MSFC Small Spacecraft Development Experience

ES10/MacLeod

FASTSAT Overview

- **FASTSAT-0**
  - Developed in 2007 (12 Month development)
  - Scheduled to carry an Army payload and launch on a Super Strypi rocket
  - Total Budget was $4M
  - Weighed approximately 200 pounds
  - Body mounted solar panels produce approximately 100 Watts
  - First satellite design to exclusively use magnetic torque rods for attitude control
  - Early in the project, issues with the Army payload and the Super Strypi programs caused the mission to be cancelled. The satellite was completed without a known payload or launch vehicle.

FASTSAT Overview

- **FASTSAT-HSV-01**
  - Developed in 2009 – 2010 (~15 Month development)
  - Partner with the Air Force, Von Braun Center for Science and Innovation and Dynetics Corporation
  - External NASA funding (Air Force and Dynetics) was coordinated through VCSI
  - Carried 7 payloads from NASA GSFC, NASA MSFC, Naval Research Laboratory and the Air Force
  - Launched in November 2010
  - Ground operations controlled by MSFC
  - Planned 6 month mission was extended to over 2 years
  - No significant anomalies during the mission
  - Decommissioned June 2013

Mission Overview

Integrated at Kodiak Launch Complex

Launched Nov. 19 2010 on Minotaur IV

Carried 6 Experiments on FASTSAT-HSV01

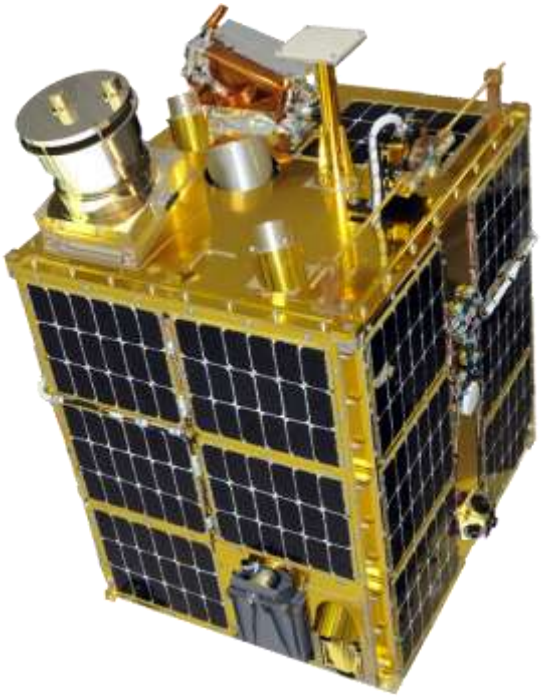
- Demonstrate multi-payload capability on Minotaur IV
  - 4 EELV Secondary Payload Adapter (ESPA) class spacecraft and 2 CubeSats
  - FASTSAT-HSV01 manifested as 1 of the ESPA class spacecrafts
  - Successful deployment of all 6 spacecraft into the desired orbit
- Access to Space for Space Experiment Review Board (SERB) experiments
  - STP-S26 launched 16 total experiments on 6 spacecrafts
  - **FASTSAT-HSV01 would carry 7 experiments and perform the first launch/ejection of a CubeSat from a free-flying ESPA class mini satellite**

Key Milestones

- Mission Selection: Dec 2008
- Preliminary Design Review: Feb 2009
- Critical Design Review: June 4, 2009
- PSR: May 7, 2010
- ORR: August 15, 2010
- FRR: September 27, 2010
- Launch: November 19, 2010
- Mission Completed Nov 2012
- End of Life June 2013

FASTSAT was designed, developed, integrated, tested and certified for flight in 15 months using an innovative business model, tailored processes, co-located and experienced team.

