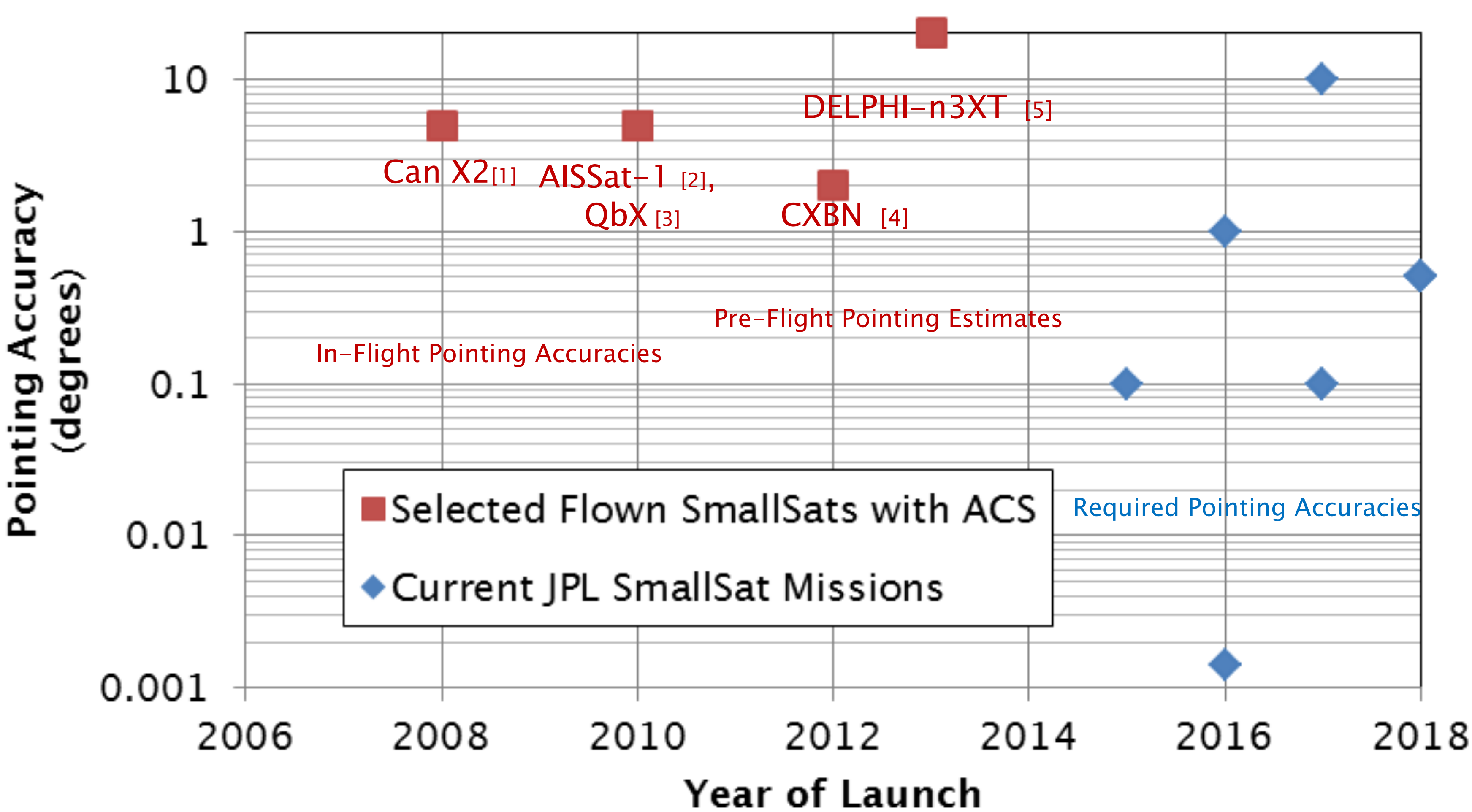
Small Satellite Dynamics Laboratory (SSDT)

Laura Jones
Swati Mohan
4/28/15

Jet Propulsion Laboratory, California Institute of Technology.

