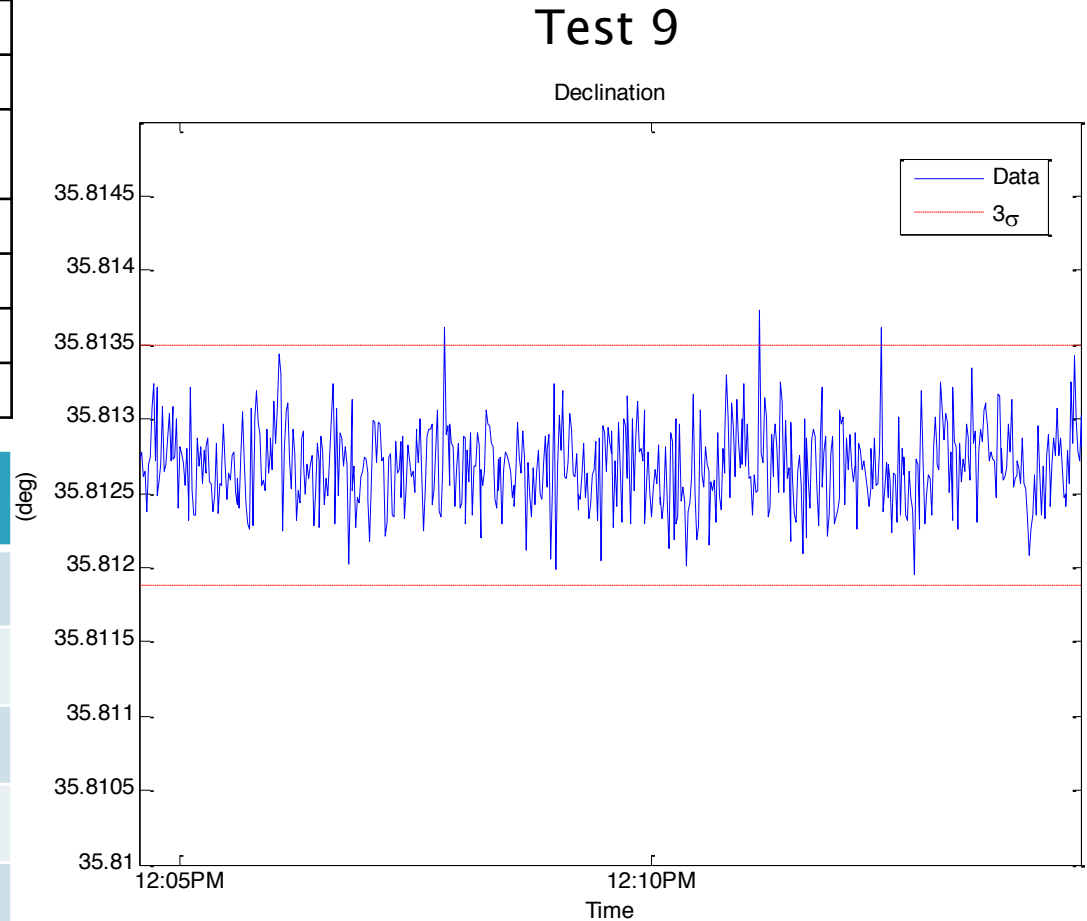
NEA+LFE+HFE Boresight & Roll Performance

