XSS-10 Micro-Satellite Flight Demonstration Program

Presented to 17th Annual AIAA/USU Conference on Small Satellites
12 August 2003
Background

- XSS-10 was a technology program to demonstrate basic proximity operations capabilities on-orbit
  - Addressed both technical and operational risks before committing to micro-satellite system development programs
  - Fundamental part of the AFSPC Strategic Master Plan for ensuring space superiority
- Initiated in 1996, the program was realigned several times due to budget and launch changes
- Originally planned for Shuttle launch, NASA withdrew ride in 1998 due to priorities for International Space Station
- Air Force launch secured as secondary payload on Delta II Global Positioning Star satellite operational mission
- Strong senior leadership support throughout program
XSS-10 Program
Pathfinder for Micro-Satellite Proximity Operations

- First on-orbit flight demonstration of micro-satellite proximity operations

- **Demonstrates:**
  - Semi-autonomous and manual control of micro-satellite on-orbit
  - Navigation and inspection of object of interest (Delta 2nd Stage) by micro-sat
  - Demonstration of several advanced micro-sat technology components

- Significant risk reduction for XSS-11

Mini-communications system (SGLS)  Integrated imager and star camera  Lightweight propulsion system  Lithium polymer batteries
XSS-10 Microsatellite Team

- Program Oversight
- CONOPS
- Mission Analysis
- System Integration & Environmental Testing
- Launch Vehicle Integration
- Mission Planning & Operations
- Microsat Support Platform Design & Fabrication

- System Engineering
- Mission Planning
- Systems Safety

- Integration & Test
- Environmental Testing
- Ground Operations

- GN&C Software Design
- Telemetry Display and PIL
- Software Integration & Test

- Mission Operations
- SGLS

- Vehicle Design
- System Integration and Test
- DSP Software Design
- Avionics Design
- Avionics Fabrication
- Avionics Integration & Test
- Software Integration & Test

- Launch System Support
- Delta II Secondary Payload

- Sconce
- Dynamic Model Analysis

- Visual Camera System
**Microsat and Support Hardware**

- **Sconce Payload Platform**
- **Support Electronics Platform**

**XSS-10 Microsat**

- **Primary Structure**
- **Avionics Module**
- **Batteries (2X)**
- **Divert Thruster (4X)**
- **ACS Thruster (8X)**
- **Pressurant Module**
- **IMU Structure**
- **IMU**
- **Sensor Assembly**
- **Uni-body Propellant Tanks**
- **SGLS**

**31 kg in weight; volume: approximately 43cm x 84cm**

**Highly energetic vehicle with approximately 300m/s**
Satellite Payload Platform

XSS-10 Inside Fairing

XSS-10 Stowed

MicroSat Tipout

MicroSat Release
Program Development Activities

Flight Hardware
- Micro-satellite fabricated at Boeing Rocketdyne Canoga Park facility
- All environmental and space qualification testing complete at Kirtland AFB Aerospace Engineering Facility
- Functional checkout, propellant loading, and integration with Delta II launch vehicle accomplished at CCAFS

Flight Software
- Guidance, Navigation, and Control (GNC) software developed by Octant Technologies
- Digital Signal Processing (DSP) software written by Boeing-Anaheim
- “Air Bearing” Test #2 completed in June ‘01
- Final software “buyoff” of final revisions to flight/mission software completed at Boeing-Anaheim facility in Jan ‘03
XSS-10 Launch Vehicle

- Launched on 29 January 2003 as first Air Force secondary mission aboard a Delta II launch vehicle carrying a GPS satellite on mission IIR-8

- Vehicle configuration: 7925
- Launch site: SLC-17 at CCAFS

Ground Rules: No Impact to GPS!
Launch Operations

- Ground Operations Working Groups (GOWG) established in December 2000
  - Members included Boeing/HB, Lockheed Martin, AFRL, and 45th Space Wing
  - Identified facilities and coordinated integrated schedule
  - XSS-10 Missile System Pre-launch Safety Package developed and approved
- Delta II second stage modified for XSS-10
  - “Fit check” at Pueblo in May 2001
  - Functional check completed at CCAFS in November 2001
- Processing flow:
  - Functional checkouts at NAVSTAR Processing Facility
  - Moved to DSCS Processing Facility, fueling activities
  - Launch pad 17B, integrated onto Delta II
XSS-10 mission operations activities accomplished through SMC Detachment 12 (RSC) utilizing AF Satellite Control Network

Command and telemetry databases completed; commanding ability verified through the AFSCN to the XSS-10 vehicle

*High risk, complex mission requirements, never previously accomplished! Short duration mission (<24 hours)*

- Proximity operations—*never before attempted*
- Rotating ejection platform
- Single-string experimental space vehicle
- External ranging support is required to assist AFSCN in tracking micro satellite

AFRL/ SMC Det. 12 mission operations team performed flawlessly
**XSS-10 Mission Architecture**

**Mission specifics**
- Retrievable elements: none
- Orbital altitude: 800 km
- Orbital inclination: 39.6 degrees
- Lifetime: ~24 hours

**Mission Overview**
- Eject
- Perform initial orientation ("lost in space")
- Perform inspection at ~100 meters
- Close-in inspection
  - divert to ~50 meters
  - cold gas axial thrust ~35 meters
- Demonstrate low-power (sleep) mode
- Wake and do "extra credit" (rendezvous)