Spacecraft Requirements and Design



Dynetics The Power of Solutions

VCSI

- 12-month LEO mission
- Class D ESPA class spacecraft
- 7 instrument capacity
- NanoSat (CubeSat) Payload Deployer (P-POD)
- Spacecraft mass: ~150 kg
- Size 24” x 28” x 38” (ESPA)
- Payload mass: 21 kg
- Payload power: 30 W average
- S-Band downlink 1 Mbps
- S-Band uplink 50 Kbps
- Stabilization: single axis (magnetic torque rods)
- Pointing accuracy: 20° /3-axis; 10° /single axis
- Pointing knowledge: 0.1°

FASTSAT-HSV01
Seven Instruments on One Platform

NASA and USNA Miniature Imager for Neutral Ionosphere Atoms and Magnetosphreric Electrons (MINI-ME)
- Improve space weather forecasting for operational use

AFRL Light Detection System (LDS)
- Evaluate atmospheric propagating characteristics on coherent light generated from known ground stations

NASA + ARMY SMDC + AFRL + VCSI Nano Sail Demonstration (NSD)
- Demonstrate deployment of a compact 10-m^2 solar sail ejected as a CubeSat

NASA MSFC Memory Test Experiment (MTE)
- Flight Demonstration of Ferroelectric Memory technology

NASA and USNA Thermospheric Temperature Imager (TTI)
- Increase accuracy of orbital predictions for low-Earth orbiting assets

NASA & USNA Plasma Impedance Spectrum Analyzer (PISA)
- Permit better predictive models of space weather effects on communications and GPS signals

AFRL + NASA + AF Miniature Star Tracker (MST)
- Demonstrate small and low-power star tracker

Project Tailoring

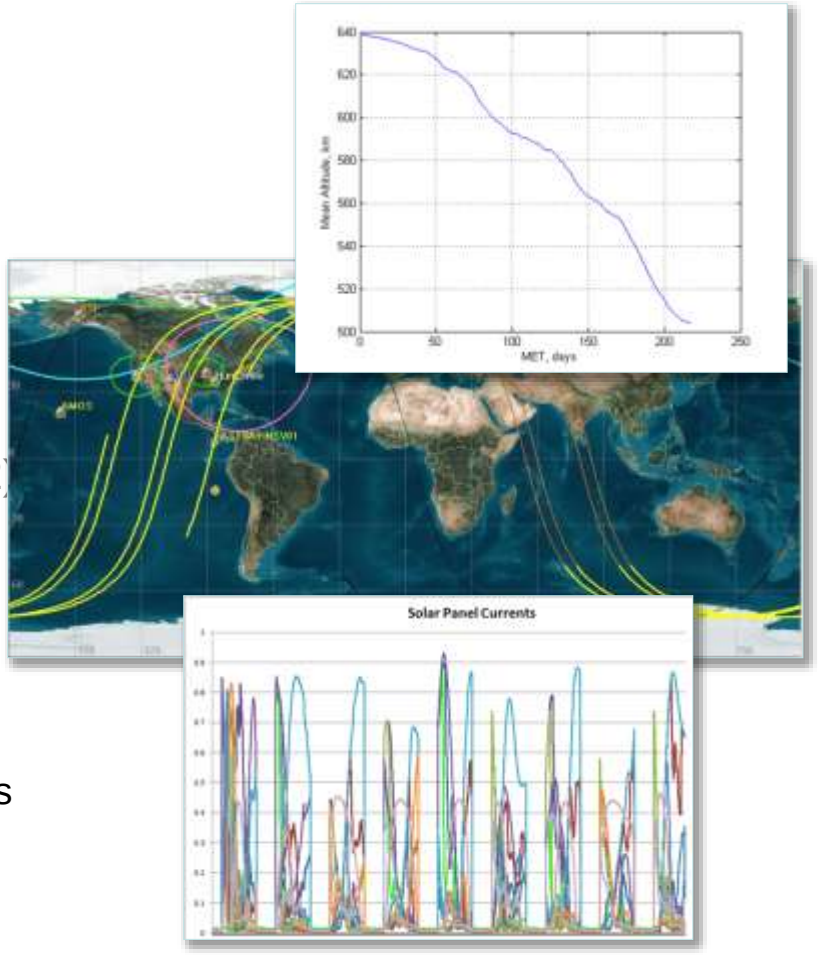
- The project followed NPR-7120.5 with significant tailoring
  - The number of documents were reduced by combining and elimination
  - The proscribed number of project reviews were reduced to 4
  - Configuration Management was accomplished through a simplified Project Release system
  - A small co-located team reduced the number of formal status meetings
- The project followed NPR-7150 on software development with significant tailoring
- The project only carried workforce when they were needed by the project. Once a person's task was completed they were rolled off the charge code.
- The project was managed as a Class D project with additional rigor only given to areas perceived as high risk
- Use of NASA's Near Earth Network for downlink was a cost savings
- Most of the project personnel already had experience in working low-cost flight projects, including small satellites

