UniCubeSat

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Scuola di Ingegneria Aerospaziale, Università di Roma “La Sapienza”,

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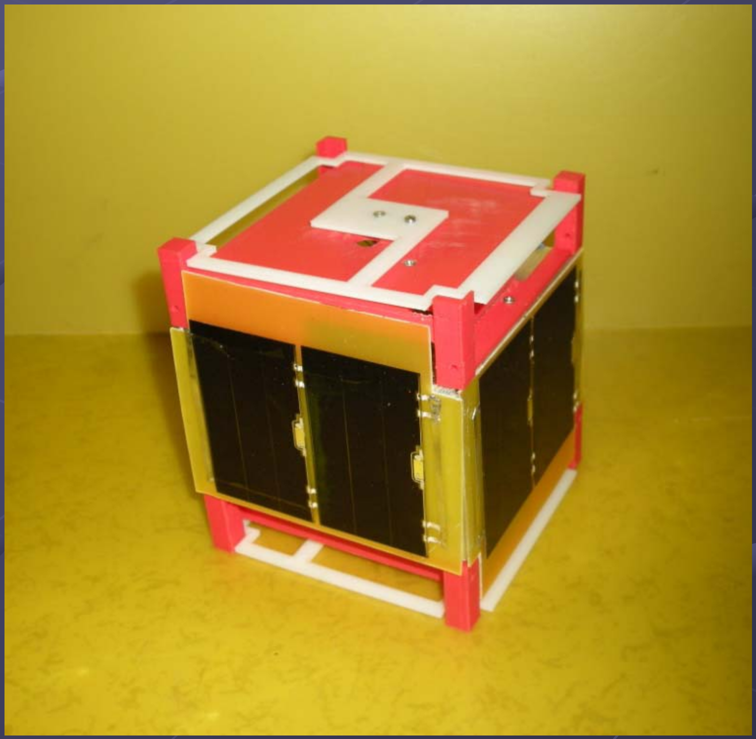
Cal Poly, San Luis Obispo
April 22-25