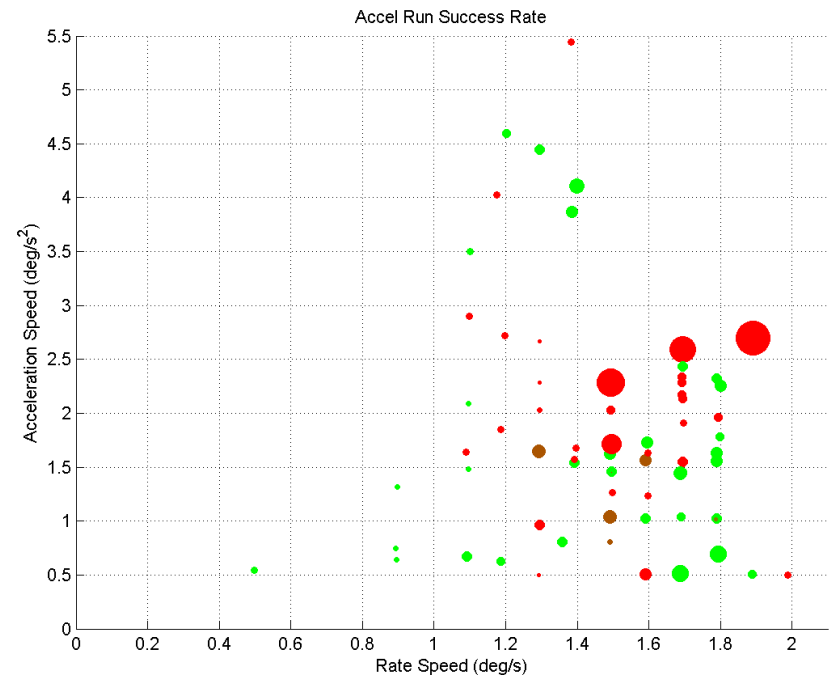| Conditions of Test	
Target	Local Zenith
Duration of Each Test	~60 minutes
Pointing Conditions	Zenith pointed
Number of Tests	2 tests
Date of Tests	August 26, 2015
Facility	0.6m Telescope
Data used for Analysis	SRU Declination
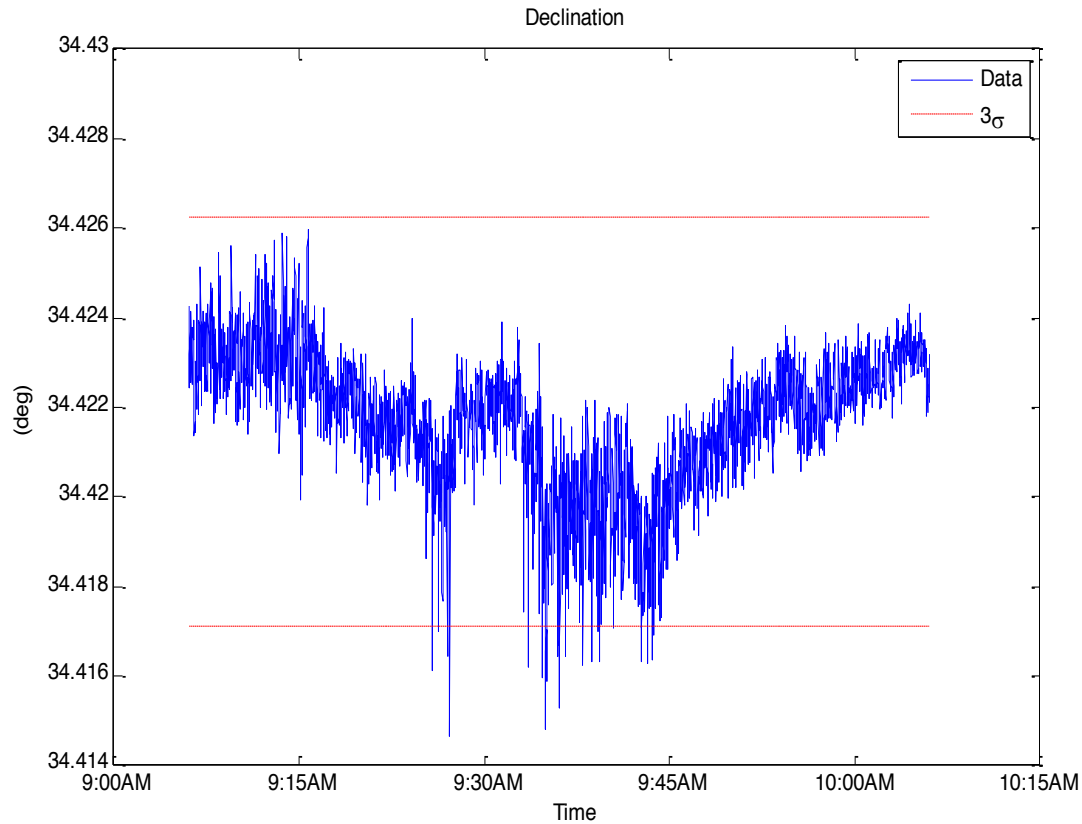
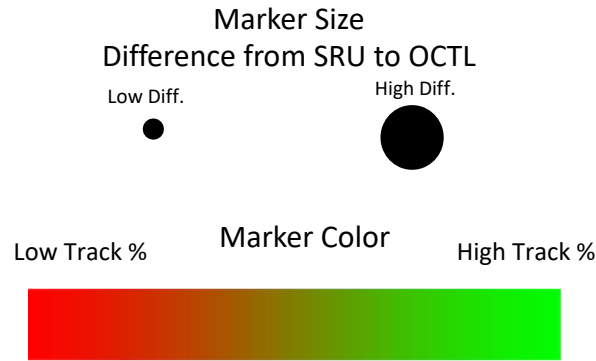## NEA+LFE+HFE Results (1σ)

	Boresight	Roll	# Stars Tracked
Test 1	2.1424 arcseconds	31.9468 arcseconds	19 Stars Tracked
Test 6	5.4779 arcseconds	48.5696 arcseconds	9 Stars Tracked
Test Mean	3.8102 arcseconds	40.2321 arcseconds	14 Stars Average

Test 6

Declination

Rate and Acceleration Limits

Conditions of Test	
Target	Unobstructed sky
Duration of Each Test	1 minute
Pointing Conditions	Programmed acceleration and rate curve
Average Stars Tracked	9 Stars Tracked
Number of Tests	110
Date of Tests	August 31, 2015
Facility	OCTL

Marker Size
Difference from SRU to OCTL

Low Diff.   High Diff.

