Gateway to Space

Space Grant & Hands-on Opportunities

Lee Jasper, Ph.D
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Then: ~2006

Now: ~2014
• As far as a topic, something about things you've worked on at Boulder would be great.
• Perhaps on overview of the projects you've worked on, with specifics on the technical things you work on.
• The goal would be to let them see where participating in space grant can lead, as well as the types of skills they need to develop to get there.
Past Projects: Space Grant

RocketSat: sounding rocket

White Sands and Wallops

Hermes CubeSat: March 2010

DANDE: UN5 Winner 2009
What are your goals professionally?

Space Grant and other hands-on labs can make a huge difference in the opportunities you get and how rewarding college is...
RocketSat 2006 - 2007

- First Project (sophomore)
- Designed, tested & built tiered structure
  - Defined structure requirements
  - Trade study of designs
  - Trade study of materials
- Testing
  - Hammer test
RocketSat

- First Flight
- Second Flight
- Third Flight
- Crashed...badly
  - “Atmospheric anomaly”
- Crashed...less badly
  - Video showed poor parachute deployment
- Great flight
- I put something in space!
RocketSat Today

- **RocketSat 11**
  - Boulder team
- **RocketSat X**
  - Exposure to high-altitude environment
- **RocketSat C**
  - Higher altitude
Hermes CubeSat

Testing the viability of High Speed Communications for future educational picosatellites

A member in NASA’s first ELaNa Program

2007 - 2008
Hermes Overview

**HERMES — NAMED AFTER GREEK MESSENGER GOD**

**Primary Mission Goal**
- *Provide knowledge* and experience to undergraduate students
- *Create* a generic bus for future use

**Secondary Mission Goal**
- *Demonstrate* the use of S-Band communication or higher data throughput
- *Gather* environmental data
System Overview

1 Unit (1U):
Size: 10cm x 10cm x 10cm Cube
Mass: 1 kg

First CubeSat Project:
COSGC’s first orbiting mission

Hermes Communications:
• COSGC Ground Station
  • PCOM: 437.425MHz
• S-Band Ground Station:
  • HSCOM: 2.4GHz

Subsystems not shown:
Ground Software, Mission Operations, Ground Station
Hermes Overview

1 Unit (1U):
Size: 10cm x 10cm x 10cm Cube
Mass: 1 kg

First CubeSat Project:
COSGC’s first orbiting mission

Educational Launch of Nanosatellite (ELaNa)

Subsystems not shown:
Ground Software, Mission Operations, Ground Station

Explorer-1 PRIME [E1P]
• Montana State University

Hermes
• University of Colorado

KySat1
• Kentucky Space
NASA’s ELaNa Program

Educational Launch of Nanosatellite
“Launching Education Into Space”

Explorer-1 PRIME [E1P]
• Montana State University

Hermes
• University of Colorado

KySat1
• Kentucky Space
Hermes Timeline – 2010-2011

System Testing
- Long Range Communications
- Day In The Life

Environmental Testing
- Random Vibration
- Shock
- Thermal Vacuum Bakeout

Delivery
- Integration to P-POD
- Acceptance Environments
- Diagnostics

Ground Segment
- S-Band testing
- Mission Operations
- Training
- Simulations

LAUNCH!!!
Launch with NASA’s Glory Mission

**DETAILS:**

**The Primary:**
NASA’s Glory Mission

**The Secondary:**
First ELaNa Mission
(University of Colorado, Montana State University, Kentucky Space)

**The Rocket:**
Orbital Sciences Taurus XL

**The date:**
March 3\textsuperscript{rd}, 2011*

*Unfortunately, Glory & the ELaNa CubeSat’s did not make it to orbit due to a Taurus XL vehicle failure.
What I learned with Hermes

Project Management
• Team of > 15 people
• Budget of over $10 k
• Schedule

System Engineering
• Requirements
• Consequences of decisions
• Design process

Satellite Design
• Design for environment(s)
• Best practices
• ‘Generic’ bus is very hard to do!
Drag and Atmospheric Neutral Density Explorer (DANDE)

Colorado Space Grant Consortium and CU Aerospace Engineering Sciences
2008 - 2010
DANDE Mission

Mission Statement
Explore the spatial and temporal variability of the neutral thermosphere at altitudes of 350 - 200 km, and investigate how wind and density variability translate to drag forces on satellites.
Operational Importance of Drag

The density of the atmosphere in this region varies greatly (300% to 800%*) due to space weather and not yet understood coupled processes.