Mission Parameters

Launch Date @ ATP – December 2009
Actual Launch Date – November 19, 2010
Orbit – 650 km circular
Inclination – 72 degrees
Location - Kodiak, Alaska

FASTSAT Mission Accomplishments

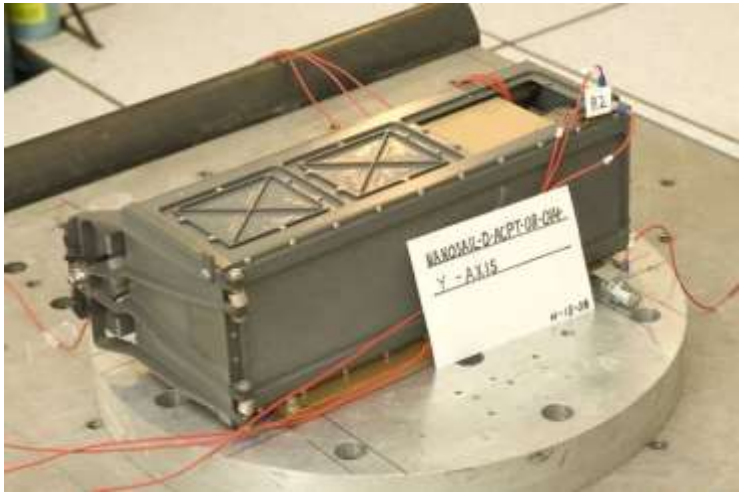
- ✓Launch Nov 19 at 7:25 PM CST
  - Spacecraft Powered Up 52 minutes Later (nominal)
  - Sustained Ground Contact within12 Hours (nominal)
  - Completed all level I S&T payload data gathering for SERB payloads by April 30, 2011 (nominal)
  - Spacecraft to ground contacts entering 21st month
- ✓Mission Operation Center at NASA MSFC
  - Reliable Commanding and Telemetry Established
  - Portal and Remote Telemetry to PI's Established
- ✓ Science Operations (Continued through Nov 2012)
  - ✓Aliveness Tests Successful for PISA, TTI, MINI ME, LDS, & Miniature Star Tracker
  - ✓NSD Ejected and Sail deployed with planned re-entry
  - ✓PISA achieved full science level I requirements
  - ✓MINI-ME achieved full science level I requirements
  - ✓TTI achieved full science level I requirements
  - ✓Miniature Star Tracker successfully acquired star fields images, quaternion(s) generated
  - ✓Additional data gathering for PISA, TTI, MINI-ME and LDS underway for acquisition of reach goals (Science Continues)