Marker Color

Low Track %   High Track %

Attitude Profile

Rate Portion

Accel Portion

Rate Run Success Rate

Accel Run Success Rate
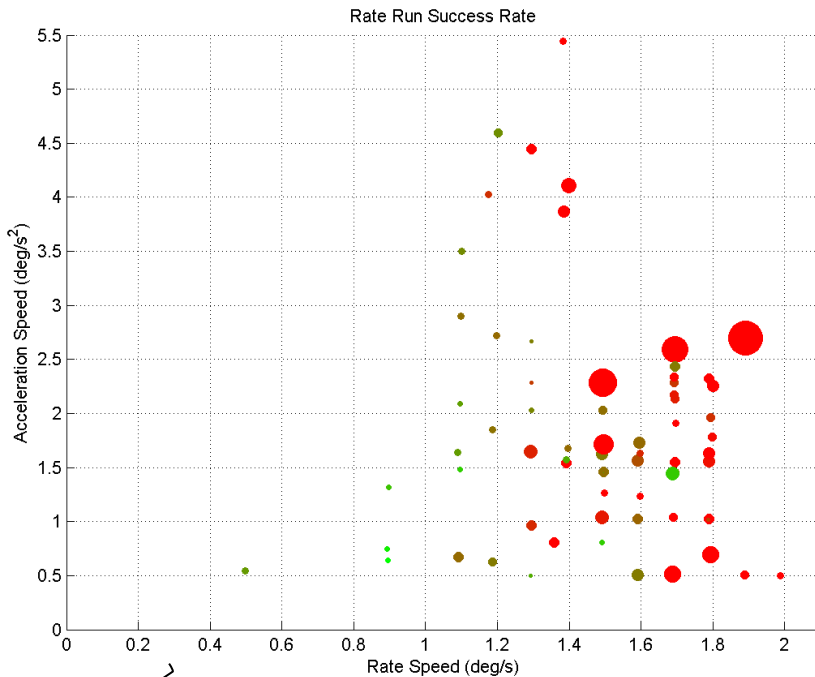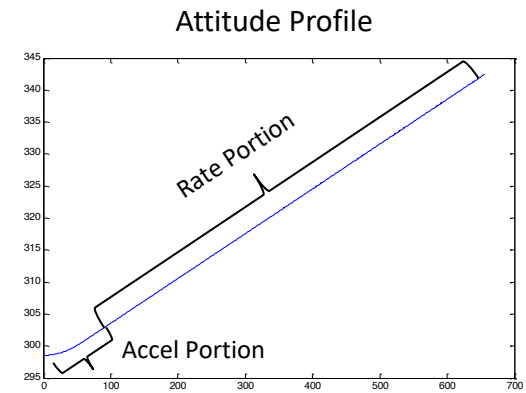
Conclusions

NST Performance	Vendor-Specified Performance	Measured (Average from Tests)[1]
Noise Equivalent Angle (NEA) Boresight	None Specified	2.13 arcseconds (1σ)
NEA + LFE + HFE Boresight	None Specified, but Boresight Accuracy reported as 6 arcseconds (1σ)	3.81 arcseconds (1σ)[2]
NEA + LFE + HFE Roll	None Specified, Roll Accuracy reported as 40 arcseconds (1σ)	40.23 arcseconds (σ)[3]
Slew Rate Tracking Threshold	>= 0.5 deg/s	Minimal Degradation at 1 °/s Variable performance up to 2 °/s
Slew Acceleration Limit	None Specified	Varies between 1 °/s^2 to 5 °/s^2

1. Natural environmental factors not included in analysis numbers. These include ground/space differences, telescope error, quality of night sky, # of stars tracked, thermal alignments, etc.
2. The best test resulted in 2.14 arcseconds for accuracy, but the average between 2 tests of the NEA+LFE+HFE accuracy was used to obtain this value
3. The best test resulted in 31.95 arcseconds for accuracy, but the average between 2 tests of NEA+LFE+HFE accuracy as used to obtain this value