An Overview of the Recent Progress of UCF’s CubeSat Program

AMSAT Space Symposium

Jacob Belli
Brad Sease

Dr. Eric T. Bradley
Dr. Yunjun Xu
Dr. Kuo-Chi Lin
Outline

• Past Projects
  – Senior Design (most recent)
    • IonicKnight
    • [Knight]$^3$
  – University NanoSatellite Program
    • KnightSat II

• Current Project
  – Dust Detector Mission
IonicKNIGHT CubeSAT

University of Central Florida
Mission Objective

Scientific Mission

• Understanding the formation and evolution characteristics and changes with latitude, longitude, and altitude of IONOSPHERIC BUBBLES.

Scientific Significance

• IONOSPHERIC BUBBLES are pockets of air with low electron density that rise to between 150 and 800 Km above sea level, an area of high electron density, usually after sunset, and close to the equator. The bubbles adversely affect radio, GPS, and RF satellite communications in general.
Orbital Parameters

Orbital Elements
- Apogee Altitude = 630 km
- Period = 95.96 minutes
- Eccentricity = 0.009362
- Perigee Altitude = 500 km
- Inclination = 10 degrees
- Semimajor Axis = 6943 km
- RAAN = 0 degrees

Degradation
- Lifetime = 16.3 years
- Lifetime = 90926 orbits
Structural Design

- Structural Design
  - 30x10x10 cm cube
  - 1.05 kg frame
  - AL6061

<table>
<thead>
<tr>
<th>Part</th>
<th>Quantity</th>
<th>Weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slotted Panel</td>
<td>1</td>
<td>464.58</td>
</tr>
<tr>
<td>Thick Panel</td>
<td>1</td>
<td>497.99</td>
</tr>
<tr>
<td>Side Profile</td>
<td>2</td>
<td>9.46</td>
</tr>
<tr>
<td>Top Panel</td>
<td>2</td>
<td>80.76</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>1052.80</strong></td>
</tr>
</tbody>
</table>
Interior Design

- **Blade Design**
  - Use PCB Boards to decrease wiring and volume used
  - Can be used with an array of missions
  - Easily Installed/Replaced
  - Main board has 19 slot positions
  - Each slot has 2 rows of 30 pins
  - All pin positions are connected in parallel
  - Allows for independent card positioning
Electrical Design

- **CPU/IMU Board**
  - IMU and CPU share same slot board
  - IMU outputs logic at 3.3V
  - CPU handles logic at 1.8V
  - CPU outputs PWM signals for Torque Rods on separate board

- **Torque Rod Control Board**
  - Torque Rods controlled using on chip H-Bridge amplifier
  - Special care taken designing the PCB layout
    - Trace length
    - Thermal panes
    - Component distances and spacing
Helmholtz Coil Design

• Each coil capable of independent control using an H-Bridge circuit controlled by an Arduino through Matlab

• The Helmholtz Coil is capable of creating a 10 Gauss magnetic field in X, Y, & Z directions independently
  – X Coils: 0.48m diameter, 121 turns
  – Y Coils: 0.51m diameter, 129 turns
  – Z Coils: 0.54m diameter, 137 turns
Mission: Langmuir Probe

• Mission
  – Gather important atmospheric data from 650 km, Sun-Synchronous orbit
  – Effects of specific solar activity on the Earth’s climate

• Langmuir Probe: Used to determine the electron temperature, electron density, and electric potential of plasma in the Ionosphere.