SmallSats and Attitude Control



SmallSats and Verification/Testing

Small Satellites have unique ACS testing needs:

- Different class of ACS hardware and software → Limited mass, power, processing
- Different dynamical regime → Testbeds must be smaller/lighter
- Short schedules and small budgets → Early hardware-in-the-loop testing critical

→ Understand what Verification & Validation activities are required based on the complexity of the mission

→ Use ACS testbeds designed specifically for Small Satellites needs

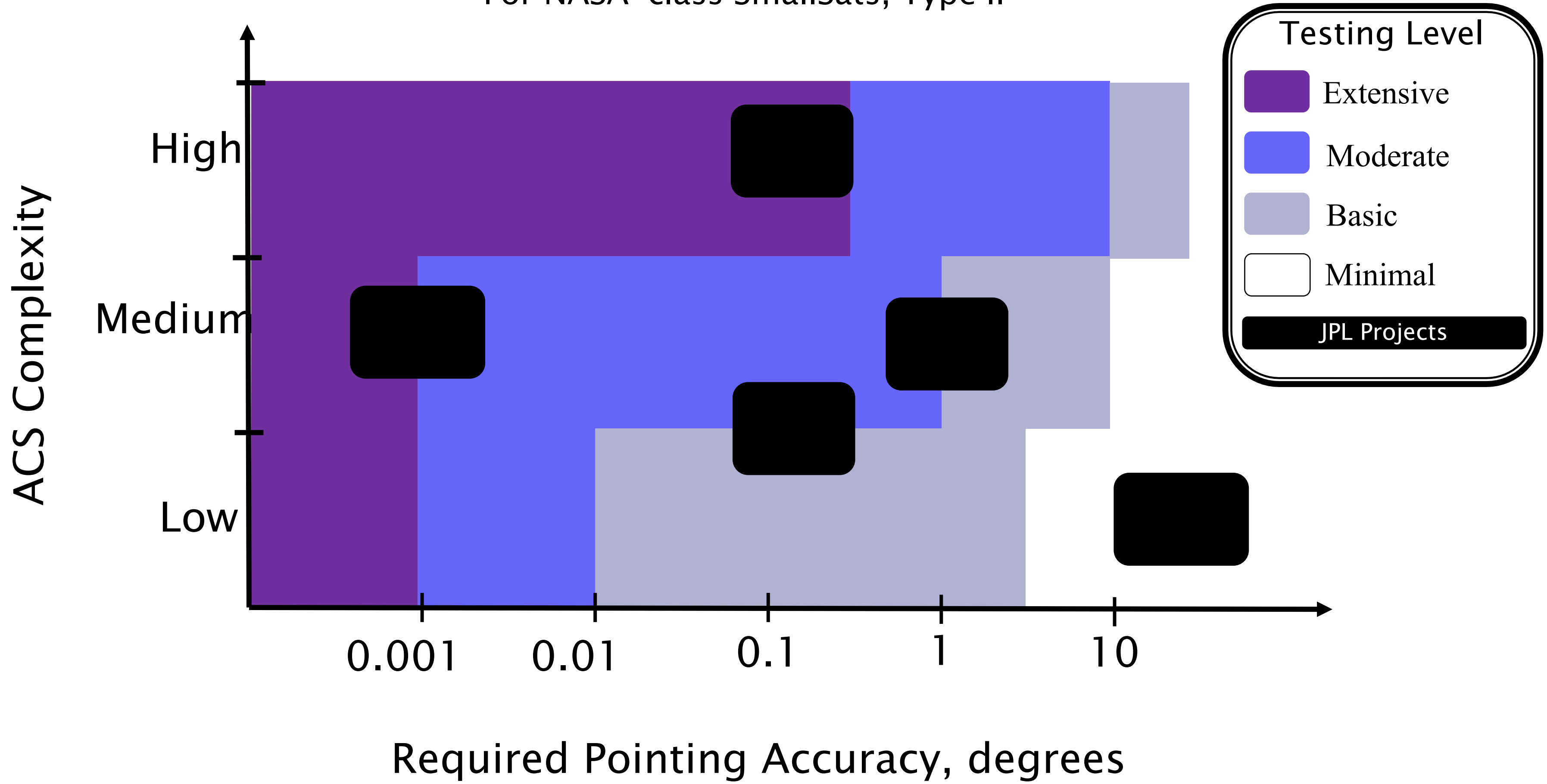
Defining ACS Complexity

ACS Complexity	Structural Complexity	Environment/ Mission	Jitter/ Maneuvering Req.	Degree of ACS Customization & Vendor Complexity
High	Large flexible structures, flexible structures with tight pointing (Ka band antennas, instruments), risk of control-structure interaction	Unusual disturbance environments (NEA, Venus atmosphere, Jupiter, etc.) , or > 1 year	Highly precise systems with tight jitter over long durations, highly agile systems with rapid slews, timing drives mission success	Major modifications to COTS components, fully customized system, multi-stage control, foreign companies/ partnerships
Medium	Rigid bus with flexible components that don't have tight pointing (deployable solar panels, S band or X band antennas)	Significant planetary body disturbances (Mars, lunar) or unique dynamics considerations (Lagrange points, etc.) or 6 months – 1 year	Tight jitter over short periods of time, loose jitter over long periods of time, regular maneuvering where timing is important	Small changes to COTS options, subcontracts with limited scope
Low	Rigid body pointing, no control-structure interactions	Small disturbances (deep space), or common SmallSat environments (LEO), or <6 months	Short time durations for any jitter requirements, slow slewing with limited maneuvering, timing useful but not mission-critical	COTS performance acceptable, no modification, limited contract complexity (PO)

ACS Complexity and Pointing Accuracy

Recommended Levels of Testing/Verification for SmallSat ACS Systems

For NASA-class SmallSats, Type II



Flight SmallSats and ACS Testing and Verification