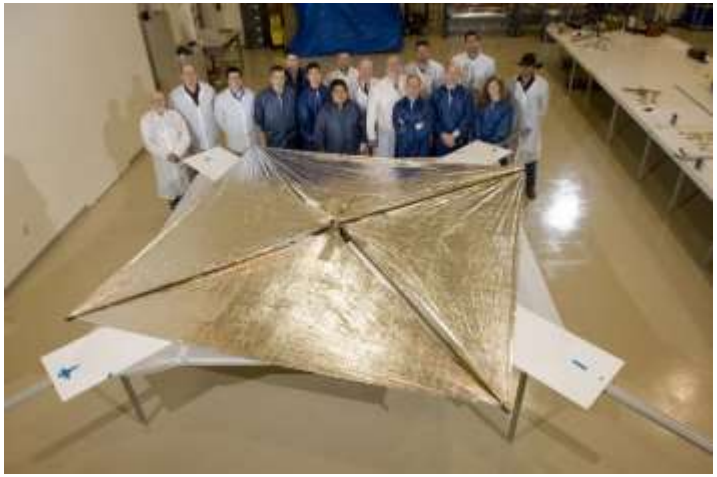


FASTSAT-HSV01 project accomplished the mission goals within nine months of launch and the payload technology readiness levels are now ≥ TRL 8

FASTSAT Overview

- **NanoSail-D**
  - Developed in 2007 -2008
  - Launched on Falcon 1 on 8/3/2008 (Launch vehicle failure)
  - Launched Backup spacecraft in FASTSAT-HSV01 in November 2010
  - Partner with Ames Research Center and NeXolve
  - Deployed from FASTSAT-HSV01 in January 2011
  - Deployed a 10 meter square solar sail in LEO
  - The Nanosail-D spacecraft de-orbited in approximately 120 days. Analysis showed that that the spacecraft would have taken approximately 50 years to de-orbit without the sail





MSFC Engineering Capabilities for Small Satellites

- **Plasma Experiment Satellite Test (PEST)/ Joint Air Force Weber State Satellite (JAWSAT)**
  - Developed in 1999 (6 month development)
  - Launched 1/27/2000 on Minotaur 1
  - MSFC developed plasma detector, command and data system, power system and instrument deployment system
  - Weber State bus failed to transmit data

MSFC Engineering Capabilities for Small Satellites

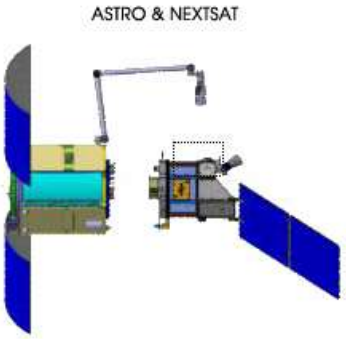
- **Small Payload Access to Space Experiment (SPASE)**
  - Developed in 2000 (12 month development)
  - Partnership with AeroAstro to develop low-cost small satellites
  - Scheduled to Launch on Shuttle (Hitchhiker) originally in 2001. Rescheduled for 2003, but the Columbia accident canceled its launch
  - Approximately 80 Lbs, passive magnetic attitude control, no moving parts
  - Contained a micro-gravity crystal growth experiment
  - Used in ground tests by the Air Force for imaging of small satellites

MSFC Engineering Capabilities for Small Satellites

- **Demonstration for Autonomous Rendezvous Technology - DART**
  - Developed in 2003-2004
  - Launched 4/15/2005 on a Pegasus
  - Joint project with MSFC and Orbital Science
  - DART was to rendezvous with the Multiple Paths, Beyond-Line-of-Sight Communications (MUBLCOM) satellite, but due to system failures the DART spacecraft made contact with the MUBLCOM and use up all of its propellant
  - MSFC developed the Advanced Video Guidance System (AVGS) to perform the proximity operations. The AVCG system was never fully activated during the mission
  - MSFC also performed development testing using the Flight Robotics Laboratory

