Operationally Responsive Satellite System CuSat - Nanosat with an Attitude

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Objectives and Agenda

- Mission Objectives
- Key Attributes
- System Overview
- GSAW relevance
- Mission Details
  - CDGPS, Inspection details, etc.
- Ground Segment specifics
- Upcoming Launch Opportunity
  - Details of Falcon 1, when, where, orbit, pass times, etc.
- CUsat meets ORS needs
- Summary
Mission Objectives

CUSat demonstrates an end-to-end autonomous on orbit inspection system. Centimeter-level accurate Carrier-phase Differential GPS (CDGPS) enables CUSat to navigate and use its cameras to gather target-satellite imagery. In the Ground Segment, image-processing techniques verify the CDGPS relative distance and orientation estimates and provide a 3D model of the target satellite for the user.
Key Attributes

Demonstrate that on orbit Carrier-phase Differential GPS can support inspection operations.

- **Objective Motivation**: CDGPS makes centimeter-accurate relative position determination possible. This technology enables:
  - Close-proximity navigation for specific uses in
  - On orbit inspection
  - On orbit construction
- A common solution for a wide variety of orbits and mission architectures.
- Increase TRL of CDGPS real-time calculations in space
- A modularized architecture for absolute and relative positioning that can be easily integrated into a wide variety of missions.
Key Attributes

Demonstrate an end-to-end autonomous on orbit visual inspection system.

- **Objective Motivation**: CUSat is an end-to-end system that autonomously inspects objects on orbit and transmits, processes, and formats this inspection data. This system has the following benefits:
  - In-space surface failure detection and diagnosis
  - Monitoring target system health and operations
  - Increases the TRL of GPS-based inspection/navigation systems through actual flight demonstration
System Overview
CDGPS Performance

3σ position error of 4mm (measured)

Average angular error of 2.03° (Monte Carlo sim), 25cm baseline distance, 3 vectors

PDF as a histogram of 100,000 cases
CUSat Spacecraft Communication Hardware

- **Kenwood TH-D7A Transceiver board**
- **Built-in TNC modem 437 MHz radio**
  - Command uplink
  - Telemetry downlink
  - Image data downlink
  - Beacon downlink
  - Crosslink

- **T&C Control Board**
  - Memory (for store and forward)
  - Voltage Regulators

- **T&C Control MCU**

- **Power Board**

- **Power Lines**
- **Data Lines**
- **Electronics Backplane**
GSAW focus areas addressed

- Net-centric and service-oriented architectures
- Frameworks and infrastructure
- Space and ground communication architectures
- Off-the-shelf and open-source components and software reuse
- Operations and sustainment
- Autonomy and automation
CUSat Ground Segment

- CONOPS and Mission Operation
- Components
  - Space Communications HW
  - Ground Communications HW
- Architecture & Dataflow View
- Control & Data Processing Software
- Ground Data Products
CONOPS and Mission Operation

- Mission Management Center (MMC) at Cornell
- Mission Management software: InControl
  - Provided by L-3 West Telemetry
- MMC interfaces with remote ground stations via VPN over Internet
- LEO satellite provides several ~10 minute pass opportunities per day over ground stations
  - Ground stations are placed to maximize pass opportunities
- Digital communications via UHF packet radio
  - Commands are uplinked to schedule or initiate next inspection sequence or other spacecraft operations
  - Beacons, telemetry and image data and are stored and downlinked on schedule
Ground Segment Software Architecture

Multiple Ground Stations are supported by the server software

- Ground Station 1: TS-2000 → Gateway
- Ground Station 2: TS-2000 → Gateway
- Ground Station 3: TS-2000 → Gateway
- Israel Ground Station: Legacy Hardware

Mission Management Center (Ithaca):
- L-3 InControl
- InControl Private Interface
- Ground Segment Link GSL Command Generator

Public viewer GUI

Public Viewer
CUSat Ground Station Hardware Diagram

- **Yaesu G5500 2-axis Rotator**
- **Circularly Polarized Yagi Antenna**
- **Kenwood TS-2000 Transceiver**
- **Kantronics KAM XL TNC**
- **Yaesu Rotator Controller**
- **GS-232B Interface Converter**
- **Control computer**
- **Serial Ports**
- **Ethernet**
- **437 MHz RF Coax**
- **9600 bps modem**
- **Internet**
- **CUSat Mission Management**

Connections:
- Rotator control
- 437 MHz RF
- Telem + data
- S/C commands
- T/R Audio
- Transceiver Tune Commands
- Serial Ports
- Ethernet
- Control computer

Modem:
- **437 MHz RF**
- **Telem + data**
- **S/C commands**

Computer Interface:
- **Serial Ports**
- **Ethernet**

CUSat Mission Management

Northrop Grumman

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Gateway Software in Ground Station

- Each Ground Station has Gateway copy
- The Gateway receives commands from MMC via Internet
- The Ground Segment Link (GSL) State Machine provides intelligence at the ground that responds to spacecraft modes
- Radio Traffic Scheduler works with GSL State Machine to manage traffic to and from the spacecraft
Ground Segment Link State Machine

- High level logic for controlling interaction with the satellites
- Interacts with spacecraft states to ensure proper operation and response to contingencies
Communications Datalink Scheduling

- CUSat rides on available launch opportunity
- Original expectation was polar orbit or other high inclination
  - Ground station plan included 3 CONUS sites plus existing station in Israel
  - Provided 4 to 6 pass opportunities per day

