UniCubeSat

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Main UNICubesat Experiment

- Local, not orbit average, in situ thermosphere neutral density measurement using the Broglio drag balance concept
- School of Aerospace Engineering of University of Rome tradition in Aeronomy: San Marco satellites
- GAUSS group experience in university satellites
San Marco 1
December 15, 1964

S. Marco Equatorial Range

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UNISAT microsatellites

Unisat
26 September 2000

Unisat-2
20 December 2002

Unisat-3
29 June 2004

Unisat-4
26 July 2006

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At present GAUSS is developing three educational projects:

**UNISAT-5**    **UNICubeSAT**    and    **EduSAT**

**UNISAT-5 based on the UNISAT BUS**

**UNICubeSAT**

**EduSAT**
The Drag Balance concept

\[ M \]

\[ m \]

\[ F \]

\[ \text{Accelerometer} \]

\[ \text{Drag Balance} \]

\[ x_a = \frac{m}{M + m} \frac{F}{k} \]

\[ x_b = \frac{M}{M + m} \frac{F}{k} \]

\[ \text{Mass factor gain:} \quad \frac{x_b}{x_a} = \frac{M}{m} = 100 \div 1000 \]
San Marco implementation

- Spherical satellite spin stabilized
- Two redundant measurements

\[ F_{BX} = \frac{1}{2} \rho S c_D v^2 \cos(\tau_0 t) \]
\[ F_{BY} = \frac{1}{2} \rho S c_D v^2 \sin(\tau_0 t) \]
UNICubeSAT implementation

The satellite and drag balance aerodynamic forces:
Aerodynamic coefficients are odd functions of the angle of attack.
Drag balance displacement

The drag balance equation of motion is:

\[ \ddot{x} + \omega_n^2 x = \frac{1}{2} \frac{\rho v^2 S}{m_{BAL}(1 - \mu)} \left[ C^{(N)}_{BAL}(r_0 t) - \mu C^{(T)}_{SAT}(r_0 t) \right] \]

\[ \mu = \frac{m_{BAL}}{m_{SAT} + m_{BAL}} << 1 \]

\[ \omega_n^2 = \frac{k}{m_{BAL}(1 - \mu)} - r_0^2 \approx \frac{k}{m_{BAL}} \]

Second order oscillator where the forcing term contains the drag coefficients, which vary periodically at the spin frequency.

The drag balance displacement contains:

- Drag balance natural frequency \( (\omega_n >> r_0) \)
- Spin frequency + odd harmonics \( (r_0, 3r_0, 5r_0 \ldots) \)
Numerical simulation

Displacement

![Displacement graph](graph_image.png)
Frequency content of the displacement

- Spin frequency
- Spin frequency harmonic
- Drag balance frequency

PSD (Normalized)

Frequency content of the displacement

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Filtered signal at spin frequency
Density evaluation from the amplitude of the spin frequency harmonic of the displacement $x_1$:

$$
\rho = \frac{2m_{BAL}(1 - \mu)(\omega_n^2 - r_0^2)}{v^2 S A_1(C_{BAL})} x_1
$$

- $x_1$ = amplitude of the spin frequency harmonic of the drag balance displacement
- $A_1(C_{BAL})$ = amplitude of the spin frequency harmonic of the forcing term
Density evaluation error budget

\[
\frac{d\rho}{\rho} = \frac{dm}{m} + \frac{d\left(\omega_n^2 - r_0^2\right)}{\left(\omega_n^2 - r_0^2\right)} + \frac{dx_1}{x_1} - 2 \frac{dv}{v} - \frac{dS}{S} - \frac{dA_1(C_{BAL})}{A_1(C_{BAL})}
\]

\[\text{0.1\%} + \text{1\%} + \text{1\% + 2(5\%) + 0.5\%} + \text{15\%} = 28\%\]

- Temperature effect on drag balance spring stiffness
- Thermospheric winds
- Drag balance displacement measurement error
- Attitude
- Temperature
- Accommodation coefficients (diffuse vs. specular reflection)
- Gas species (height dependent)
Critical aspects of the experiment

- Scaling down the drag balance implementation from the original 200kg satellite, down to 1kg
- Drag balance release mechanism
- Drag balance and satellite attitude motion coupling: center of mass position and principal axis of inertia orientation (balancing procedure)
- Reconstruction of dynamic pressure from raw data (filtering procedure) and uncertainties in aerodynamic coefficients introduced by the cube shape and monodimensional implementation
- Instrument well suited for altitudes below 350km, adapted for 350-450km range
- Radiation environment near the apogee (1400 km)
- Instrument test and calibration
Displacement sensor

Measurement range ±0.8 mm
Accuracy: 2 μm

Subminiature controller
Sensor calibration

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Displacement measurements

balance sensor measures [mm]

palmer calibre measures [mm]
Sensor measures linear fitting

\[ y = 1.1x - 0.2 \]
Sensor measures polynomial fitting

\[ y = 0.0027x^5 - 0.014x^4 - 0.066x^3 + 0.17x^2 + 1.1x - 0.34 \]

5th degree: norm of residuals = 0.11159
Drag balance ground calibration set-up

Compressed air bearing reduces friction

1/1000 weight

Variable angle Inclined plane
Drag balance ground calibration set-up
UNICubeSAT configuration

UNICubeSAT in stowed configuration

UNICubeSAT electronics packs assembly
UNICubeSAT drag balance and antenna release system

Thermal cutter system already qualified for flight on DNEPR LV
UNICubeSAT OBDH scheme

- Balance displacement sensors
- Flash memory for data storage
- MODEM + HDLC protocol
- UHF transceiver
- Magnetic coils
- μ-processor
- Switches
- A/D
- SPI
- Tone decoder
- Temperature, voltage and current sensors
UNICubeSAT OBDH electronics board

Tested on BEXUS 7 flight
October 2008
Wooden mock up of UNICubeSAT on the balancing test system
- Center of mass position
- Principal axis of inertia

UNICubeSAT magnetometer

UNICubeSAT magnetic coils prototype
Control law: minus $B$ dot

It controls the spin axis orientation and spin angular rate rate using magnetometer readings only.

### Attitude Numerical Simulations

Graph showing the angle between the satellite spin axis and orbit normal over time. The graph plots degrees on the y-axis and time (in minutes) on the x-axis.
Conclusions

• The instrument error budget at launch is about 30%
• Calibration of drag coefficient in orbit (TLE, laser ranging?) could reduce the measurement error after a few time in orbit
• At present in situ air density measurements have been obtained by very expensive geodetic satellites at high altitudes.
• Our main goal remains student education
• UNICubeSAT represents an affordable sensing system despite the CUBESAT bus on board resources constraints
• It could be a testbed for an in situ air density measurements satellite network to achieve simultaneous measurements in different locations