- European Space Agency Debris Tracking
Operational Importance of Drag

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The University Nanosat Program

• University Nanosat – The National Championships of Spacecraft Design
  – 2 year program now in its seventh iteration
  – 10 out of 30 university proposals selected based on Air Force Relevance
  – $85k initial seed funding for hardware and student support
  – On January 20th 2009, CU wins the Nanosat 5 competition. Winning an additional $85k, I&T at Kirtland, and flight to Orbit

• CU Nanosat Entry
  – Has involved a core team of graduate students and expanded to over 100 graduate and undergraduate students
  – Has leveraged over $240k from University, Department, DoD, and COSGC Funds
  – Graduate and Undergraduates from AES, ECE, ME, CS
DANDE Mission & Operational Importance
• Identifying all components of the constituents of the drag equation.
• With a near-spherical shape, an a-priori physical drag coefficient may be calculated and a physical density can be obtained from the measurements.
Dual Instrument Approach to Drag Measurement
Accelerometer Subsystem
As the spacecraft rotates, it modulates the drag signal to a known frequency. The unique accelerometer subsystem takes advantage of this by filtering the noise from unwanted frequencies and processing the data onboard from all accelerometers. This provides the sub-μg precision required for drag measurements.

Wind and Temperature Spectrometer
This instrument was invented by Dr. Fred Herrero at NASA Goddard and implemented for the DANDE platform by students at CU with NASA support. It is capable of measuring the wind direction and magnitude, atmospheric temperature, as well as the O:N$_2$ ratio.
DANDE System
Inside of DANDE

- horizon crossing indicator (x2)
- battery box (x2)
- ball & tube nutation dampener (x2)
- mass trim system (x8)
- Accelerometers (x6)
- 3-axis magnetometer
- Brass ballast: higher inertia (x24)
- Subsystem box (x3)
- wind sensor
- Stiffeners (x4)
- separation mechanisms (x2)
- EGSE connector
- kinematic mounts (x4)
- lightband adapter bracket
Evolution of DANDE
Integration Planning – Wiring Harness
Testing DANDE
DANDE Attitude

- Spin stabilization about orbit normal
  - 40°/sec (10 rpm)
  - Only two maneuvers: spin-up and axis alignment
- Sensors
  - Magnetometer for spin-up
  - Horizon Crossing Indicators for spin axis alignment
- Actuators
  - 2x Torque rods: one along spin axis and one transverse
  - Passive nutation damper
Nutation Damper

- As a rigid body spins it will wobble (nutation)
  - This is not desirable for science mission

- Damper design
  - Simply a ball-in-tube
  - Friction removes energy

Kinematics
\[ \Delta x' = r \Delta \theta \]

or
\[ dx' = rd\theta \]

with respect to time
\[ \frac{dx'}{dt} = r \frac{d\theta}{dt} + \frac{dr}{dt} \theta \]

but \( r = \text{cons} \tan t \)
\[ \frac{dx'}{dt} = r \frac{d\theta}{dt} = r\omega \]

Dynamics
\[ \tau = r \times F_f = I\alpha \]
\[ \tau = r * F_f = I\alpha \]
\[ F_f = \frac{I\alpha}{r} \]
\[ F_f = \left( \frac{1}{r} \right) \left( \frac{2}{5} mr^2 \right) \left( \frac{\ddot{x'}}{r} \right) \]
\[ F_f = \left( \frac{2}{5} m \right) \dddot{x'} \]
DANDE Testing

Vibration

Zero-g

Thermal Vacuum

Mass Properties – Spin
Separation System: Testing & Qualification

- Starsys, now SNC, partnership
- First flight will be with the DANDE mission
  - Requires a full testing suite before launch
    - Microgravity flight
    - Proto-qual Vibe Testing
    - Thermal Vacuum (Hot & Cold Separations)
    - Countless Releases outside of specialized testing
Communications System