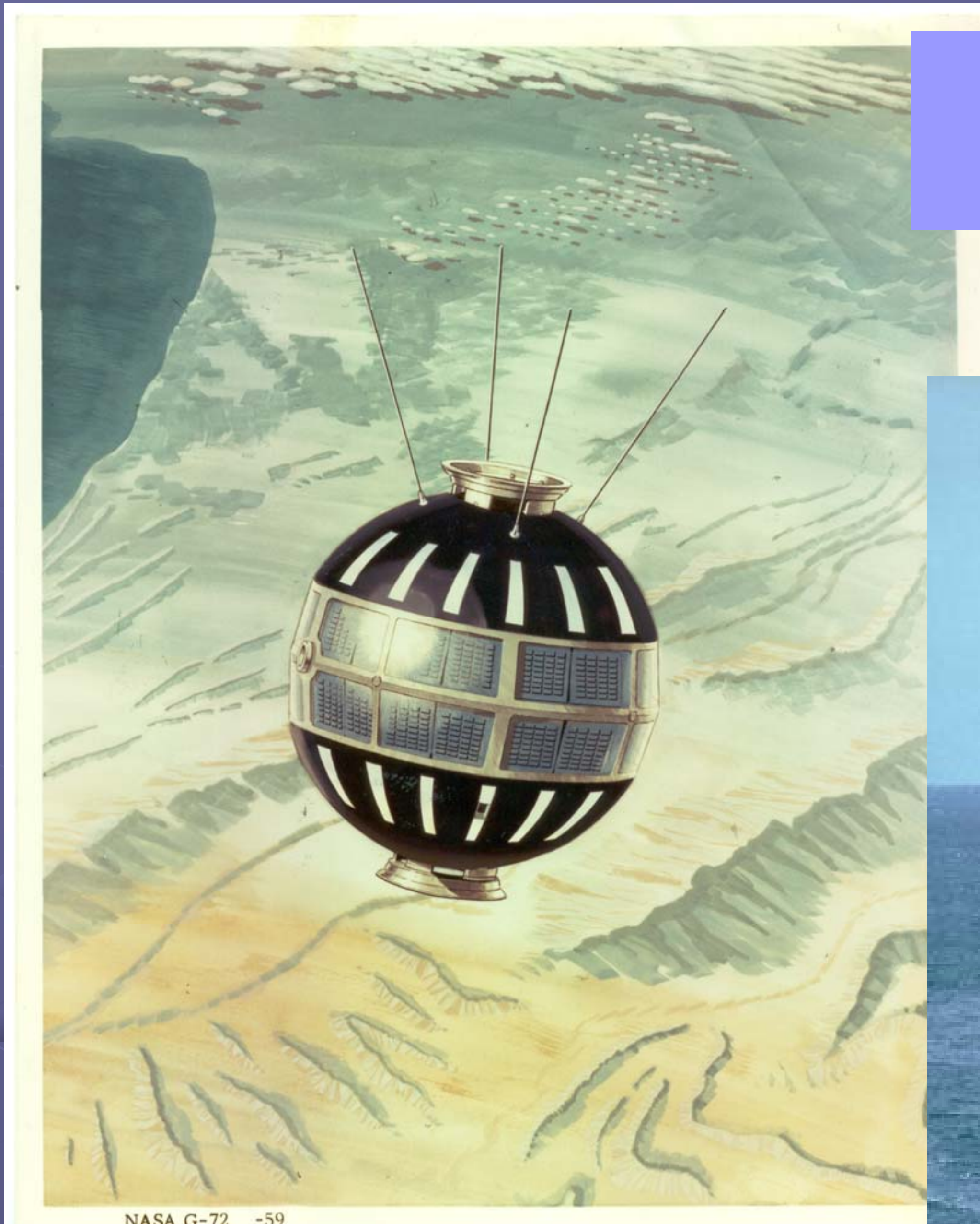
Main UNICubesat Esperiment

- 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



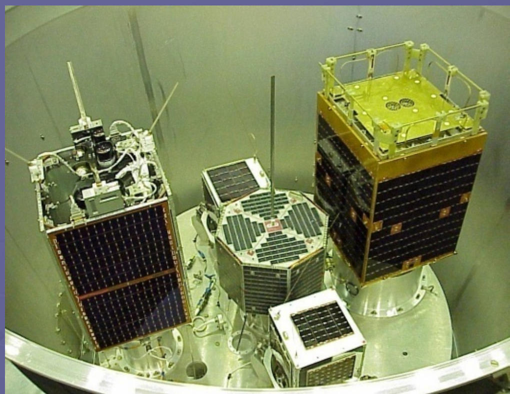
San Marco 1

December 15, 1964



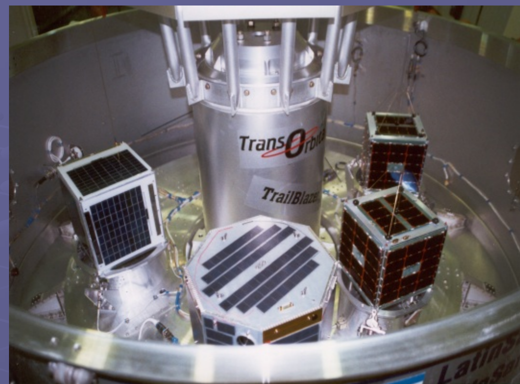
S. Marco Equatorial Range

UNISAT microsatellites



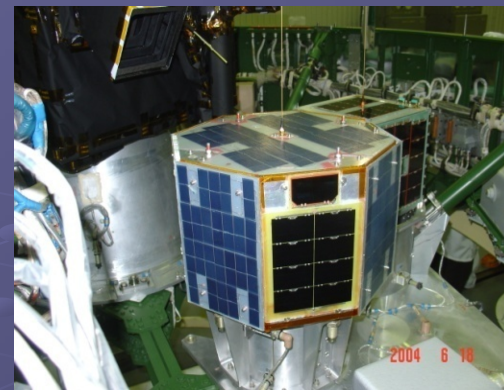
Unisat