• The ionosphere (85-600 km) influences radio propagation and GPS signals, and is responsible for auroras.
**Structure - Prototype**

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass [grams]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torque coils (3)</td>
<td>66</td>
</tr>
<tr>
<td>Battery</td>
<td>31</td>
</tr>
<tr>
<td>Circuits</td>
<td>95</td>
</tr>
<tr>
<td>CPU</td>
<td>87</td>
</tr>
<tr>
<td>IMU</td>
<td>47</td>
</tr>
<tr>
<td>Chassis</td>
<td>208</td>
</tr>
<tr>
<td>Payload probe</td>
<td>77</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>611</strong></td>
</tr>
</tbody>
</table>
Structure - Hardware

- Hardware was fastened to the faces of the CubeSat
Power Subsystem

Solar panel size of slightly less than 10cm will provide about 12.876 W

<table>
<thead>
<tr>
<th>Solar input max (W)</th>
<th>Expected</th>
<th>Tested</th>
<th>Deviation %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery output (W avg)</td>
<td>5.6</td>
<td>5.3</td>
<td>-4.2</td>
</tr>
<tr>
<td>Bus output (V)</td>
<td>4.4</td>
<td>4.2</td>
<td>-4.8</td>
</tr>
<tr>
<td>Voltage Reg (V)</td>
<td>5.0</td>
<td>4.9</td>
<td>-2.0</td>
</tr>
<tr>
<td>Solenoid input (V)</td>
<td>2.5</td>
<td>2.3</td>
<td>-8.7</td>
</tr>
<tr>
<td>Charging time (Min)</td>
<td>63.0</td>
<td>56.0</td>
<td>12.5</td>
</tr>
</tbody>
</table>

Table showing expected vs tested values and deviation percentage.
ADCS - Overview

- Satellite attitude controlled by three torque coils
- Gravity gradient boom used to aid in pointing
- VectorNav IMU capable of 200 Hz update rate
The Development of a Propellantless Navigation and Attitude Control Drag Sail for LEO Satellites
University Nanosatellite Program

• Satellite design and fabrication competition for universities sponsored by Air Force Research Laboratory (AFRL) through AFoSR.
• UCF is one of the 11 universities selected to participate in the competition.
• Other universities include MIT, Georgia Tech., Cornell, University of Minnesota, etc.
• About 10 students participated from the beginning to the end, and roughly 15 more students participated at various stages of the project. They come from
  – Aerospace Engineering, Mechanical Engineering, Electrical Engineering, Computer Engineering, Computer Science, Civil Engineering
• Several subsystems have been the subjects of the senior design projects.
Mission Requirements

- Design and build a deployable gossamer sail with magnetic coils for the propellantless navigation and attitude control system of a LEO nanosatellite.
- Demonstrate and validate the sail system for propellantless orbital maneuvering, and attitude control

<table>
<thead>
<tr>
<th>Requirement (SR)</th>
<th>Description</th>
<th>Mission Requirement (MR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR-1-1</td>
<td>KnightSat II must deploy gossamer sail by way of C&amp;DH after stabilization</td>
<td>MR-1-1</td>
</tr>
<tr>
<td>SR-1-2</td>
<td>ADCS must control ACADS and provide attitude control capabilities of +/- 10°</td>
<td>MR-1-2</td>
</tr>
<tr>
<td>SR-1-3</td>
<td>Satellite must survive a minimum of 12 months and provide health monitoring information</td>
<td>MR-1-1</td>
</tr>
</tbody>
</table>
Attitude Control & Aerodynamic Drag Sail (ACADS)

- Maintains the ability to reverse current direction through the ACAD’s torque coil to provide attitude control
- Has a large enough cross section to be easily monitored with a NORAD TLE
- Simulation shows the ACADS de-orbits the satellite from 580km in under 6 months
Attitude Determination and Control System

- Active magnetic control provides initial stabilization for deployment of ACADS
- ADCS will turn over partial attitude control to ACADS
- Overall pointing accuracy is +/- 10 degrees
Structure
Low Cost Dust Detector for Low Earth Orbit
Payload

- **Dust Detector**
  - 10x10x0.1cm
  - 1 W current power estimate

- **Purpose**: Determining the quantity of particles present in LEO (Low Earth Orbit)
- **Mission time**: 1 year
- **Very thin**, will be attached to outside of satellite
- **Specific properties of Dust Detector** still in testing phase
- **Thermal cycling issues**
Orbit