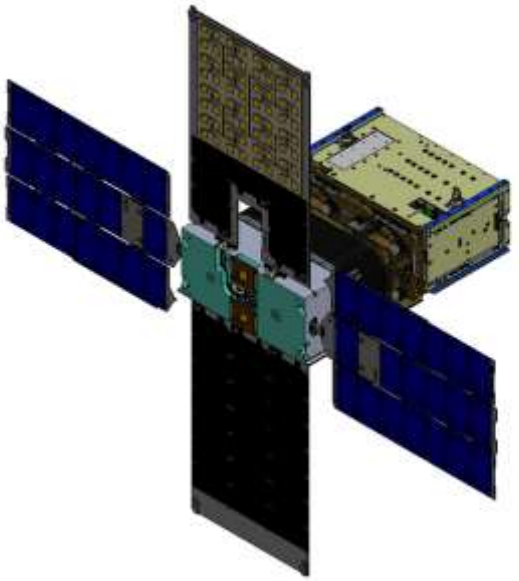
MSFC Engineering Capabilities for Small Satellites

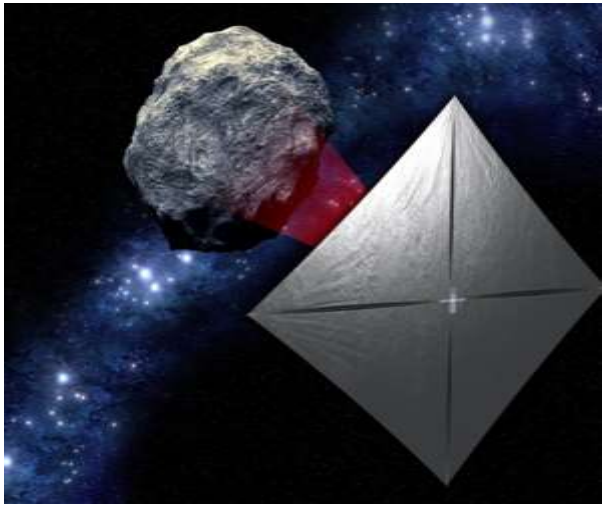
- **Orbital Express**
  - Developed in 2005 -2006
  - Launched March 2007
  - Partner with DARPA, Boeing and Ball Aerospace
  - The project rendezvous and docked two spacecraft ASTRO and NEXTSAT to demonstrate proximity operations and refueling.
  - MSFC developed the Advanced Video Guidance System (AVGS) to perform the proximity operations. The AVCG system work flawlessly during the mission
  - MSFC also performed development testing using the Flight Robotics Laboratory



MSFC Engineering Capabilities for Small Satellites

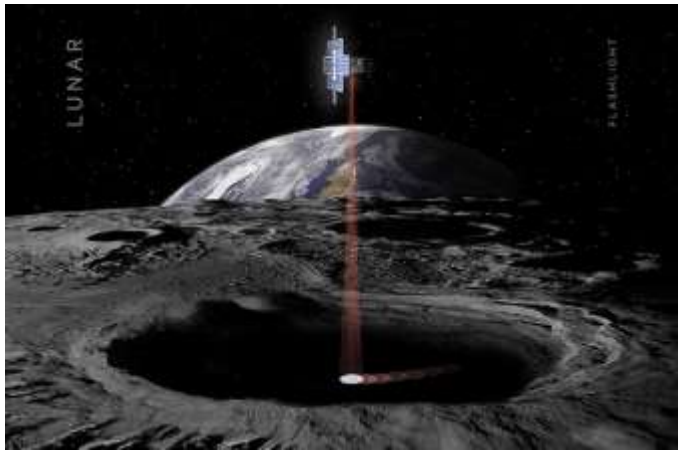
- **NEA-Scout**
  - In development
  - Funded by Advanced Exploration Systems (AES)
  - Scheduled to launch on SLS EM-1 in 2019
  - 6U cubesat form
  - Partner with JPL
  - MSFC manages the overall mission and is developing the solar sail
  - The mission is to fly in deep space and flyby one or more Near Earth Objects
  - The system has a imaging system to characterize the NEA





