Designing, Building, and Testing Engineering Development Unit (EDU) 6U CubeSats (2013)
3 Course Sequence Provides the Students an Immersive Hands on Experience

ASYS 531
Space Mission Analysis & Systems Design

Mission Analysis
Risk Management
Concept of Operations
Cost Analysis
Requirements Development
Preliminary Design

ASYS 631
Spacecraft Systems Engineering

ASYS 632
Satellite Design & Test

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Students Design, Build, and Test EDU CubeSat Hardware & Software

AVR-32 based bus electronics: C&DH, PIB, EPS, & ADCS

Ground station (MATLAB-based)

Bus software (FreeRTOS & C)

6U aluminum chassis

6U Solar Panel

BLACKBOX to connect to a PC

Bus Electronics Before Integration

2013 6U CHASSIS

MATLAB-based Ground Station

C&DH

EPS

PIB

ADCS

2013 6U CHASSIS

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Functional Block Diagram Shows All Components and Interconnects

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CAD Models Bring to Light Integration Issues

- 6U Form Factor w/ 3 Solar Panels
- Meets all Planetary Systems Corp. (PSC) Containerized Satellite Deployer (CSD) Specs

Complete 6U w/out side panels

Complete 6U w/out top showing six 1U stacks

Six 1U stacks w/out chassis

Payload Stacks

EPS Stack

Star Tracker

ADCS Stack

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Finite Element Analyses are Used to Predict the CubeSat’s First Natural Frequency

Finite Element (FE) Model of Chassis with six 1U stacks

Relationship Between Total Mass, Internal Crossbracing, and First Natural Frequency
Chassis Designed to Protect and Support All Internal Components

The AFIT of Today is the Air Force of Tomorrow.

Chassis is a joint AFIT/Pumpkin design and was created at the AFIT Machine Shop

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Building Ground Station Software in MATLAB makes it Easy to Create & Modify

- Commands are sent and telemetry is received via WiFi in the classroom
- MATLAB interface is easy to generate and modify
- Bus software is written in C and runs in the FreeRTOS operating system
Students Design, Build & Test Solar Panels to Generate 20 Watts per Panel on Orbit

*The AFIT of Today is the Air Force of Tomorrow.*

**STEPS:** Solder interconnects on each cell, add bypass diodes to each cell, outgas adhesives, attach coverglass, bakeout, solder strings of cells together, glue strings to panel, solder strings to board.

Designed for two 10 cell strings producing 25 V per string. Predicted power ~10 W on orbit per string.

**Test Results**

<table>
<thead>
<tr>
<th>Environment</th>
<th>Predicted solar flux W/m²</th>
<th>Area m²</th>
<th>Predicted avg efficiency</th>
<th>Power generated W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground test sunny summer day</td>
<td>1000</td>
<td>0.029</td>
<td>25%</td>
<td>7.31 (measured)</td>
</tr>
<tr>
<td>Space</td>
<td>1367</td>
<td>0.029</td>
<td>25%</td>
<td>9.99</td>
</tr>
</tbody>
</table>

**String 1**

Peak Power: 7.31 W
Earth Sensor Detects the Earth/Space Transition to Determine Satellite Attitude

- 1 sensor along spacecraft axis and 4 sensors pointing to the limb – see pictures below
- A 10° angle provides sensors see both Earth and space when array is nadir-pointing at mission altitude

Predicted Earth Sensor View

Earth Sensor
Torque Coils are added for Detumbling and Momentum Dumping

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- 3-axis magnetic torquer system
- Fits on inside walls of chassis
- Built plastic prototype support structures for coils
- 400-turn, insulated 30 AWG copper wire
- Applied regulated switched +/-12 V

Control Software
- B-dot bang-bang controller works to detumble CubeSat
- Algorithm for momentum dumping is in work to desaturate the reaction wheel array

3 Prototype Torque Coils in 6U Chassis
Attitude Determination and Control Subsystem determines & controls pointing

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- Four-wheel pyramid assembly provides smooth and precise pointing control
- Quaternion-based Proportional-Integral-Derivative (PID) controller is capable of 3-axis control
- Hardware
  - Nominal (max) torque:
    - X-axis: 15.02 (31.00) mN-m
    - Y-axis: 21.24 (43.84) mN-m
    - Z-axis: 15.02 (31.00) mN-m
  - 1U Stack Mass: 1.23 kg

1U ADCS Stack

ADCS Card
Motor Controller Card
Reaction wheel array (RWA)
Integration is Relatively Easy when Building CubeSat in Stacks

Single Bus Card → Connect Cards → Test Entire Bus → Build Inv. Stacks → Integrate Stacks into Chassis

Connect Inv. Stacks & Prep for Integration
Thermal Vacuum (TVac) Test is Conducted to Determine Performance in Space

The AFIT of Today is the Air Force of Tomorrow.

• Planned test profile
  • Vacuum (1E-5 Torr)
  • Decrease temp to -20 °C
  • Increase temp to 40 °C
  • Return to ambient environment
  • Perform functional tests at each temp step

• Temperature instrumentation
  • All on-board temperature sensors functioning
  • 3 external thermocouples per CubeSat

Two 6U EDU CubeSats Undergoing TVac Tests

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