Spacecraft

CDH

SYMEK TNC31S

MODEM 38,400 TX 9,600 RX

SYMEX TX

LOW POWER RF

SPLITTER (tbd)

S'GART POWER AMP

HIGH POWER RF

2m PATCH ANTENNA

70cm PATCH ANTENNA

Ground Station

PC

SYMEK TNC3

MODEM 38,400 RX 9,600 TX

SYMEX TX

LOW POWER RF

SYMEX ICD MOD

YAESU FT847

70cm YAGI

HIGH POWER RF

2m YAGI

RS-232
Spacecraft RX Antenna

- Ground plane is the spacecraft primary structure & hemispheres
- RX antenna: \( \frac{1}{4} \) wave patch antenna
- Gain: -25dBi
- Mostly omni-directional and ground testing show the link closes. Worst RF performance shown.
Spacecraft TX Antenna

- Whip antenna uses the natural curve of Hemisphere to gain almost ideal monopole return loss -30dB.
- Tx Whip gain of -8dBi.
- Deep, narrow nulls, but operationally we will not operate in this region.
LAUNCH!

The most exciting and nerve-racking experience
Launch: September 29, 2013

- Hermes went into a ‘hydro-stationary orbit’
- DANDE is a seven year old project
  - Over 150 students
  - ~$400,000
- SpaceX Falcon 9 v.1.1 Test Launch
  Vehicle
  - Merlin 1E engines
  - Relight 1st stage for soft touch-down
  - Relight 2nd stage for GEO demo
  - Faring changes
- AND
  - SpaceX only using as test launch. No payload is a priority
- AND
  - Air Force gives launch 50-50 chance
Launch: September 29, 2013

- Rocket worked like a champ!
- Vandenberg AFB
- 9:00 am PDT
- Orbit 325 km x 1500 km, $i = 80^\circ$

- https://www.youtube.com/watch?v=RtDbDMRG3q8
Flight Operations
Acquisition

- 325 km x 1500 km orbit
- Inclination = 80°

- DANDE Beacons
  - First heard over Russia

- Hard to communicate
  - Slants and # of objects
  - Bad cable in ground station
  - Tumbling spacecraft

- Operated out of Boulder!

Yagi – on DLC roof
Since Launch

- Acquisition and Tracking-9/29/13
- Satellite Health Checkout
- Separation of the Lightband Adapter Bracket-10/30/13
- Spinning the satellite to 10 RPM
- Fault and Anomaly Handling-1/9/14
Separation

Visual confirmation from Optical Station Maui
Solar Storm

- Timing of solar storm with DANDE’s activity
- Pink line is illumination time
- Blue line is solar protons absorbed per day
- Data points display when we received data from DANDE
Opportunities due to Space Grant

- Ph.D.
  - Space Debris Removal
  - Good reputation in department
- Advised on ALLSTAR and PolarCube
- Internships
  - ATK: proposal writing, requirements, explosives!
  - Jet Propulsion Laboratory: Mars Rover
  - Air Force Research Laboratory: spacecraft formation flying
  - Laboratory for Atmospheric and Space Physics: CICERO project during Ph.D.
LASP’s CICERO 2012 - 2013

- 650 ± 50 km, sun-synchronous orbit
  - 1:30 a.m. descending node
- Nadir pointer, w/ sun pointing capability
- Single string, w/ selective redundancy
- X-band downlink, S-band uplink
- Unique EEE parts plan

**Spacecraft Overview**

<table>
<thead>
<tr>
<th>Category</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (CBE)</td>
<td>104 kg</td>
</tr>
<tr>
<td>Dimensions (Wingspan)</td>
<td>28 x 24 x 36 inches (120 inches)</td>
</tr>
<tr>
<td>Power (CBE)</td>
<td>81 W, 28 V</td>
</tr>
<tr>
<td>Data Volume</td>
<td>35 MB/orbit</td>
</tr>
<tr>
<td>Pointing</td>
<td>1°, 0.1° knowledge</td>
</tr>
</tbody>
</table>