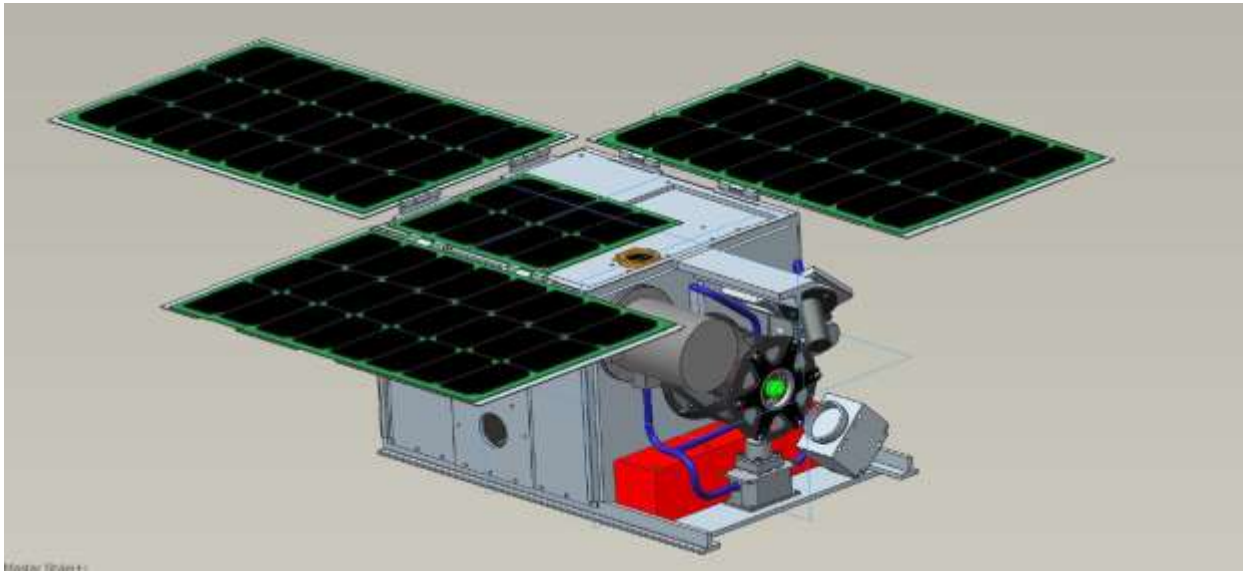
MSFC Engineering Capabilities for Small Satellites

- **Lunar Flashlight**
  - In development
  - Funded by Advanced Exploration Systems (AES)
  - Scheduled to launch on SLS EM-1 in 2019
  - 6U cubesat form
  - Partner with JPL
  - MSFC scientist is the Principal Investigator
  - JPL manages the overall mission, MSFC is developing the propulsion system
  - The mission is to orbit the moon and shine a laser into a shadowed crater at the pole and observe it with a spectrometer



MSFC Engineering Capabilities for Small Satellites

- **iSAT**
  - In development
  - The bus system is at a CDR level
  - Issues with the propulsion system maturity (at Glenn Research Center) has delayed spacecraft development
  - The mission is to demonstrate an Iodine Plasma Propulsion System in LEO
  - The iSAT propulsion system consists of a 200W Hall thruster, Iodine tank and support systems