26 September 2000



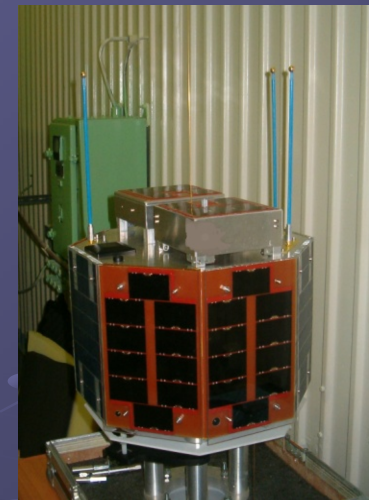
Unisat-2

20 December 2002



Unisat-3

29 June 2004

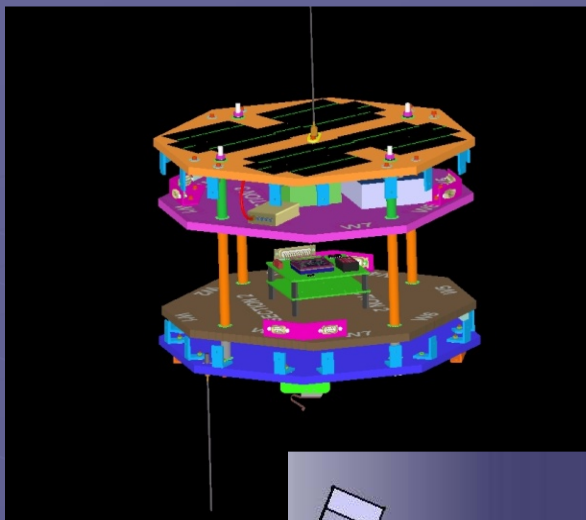


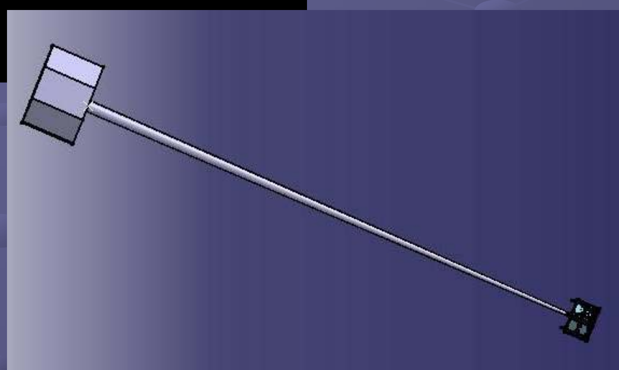
Unisat-4

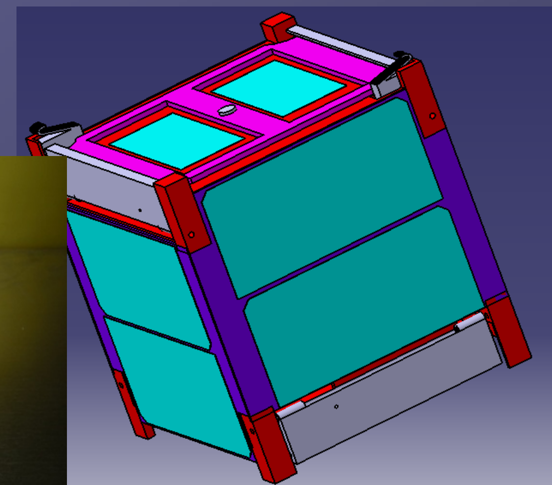
26 July 2006

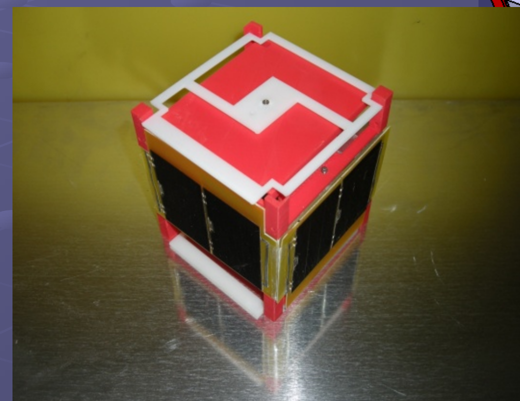
At present GAUSS is developing three educational projects:

UNISAT-5 UNICubeSAT and EduSAT



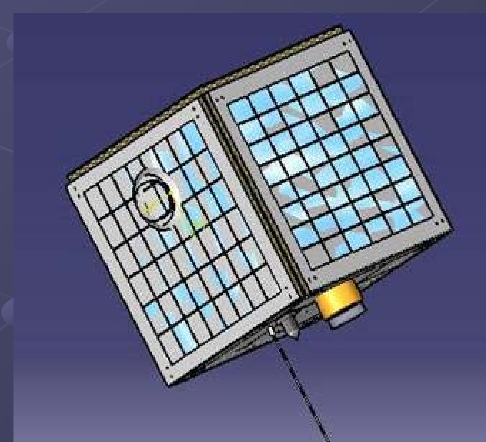






UNICubeSAT

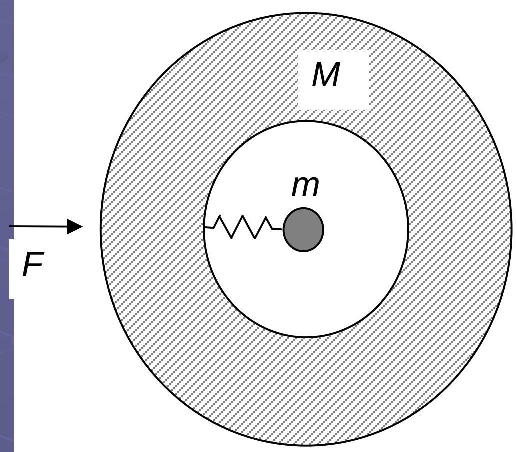
UNISAT-5 based on the UNISAT BUS



EduSAT

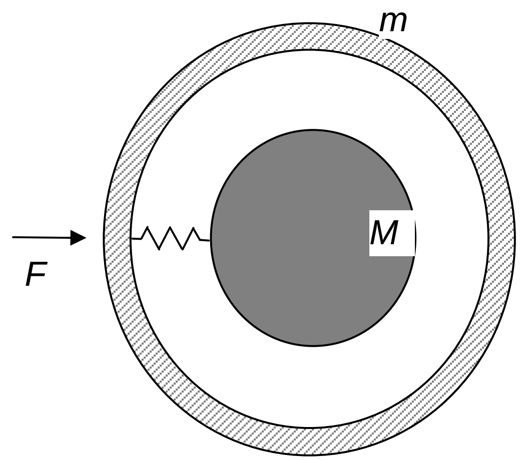
The Drag Balance concept

Accelerometer



$$x_a = \frac{m}{M+m}\frac{F}{k}$$

Drag Balance

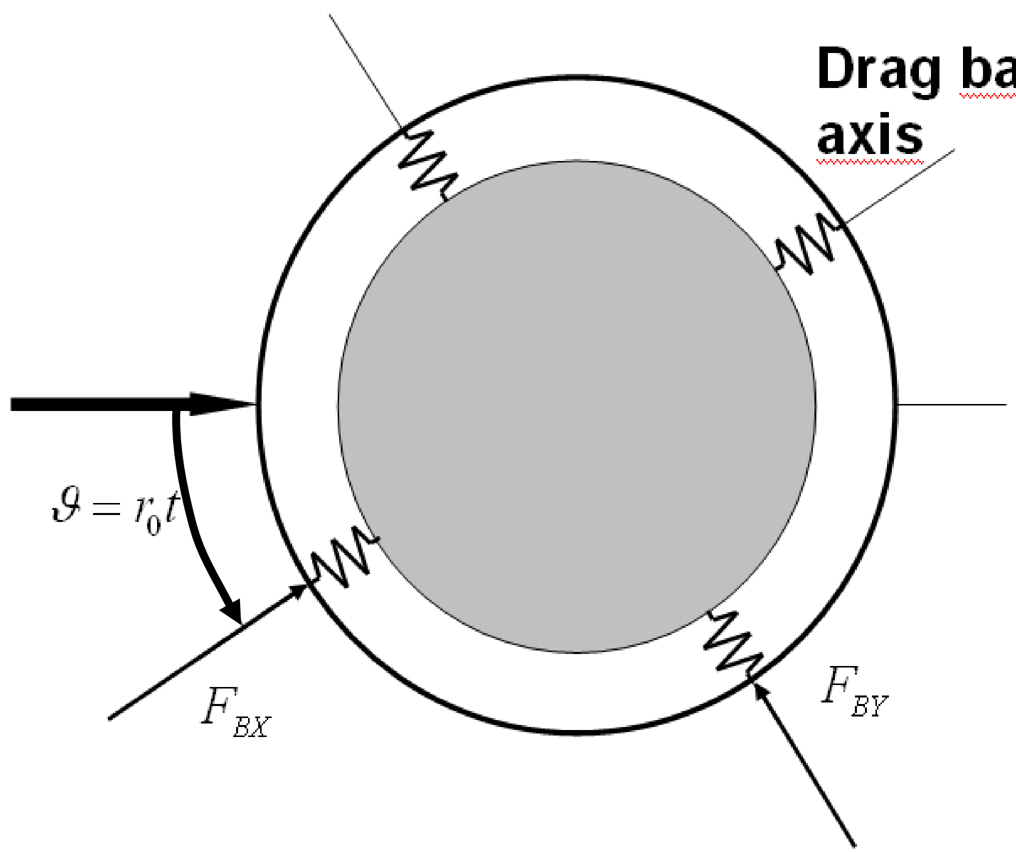