V&V Activity	Minimal	Basic	Moderate	Extensive
Modeling/ Pointing Performance Evaluation	None, or simple rigid-body models based on spec sheet or available data, simplistic disturbance modeling, simple sizing analyses	Analysis of key performance parameters, vendor analysis, models include key dynamics, simple trajectory modeling to evaluate disturbances over time, etc.	Independent analysis of key performance specs and nominal mission scenarios, models include test data for critical components, key elements of system are modeled at detailed level, more complex dynamics modeling, more integrated modeling with trajectory	Detailed analysis of performance across range of mission scenarios, models include test data across system parameters, complex dynamics modeling, fully integrated models with other subsystems, full STOP analysis, evaluate pointing with system-level tests
Hardware-in-the-Loop Algorithm Development	None	None	Basic timing checks	Detailed development or testing done with hardware
Mass Properties Characterization	CAD	CAD, weigh components	CAD, weigh system	Test, full mass properties
RWA Characterization	Spec Sheet	Spec Sheet	Vendor/Existing Test Data	Test
IMU/Gyro Characterization	Spec Sheet	Spec Sheet	Vendor/Existing Test Data	Test
SRU Characterization	Spec Sheet	Spec Sheet	Vendor/Existing Test Data	Test
Phasing	Test	Test	Test	Test at component and system levels
Functional ACS Testing	Component power/telemetry connectivity check	Component power/telemetry connectivity check, data integrity check	Component power/telemetry connectivity check, data integrity check, basic timing check	Component power/telemetry connectivity check, data integrity check, extensive timing check, system functional tests
Closed-Loop Demonstration	Yes, no performance measurements	Yes, no performance measurements	Yes, with performance measurements	Yes, with performance measurements
Maneuver Testing	None	None	Critical maneuvers /simplified testing	Complete maneuver set
Mission Scenario Testing	None	Key mode transitions (detumble, etc.)	Key mode transitions, some fault protection	Deployments, all mode transitions, fault protection