First of its kind flight demonstration of proximity operations on-orbit!
Delta II Trajectory Sequence

- Launch
- Stage 2/3 Separation
- Burn to Raise Perigee
- Burn to Lower Apogee
- Nominal Depletion Burn (Orbit Insertion)

*Assumes descending node launch*
Mission Pass - Checkout
Microsatellite Camera

(Rev 11.1 NHSB 30 Jan 2003 12:02:03z - 12:16:58z)

- 12:02z AOS @ NHSB as scheduled
- 12:03z Vehicle pre-eject checkout completed and GO/ NO-GO calls made
- Microsatellite views earth limb
- 12:04z eject command sent to vehicle, mission time (MT) = 0
Mission Pass - Ejection
Witness Camera
(Rev 11.1 NHSB 30 Jan 2003 12:02:03z – 12:16:58z)

- MT+0:20 Microsatellite ejected from Delta II 2nd stage
- Pre-eject
- Microsatellite ejection
- Witness camera video eject +

- Witness camera video eject ++

- Microsatellite drifts out at .8m/ sec until ~ 100m from 2nd stage
- Microsatellite completes drift out and turns around to look at 2\textsuperscript{nd} stage

- Range: 100 meters

- Time: MT+2:03
Mission Pass - Ins. Point 0
Microsatellite Camera
(Rev 11.1 NHSB 30 Jan 2003 12:02:03z - 12:16:58z)

- Imaging system autonomously adjusts integration time to desaturate image
- Range: 100 meters
- Time: MT+2:03
- Microsatellite moves to inspection point #1
- Range: 100 meters
- Time: MT+6:00
- Imaging system autonomously adjusts integration time to desaturate image
- Imaging system autonomously adjusts vehicle attitude to center 2\textsuperscript{nd} stage in field of view
- Centroid information is used to update vehicle position knowledge
Microsatellite moves to inspection point #2

Range: 100 meters

Time: MT+7:20

Imaging system autonomously adjusts integration time to desaturate image

Imaging system autonomously adjusts vehicle attitude to center 2\textsuperscript{nd} stage in field of view

Centroid information is used to update vehicle position knowledge
- Microsatellite begins move to inspection point #3
- Microsatellite begins move & stare maneuver
- Initial Range: 120 meters
- Initial Time: MT+8:30
- Final Range: 150? meters
- Final Time: MT+10:00
Vehicle begins move to inspection point #4 (Vbar)
Range: 100 meters
Time: MT+10:30
Early LOS @ NHSB
Inspection point #4 and axial maneuver not observed due to loss of telemetry
Delta II 2\textsuperscript{nd} Stage (100m)
Microsatellite Camera
Launch Vehicle Integration
(Commercial Digital Camera)

On-Orbit
(Microsatellite Visible Imager)
XSS-10 Mission Objectives

Minimum Success Criteria
- Deliver and release one Micro-Sat on-orbit
- Establish real-time RF link between Micro-Sat and AFSCN
- Perform maneuvers about a resident-target
- Perform 3 points of an autonomous inspection about a resident-target
- Acquire and track a resident-target with the Micro-Sat visible sensor
- Demonstrate station-keeping capability relative to a resident-target continuously

Full Success Criteria (min set plus the following)
- Establish real-time RF link between the AFSCN and both the Micro-Sat and ELV-VAS simultaneously
- Perform continuous track during maneuver between two inspection points
- Perform 100% of an autonomous 5-point inspection about a resident-target
- Demonstrate Micro-Sat axial maneuvering while imaging
- Demonstrate life extension (‘Sleep’) mode for a Micro-Sat
- Obtain images of Micro-Sat ejection and initial maneuvers about a resident-target

Additional Mission Objectives
- Reacquire resident-target after Micro-Sat has been in sleep mode
- Demonstrate real-time commanding through the Payload Test Center
- Rendezvous with resident-target to within 200m
- Perform orbit lowering maneuver to reduce Micro-Sat life on-orbit
Impact to Future Missions

- Station keeping and maneuver control logic verified and clears the way for more complex maneuvers on future missions.
- Visible camera and star tracker provided brilliant images of the nearby rocket body.
- Vehicle fault detection and handling was checked out with planned and real anomalies.
- Proven vehicle safety system will be combined with an on-board planner on subsequent missions to demonstrate autonomous proximity operations.
- Developed ground control capability enabled a small team to successfully interpret the real-time data and control the spacecraft during its short mission.
- Future missions will build on this by both further reductions in ground staff and extension to orbit changes and rendezvous with objects.
Preliminary Conclusions

- Proximity operations experiment successful
  - All primary mission objectives achieved!
- Validated the design and operations of the microsatellite
  - Autonomous operations algorithms
  - Visible and Star sensor design
- Demonstrated capability for responsive microsatellite operations
  - Quick activation and checkout
- Detailed mission analysis underway
  - XSS-10 will serve as building block for future missions
  - Results to be provided to AFRL, AFSPC, and other government agencies
Summary

- XSS-10 mission successful; all primary objectives achieved
- AFRL’s AEF provided critical capability for reducing risk and program costs!
- Dedicated team effort; outstanding support from AFSPC, SMC, 45th Space Wing, and contractor team members
- Building block for future microsatellite demonstrations