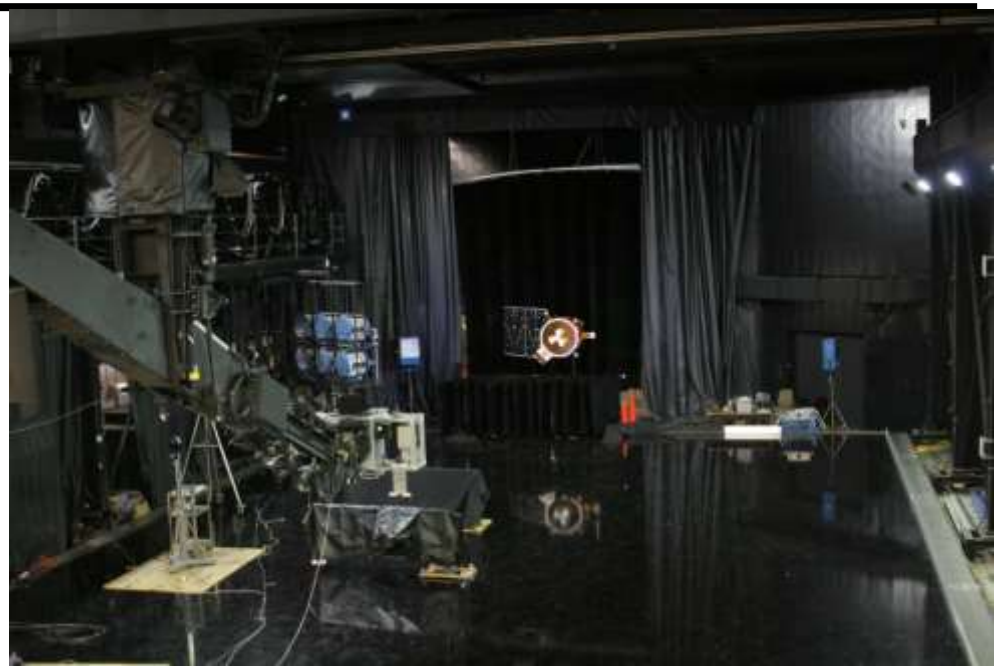


MSFC Engineering Capabilities for Small Satellites

- **Other On-going Small Sat Activities**
  - In-house development of a 3U Green Propulsion Demonstration satellite
  - Partnership with Air Force STP for a Green Propulsion system for a 90 Kg spacecraft
  - Potential Earth Science, Heliophysics and Astrophysics small satellite missions
  - Support for Air Force Research Laboratory development of a 3U cubesat
  - In-house development of an Electrically Controlled Solid Propulsion System cubesat demonstration mission
  - Small Satellite subsystem developments including:
    - S and X-band communication system (PULSAR)
    - Ultra-Capacitor energy storage
    - Additive manufacturing
    - Attitude determination and control systems
    - De-orbit systems
    - Solar Sail propulsion systems
    - Electronic Sail propulsion systems

NASA MSFC Flight Robotics Lab

Provides a full scale, integrated simulation capability to support the design, development, test, integration, validation, and operation of orbital space vehicles.



The Flight Robotics Laboratory (FRL) is built on developed technologies: air bearing vehicles, a servo drive overhead robotic simulator, precision target motion controllers, gimbals, and a mobile solar simulator with 6 lights totaling 42 KVA.

The facility is centered around a 44 foot by 86 foot precision air bearing floor - the largest of its kind.

The FRL has air-bearing vehicles ranging in size from 200 lbs to 4000 lbs, each with its own compressed air supply. An 8-Degree-of-Freedom (DOF) overhead gantry (the Dynamic Overhead Target Simulator or DOTS) provides an 800 pound payload capability for simulating relative motion with respect to a fixed target in the facility with a motion envelope of 30' x 160' x 20'. A computer system provides inverse kinematics and allows the gantry to act as a target or as the 6 DOF rendezvous vehicle. The target reaction dynamics can be simulated through force/torque feedback from sensors mounted at the payload interface.

Collaboration areas could include sensor testing, system testing, multi-vehicle algorithm simulation and testing, orbital debris tracking, automated capture and manipulation, and wireless video and control.

Past DoD collaborations include DARPA's Orbital Express mission, MARCbot reconfiguration and testing, DART mission to MUBLCom satellite, and sensor tests utilizing Army ranges and facilities.