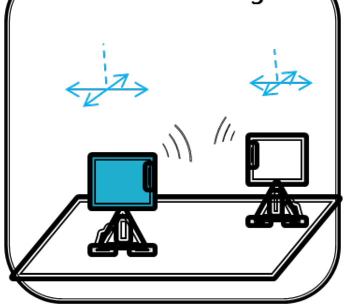
JPL's SmallSat Dynamics Testbed

3 Environments

Spherical Air Bearing

3 DOF Attitude

Planar Air Bearing



1 DOF Attitude
2 DOF Translation

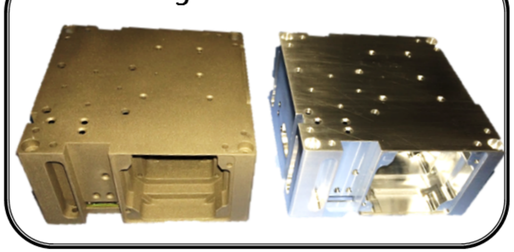
Computer Simulator

6 DOF Attitude

2 Payload Types

Up to 30 kg

Integrated ACS Units

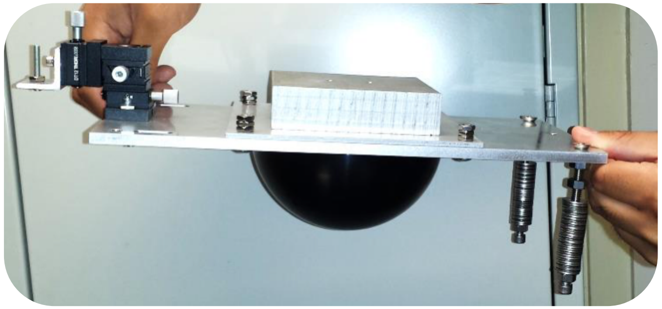


Individual Components

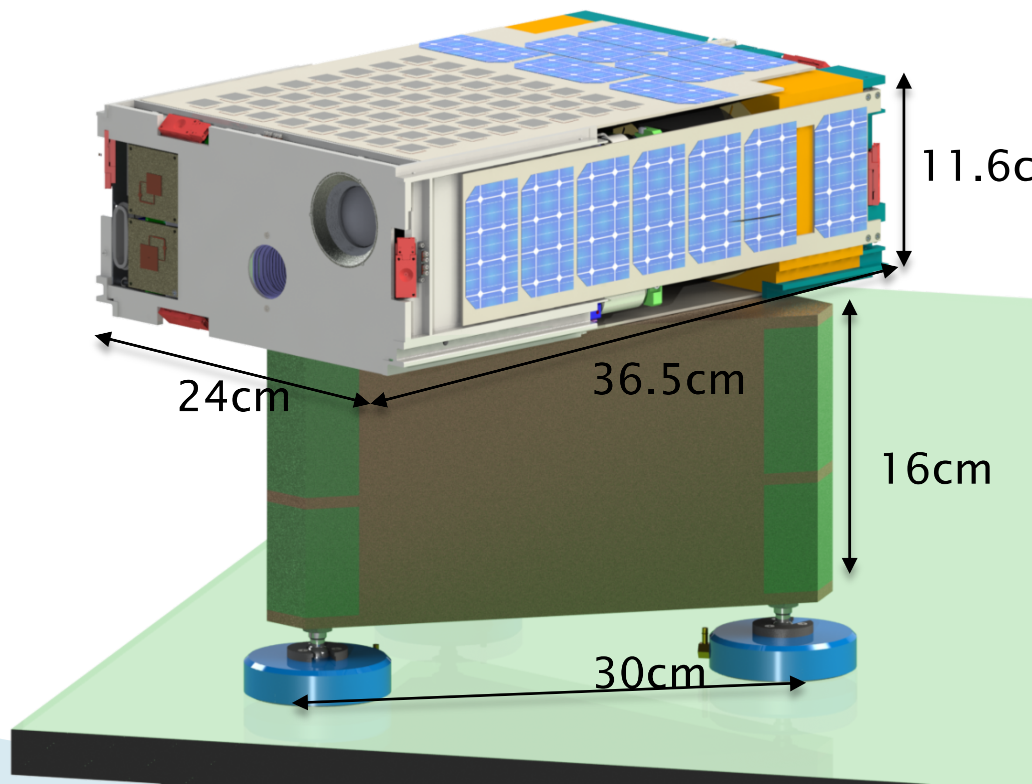
1 FCT-SSDT Shared Infrastructure

JPL's SmallSat Dynamics Testbed

Spherical Air Bearing

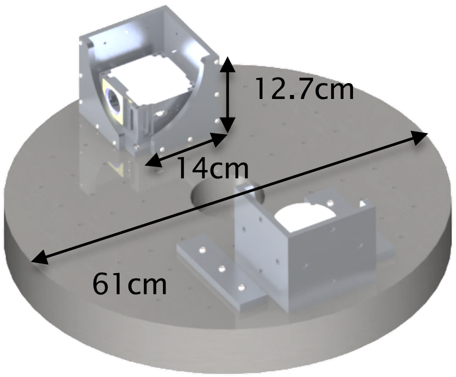


Planar Air Bearing



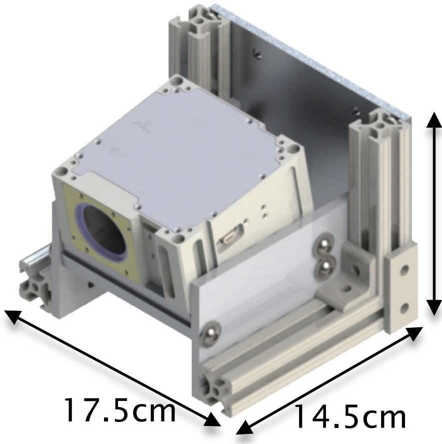
JPL's SmallSat Dynamics Testbed

Gyro Characterization



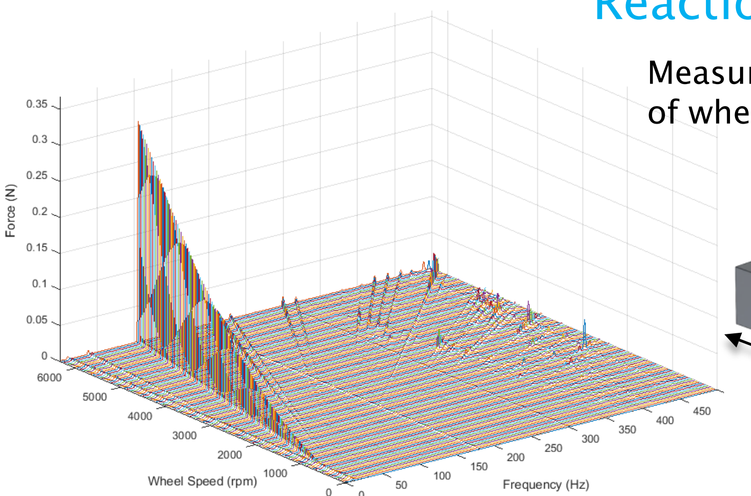
Measures angle random walk, rate random walk, angle white noise, quantization, bias repeatability, scale factor, and sense axis

Star Tracker & Sun Sensor Characterization

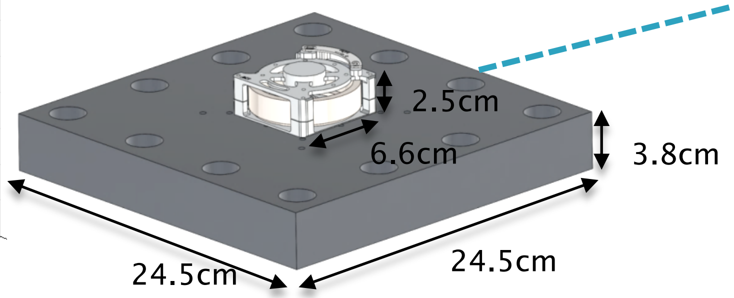


Measures noise equivalent angle, low frequency error, and velocity constraints on tracking, Measures estimate versus OCTL telescope truth

Reaction Wheel Characterization



Measures force and torque amplitude as a function of wheel speed and frequency.



sponsorship acknowledged.

Summary

- Small satellite industry trending to higher performing ACS systems
- Necessity of verification and validation activities depends on the complexity of the mission