• Circular, Sun-Synchronous Orbit
  – Inclination = 98.4°
  – Altitude = 750 km
  – Period = 99 min

• Benefits:
  – Continual solar exposure
  – Minimizes battery use
  – Eliminates thermal cycling

• Orbital degradation after 4 months leading to orbital eclipses of 20 minutes max

• Occasional lunar eclipses
Subsystem Estimates

Maximum Power Budget (W)

- ADCS, 4.5
- Comm., 1.5
- CPU, 1.14
- Dust Detector, 1
- Thermal, 1
- Stored Excess, 4.54
- Charging Circuit, 0.92

Total Power Available = 14.6 W
Peak Power Consumed = 10.06 W

Mass Budget (g)

- Structure, 910
- ADCS, 865
- Li-Ion Batteries, 512
- Solar Panels, 675
- Charging Circuit, 83
- CPU, 70
- Dust Detector, 100
- Communications, 170

Total Mass = 3.315 kg
## Satellite Run Modes

<table>
<thead>
<tr>
<th>Dead-Launch Mode</th>
<th>Pointing Mode</th>
<th>Data Collection Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>All systems separated from batteries</em></td>
<td><em>Establish payload pointing and solar panel pointing</em></td>
<td><em>Maintain payload and solar panel pointing</em></td>
</tr>
<tr>
<td></td>
<td><em>Non-critical subsystems disabled</em></td>
<td><em>Collect science and telemetry data</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>CPU in low-power mode for minor data handling</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Transmit to ground in 30 second intervals</em></td>
</tr>
<tr>
<td><strong>Active Systems:</strong> None</td>
<td><strong>Active Systems:</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>CPU: 1.14 W</em></td>
<td><em>CPU: 0.13 W</em></td>
</tr>
<tr>
<td></td>
<td><em>ADCS: 4.5 W</em></td>
<td><em>ADCS: 1.5 W</em></td>
</tr>
<tr>
<td></td>
<td><em>Charging Circuit: 0.9 W</em></td>
<td><em>Charging Circuit: 0.9 W</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Comm.: 0.25 W</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Thermal: 1 W</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Payload: 1 W</em></td>
</tr>
<tr>
<td><strong>Peak Power ~ 0 W</strong></td>
<td><strong>Peak Power ~ 6.54 W</strong></td>
<td><strong>Peak Power ~ 10.06 W</strong></td>
</tr>
<tr>
<td><strong>Average Power ~ 0 W</strong></td>
<td><strong>Average Power ~ 6.54 W</strong></td>
<td><strong>Average Power ~ 4.78 W</strong></td>
</tr>
</tbody>
</table>
Communications

• ISIS UHF Transmitter: 400-450 MHz, 1200 bps
• ISIS Deployable Antenna: Dipole, 30 cm total length
• Transmit every 30 seconds to ensure that a downlink occurs within communication access window
• Transmit telemetry data along with archive of recent detections
Thermal

• Current estimates place the temperature range from 43 to -65 °C (full sun to full eclipse)
• Typical thermal range for internal components is -20 to +60 °C
• For the periods of full sun exposure, the passive thermal properties of the craft are sufficient.
• For the eclipse periods, internal heaters will be needed to stabilize temperature and prevent thermal cycling
Development Plans

• Purely theoretical research has been done up to this point
  – Most of the chosen hardware components are awaiting funding
• More in depth modeling and analysis is planned in the near future
Acknowledgments

- [Knight]$^3$
  - Yash Joshi
  - Luis Ayalde
  - Matthew Kieselbach
  - Jorge Pastrana

- IonicKnight
  - Alfredo Arnal
  - Henry Cabrera
  - Jesse Carreiro
  - Matt Cole
  - Kyle Houser

- KnightSat II
  - Michael Pfisterer
  - Kevin Schillo
  - Christopher Valle
  - Et Al

- Also, thanks to FSGC, AFRL, and SRI for continued support