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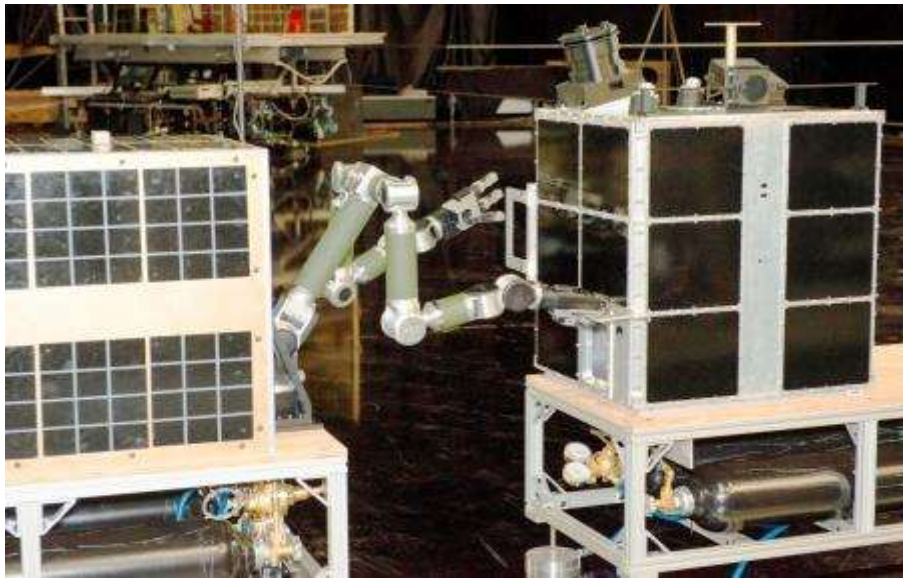
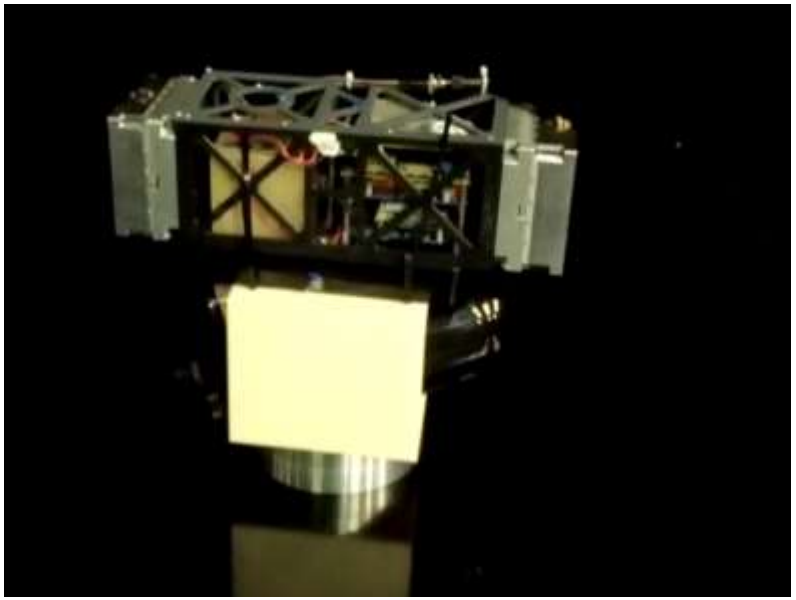
SMALL SATELLITE TESTING IN FRL

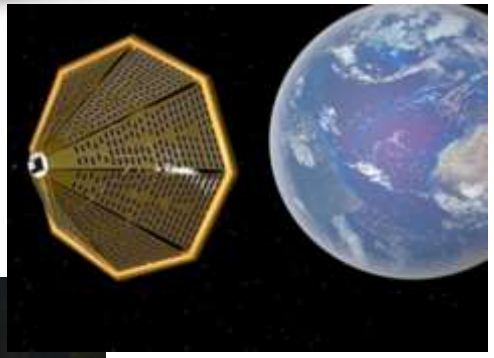


Tele-robotic small satellite capture demonstration - MSFC test on Flight Robotics Lab Flat Floor



Cubesat Propulsion - MSFC test on Flight Robotics Lab Flat Floor

Lightweight Innovative Solar Array



Accomplishments

- Can fit within a 1-U form factor
- Completed three concept design studies establishing concept feasibility:
  - 3U CubeSat mission
  - Saturn Concept
- Designed and fabricated test article
- Conducted successful inflation test