- Provided guidelines on how to ballpark the V&V activities based on the mission complexity
- JPL's SSDT supports V&V by being designed specifically for small satellites (limited support mass, component library, etc.)

References:

[1] Sarda, Karan; Grant, Cordell; Eagleson, Stuart; Kekez, Daniel; Shah, Amee; and Zee, Robert, "Canadian Advanced Nanospace Experiment 2 Orbit Operations: One Year of Pushing the Nanosatellite Performance Envelope," 23rd Annual AIA/USU Conference on Small Satellites, Logan, Utah, August 2009, SSC 09-IV-6

[2] Sarda, Karan; Beattie, Alex; Kekez, Daniel; Zee, Robert, "In-flight Experience of the High Performance Attitude Determination and Control System of the Generic Nanosatellite Bus," The 4S Symposium 2012

[3] Armstrong, James; Casey, Craid; Creamer, Glenn; Dutchover, Gilbert, "Ponting Control for Low Altitude Triple CubeSat Space Darts," 23rd Annual AIA/USU Conference on Small Satellites, Logan, Utah, August 2009, SSC 09-X-4

[4] Brown, K. Z. et al., "The Cosmic X-Ray Background NanoSat (CXBN): Measuring the Cosmic X-Ray Background Using the CubeSat Form Factor", 26th Annual AIAA/USU Conference on Small Satellites, SSC12-VII-6, Logan, UT 2012.

[5] Reijneveld, J., and Choukroun, D., "Attitude Control System of the Delfi-N3xt Satellite", Progress in Flight Dynamics, GNC, and Avionics, 6, 189-208, 2013.