- Fancy way of saying: “spacecraft”
- NISAR: NASA, ISRO Synthetic Aperture Radar
  - Land/Sea Ice (climate indicators)
  - Biomass (deforestation, climate, agriculture)
  - Earth Deformation (Earth quakes, aquifers)
- Not to mention...
  - Recruiting
  - Research proposals
  - Earth Ventures (NASA call) proposal team
  - Grad course creation with CU

Saturn's moon Dione transit May 21 2015 about 1.4million miles away
## NISAR – Mission Challenge

<table>
<thead>
<tr>
<th>Mission</th>
<th>Data Produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voyager 1 &amp; 2</td>
<td>1.64 Tb (1977 – now)</td>
</tr>
</tbody>
</table>
Skills You Need And/Or Will Develop

• Aerospace
  – Dynamics
  – Structural statics and dynamics

• Mechanical
  – Structural statics and dynamics
  – CAD including how to make a machinable part: GDT
  – Machine shop

• Software
  – Embedded programming
  – System design/architecture

• Be willing to take acceptable risks
  • Know what jobs may challenge, but not completely overwhelm you
  • Understand what is technically reasonable, state if it is not!

• Systems
  – How to write, track, and verify requirements
  – Test planning and execution
  – Many of the things from the other focuses
Questions?

Winner of University Nanosat V Competition
BACKUP
Research

- PhD at the University of Colorado, Boulder
- Advisor: Dr. Hanspeter Schaub
  - Dr. Schaub studies electrostatic actuation
    - Gossamer structures
    - ‘Tractor Beams’
  - It turns out, modeling anything other that a sphere is a challenge

\[
F = -\nabla V(q_1) \cdot q_2 = k_c \frac{q_1 q_2}{L^2}
\]

\[
V_i = k_c \frac{q_i}{r_i} + \sum_{i \neq j} k_c \frac{q_j}{L_j}
\]

\[
\bar{V} = k_c [C_M]^{-1} \bar{q}
\]

\[
[C_M]^{-1} = \begin{bmatrix}
\frac{1}{R_1} & \frac{1}{L_{1,2}} & \cdots & \frac{1}{L_{1,n}} \\
\frac{1}{L_{2,1}} & \frac{1}{R_2} & \cdots & \vdots \\
\vdots & \vdots & \ddots & \vdots \\
\frac{1}{L_{n,1}} & \cdots & \cdots & \frac{1}{R_n}
\end{bmatrix}
\]
Research

• Primary interest: Space debris & active debris removal
• Coulomb tug @ GEO
• Tether tug @ LEO/GEO

GEO ADR: Coulomb tug

• I have studied the debris environment
• Dynamic system modeling
• Flexible body control
• I have studied some of the political/economic issues too
Research

\[ g(s) = \frac{(s^2 + \omega_{c1}^2)(s^2 + \omega_{c2}^2)}{(s^2 + BW_1s + \omega_{c1}^2)(s^2 + BW_2s + \omega_{c2}^2)} \]
Satellite Drag

Satellite drag measurements suffer from errors caused by:
• Unknown acceleration contribution from in-track winds

\[
a = \frac{A_{sc} \cdot C_D \cdot \rho \cdot \|\vec{V}_w - \vec{V}_{sc}\|^2}{M_{sc}} (-\vec{V}_T)
\]

\[-\vec{V}_T = (\vec{V}_w - \vec{V}_{sc})\]

• Coefficient of drag accuracy

\[C_D = \frac{2d\rho}{M_{gas}V_T}\]

DANDE is designed to address these issues and provide acceleration, composition, and wind measurements simultaneously along with a well determined drag coefficient at ~350 km
ACC Overview

- 6 Honeywell QA-2000 navigational grade accelerometers
  - Rotate about DANDE’s spin axis, spaced by 60°

- 4th order Butterworth band pass filters
  - Pass band of 0.05 to 0.5 Hz
  - Gain of 60 dB pass band gain
  - High pass filter removes DC centripetal acceleration
  - Low pass filter removes intrinsic system high frequency noise
ACC: Primary Design Problem

Problem: The raw accelerometer output is not directly useful because it is masked by noise.

Goal: To isolate and amplify a signal from a significantly (>3 orders of magnitude) larger noise environment.