- Recent change – new launch opportunity is Space-X Falcon 1, Flight 3
  - 330 x 685km 9 degree orbital inclination
  - Requires equatorial Ground Stations
  - The good news is that one Ground station catches as many as 15 pass opportunities per day
9° Equatorial Orbit Pass Opportunities

STK Prediction

CUSat Kwajalein Ground Station Pass Durations

~ 15 passes per day

Notional ground track for 9° inclination
Ground Data Products

- Most satellite passes are beacons or command / telemetry opportunities
  - Data is not downlinked on every pass because satellite TX duty cycle is limited by solar power budget
- Each satellite pass that is dedicated to downlinking of stored image data can yield between 200k to 400K bytes of data
  - 9600 bit/second physical layer TNC modulation rate
  - 400 to 800 seconds per pass
Ground-based 3D Reconstruction and Distance Verification

- Mission results in the registration of images taken from multiple angles, to the CAD model of the target spacecraft.
Space systems integrated into a common infrastructure for ORS

- Augment/Surge
- Reconstitute

Tactical LEO Constellation (EO/IR/HSI/SAR)
Fractionated Spacecraft System (F6)
KEI
GIG
UAV Global Hawk
B2
CAOC
FBCB2
Tactical Terminals
HEO Comms/ BFT/FAC ~24/7
International Commercial National

Rapid integration & launch

Operationally Responsive Space Tier Approach

<table>
<thead>
<tr>
<th>Tier 1</th>
<th>Tier 2</th>
<th>Tier 3</th>
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<tbody>
<tr>
<td>Employ it</td>
<td>Launch/Deploy it</td>
<td>Develop it</td>
</tr>
<tr>
<td>• On demand with existing assets</td>
<td>• On call with ready to field assets</td>
<td>• Rapid transition from dev to field of new/mod capabilities</td>
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<tr>
<td>• Minutes to hours</td>
<td>• Days to weeks</td>
<td>• Months</td>
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CuSat meets most of the ORS Near term objectives

Responsive Range and Launch
- Minimize Call-up to Launch
- Increase Automation
- Assess Commonality and Standardization
- Improve Specific Range Operations
- Structural Loads Analysis Risk Reduction

Responsive Buses and Payloads
- Modular Payload Architecture and standards
- Modular RF and EO Payload Technology Development
- Rapid Assembly, Test and Integration Concepts for rapid call up to launch

Multi mission modular spacecraft
- Common core of optical payload and bus elements
- Rapidly replaceable/modifiable elements
- Base on non-proprietary industry standards
Examples of CuSat ORS Utility Features

Demonstrates ORS Tier 3 objective

- ATP to flight in 3 years. Virtually all of subsystem assembly and system integration was demonstrated on prototype hardware 2 years after ATP.

Demonstrates ORS Tier 2 Assembly, Integration, and Test

- Integration of the complete system starting from discrete configuration end-items takes 2 weeks.
- The integration of assembled subsystems into a complete system, ready for environmental test, requires less than 48 hours

Enhanced Automation

- Operators make key decisions, e.g. providing a go-ahead for spacecraft-to-spacecraft separation and permitting the first entry into normal mode. Decisions about charging and ground contact can be left to the flight computer.
- Operator tasks can be simplified to the point where a warfighter need only click on an icon representing an image to be downloaded from the flight computer.
Examples of CuSat ORS Utility Features

Carrier phased Differential GPS as an enabler technology

- First demonstration of CDGPS for simultaneous attitude and relative navigation for satellites and closed-loop formation flight and inspection of another spacecraft.
- 6 DOF CDGPS works in any LEO orbit and in any attitude, making it readily implemented on any satellite with 6DOF relative-navigation requirements.

Other Enabling s/c Technologies

- Modular electronic design
- SOA pulsed plasma thrusters
- 6DOF relnav sensors exploit the attitude- and orbit-independent performance of CDGPS for continuous, gyroless attitude and position knowledge.
- Self contained miniature reaction wheels developed by Intellitech Microsystems Inc. via DARPA.

Space Situational Awareness to the warfighter with a direct means to observe a cooperative target spacecraft.

- CuSat’s imagery of the target satellite is stored on board until the ground requests a download. The user in the field makes the ultimate decision about the data of interest to him.
Examples of CuSat ORS Utility Features

Responsive CONOPS
- Combination of COTS flight hardware and ground-station equipment provides the capability to set up ground stations within weeks and to run operations from anywhere with an appropriate internet connection.

CUSat inoperable until needed
- Launched with zero state of charge in its batteries. Wake up after sufficient exposure to the sun but to begin operations only after positive confirmation of separation.

Launch-Vehicle Independent Design
- No volatile materials in its construction, no pressurized containers, no umbilicals. Uses standard TT&C subsystems and ground segment h/w.

Low Cost
- The combined cost of the space, ground, and operations segments is less than $1M.
- Off the shelf components are used where possible, e.g. the CDGPS susbsystem components, the Adimec 2000 cameras, and the lightband separation system.
- The low cost, size and mass of the system allows the end user the luxury of deploying several CuSats for a mission, thereby accepting the potential of a single unit failure without compromising the overall mission success.
Summary

- **CuSats ORS enabling technologies** will demonstrate the key features of interest in the GSAW focus for 2008.
- CDGPS and simple ground system architectures can produce an inexpensive but high pay off concept that compliments “Big Space” systems.
- Flight demonstration on a Falcon 1 SpaceX mission this June will be a major step forward for smallsat/nanosat future.