- **Centripetal Acceleration**
  - Frequency: DC
  - Magnitude: 300 to 500 mV

- **Intrinsic Noise**
  - Frequency: DC to 10 kHz
  - Magnitude: > 50 mV

- **Drag Induced Signal**
  - Frequency: 1/6 Hz
  - Magnitude: 50 µV to 5 mV
Accelerometer Analysis

\[ \omega = \frac{\pi}{3} \text{ [rad/sec]} \]
**ACC Overview**

- 6 Honeywell QA-2000 navigational grade accelerometers
  - Rotate about DANDE’s spin axis, spaced by 60°
- 4th order Butterworth band pass filters
  - Pass band of 0.05 to 0.5 Hz
  - Gain of 60 dB pass band gain
  - Flat pass band region
  - High pass filter removes DC centripetal acceleration
  - Low pass filter removes intrinsic system high frequency noise
  - Dedicated filter for each accelerometer signal
- AD7656 ADC provides digital signals to AVR from filter outputs
  - Six independent analog to digital converters circuits in a single package
  - Simultaneous sampling of each accelerometer
ACC Thermal Calibration

- QA2000 accelerometers provide temperature calibration coefficients
- Must test to determine affect of temperature on Butterworth filters
- Test setup:
  - 1/6 Hz drag signal simulation inserted into Butterworth filter inputs
  - Amplified signal verified on filter outputs to ADC
  - Data taken for 8 minutes
  - Test in 10°C increments from -20°C to 60°C (twice at each temperature)
Wind & Temperature Spectrometer

• Measures Wind, Composition, and Temperature
• Neutral Mass Spectrometer (NMS)
• Preliminary Testing Complete
• Status: Calibration Summer 2008 – Spring 2012
• TRL 3 → TRL 6
• Important addition to observing the atmosphere
  – Applies to future SWARM missions and DSMP
Wind and Temperature Spectrometer Schematic

- COLLIMATOR
- IONIZER
- DEFLECTION ENERGY ANALYZER

- CM
- IS
- MCP Detector

- Reject Ionized Particles
- Ionize Neutrals
- Energy Selection

- Ramp 0-4096mV
- PD
- Anodes

- MICRO-CHANNEL PLATE
- DETECTOR ANODE CHANNELS
Wind & Temperature Spectrometer

Testing Results from September 2011

Even Particle Distribution Across All Anodes

Energy Level of Accelerated Species (3000mV ~ 9-11eV)
Accelerometer Measurement System

- SPACECRAFT IS SPIN STABILIZED AROUND $\vec{N}$
- DIRECTION OF FLIGHT

![Diagram showing accelerometer measurement system](image)

**PSD [g^2/Hz]**

- Low frequency bias
- Spin rate
- 70 ng

**Frequency [Hz]**

- 1x10^-5
- 1x10^-3
- 1x10^0
- 1x10^2

**ANALOG FILTERING**

**A/D CONVERSION**

**LEAST SQUARES**

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**II - Science**
Wind & Temperature Spectrometer

INCOMING NEUTRAL DISTRIBUTION

ION DISTRIBUTION

IONIZER

COLLIMATOR

DEFLECTION ENERGY ANALYZER

INSTRUMENT FOCAL POINT

ELECTRON DISTRIBUTION

channel 1
channel 2
...
channel 7
channel 8
channel 9
channel 10
channel 11
channel 12

MCP

ANODES
Nominal Operations

- 3 axis control
- 1-Degree Pointing
- 0.1° attitude knowledge
- Continuous momentum dumping
- Large data capacity and downlink rates (Mbps)
Sun-Pointing

- Kick-off/safe mode
- Solar cells within 30° of sun
- Large margins on power production
- Large thermal margins

Capable of operation in various orbits!
• Phase changes
  • $\Delta v \approx 10\text{ m/s}$
• Minimizes launch vehicle requirements
• Maintain stability during worst-case disturbance torques

\[ \hat{b}_3 = \pm \hat{i}_0 \]
CICERO: My contributions

- **ADCS Co-Lead**
  - Ran the day-to-day of the ADC subsystem: many systems engineering tasks
  - Requirements
  - Fault Detection & Error Correction
  - Flight software architecture
  - Wrote flight software: hardware interfaces + FD&C
  - Test plan: baseline design of Comprehensive Performance Test and FlatSat