$$x_b = \frac{M}{M+m}\frac{F}{k}$$

Mass factor gain: $\frac{x_b}{x_a} = \frac{M}{m} = 100 \div 1000$

San Marco implementation

- Spherical satellite spin stabilized
- Two redundant measurements

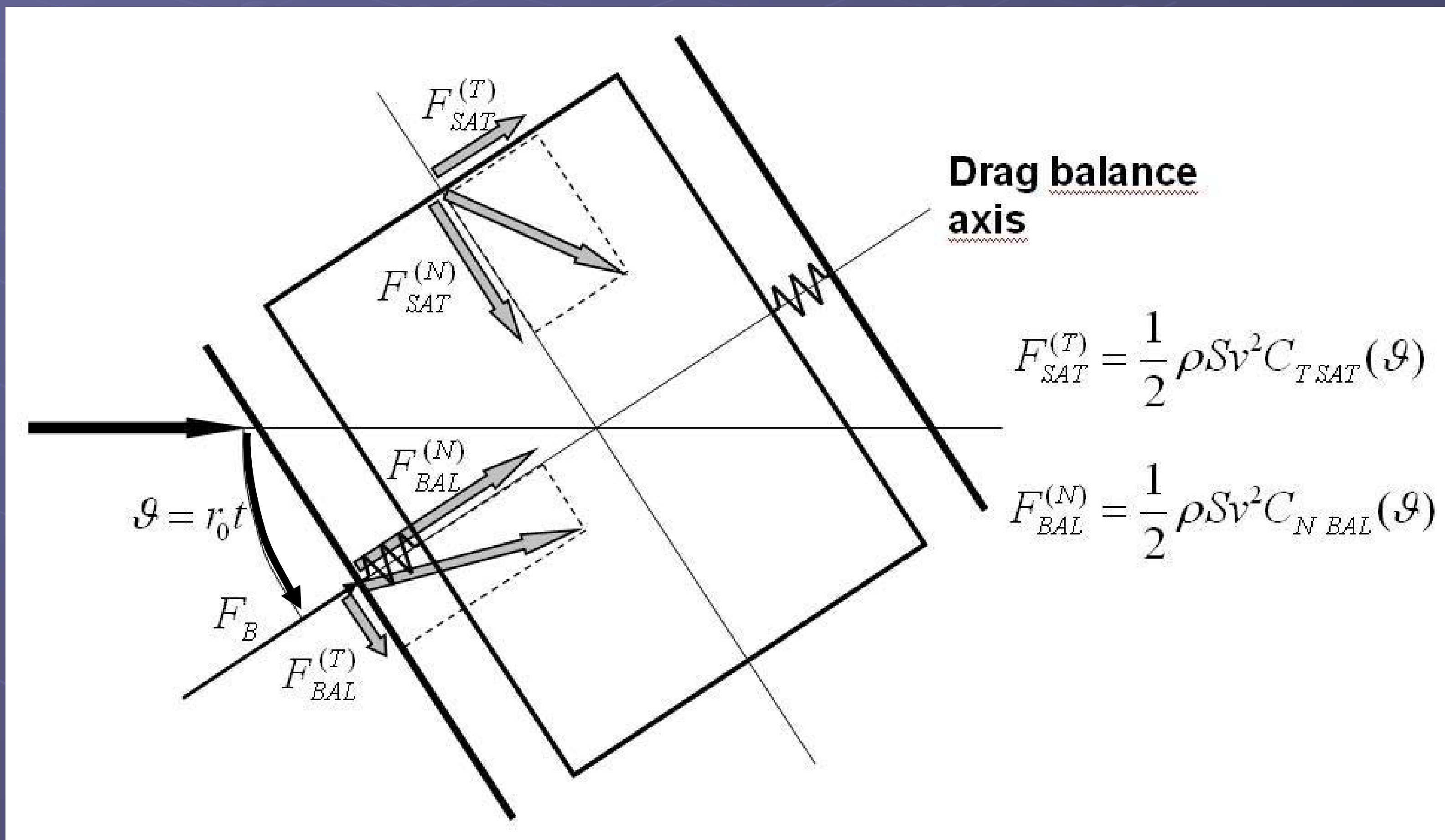


$$F_{BX} = \frac{1}{2}\rho S c_D v^2 \cos(r_0 t)$$

$$F_{BY} = \frac{1}{2}\rho S c_D v^2 \sin(r_0 t)$$

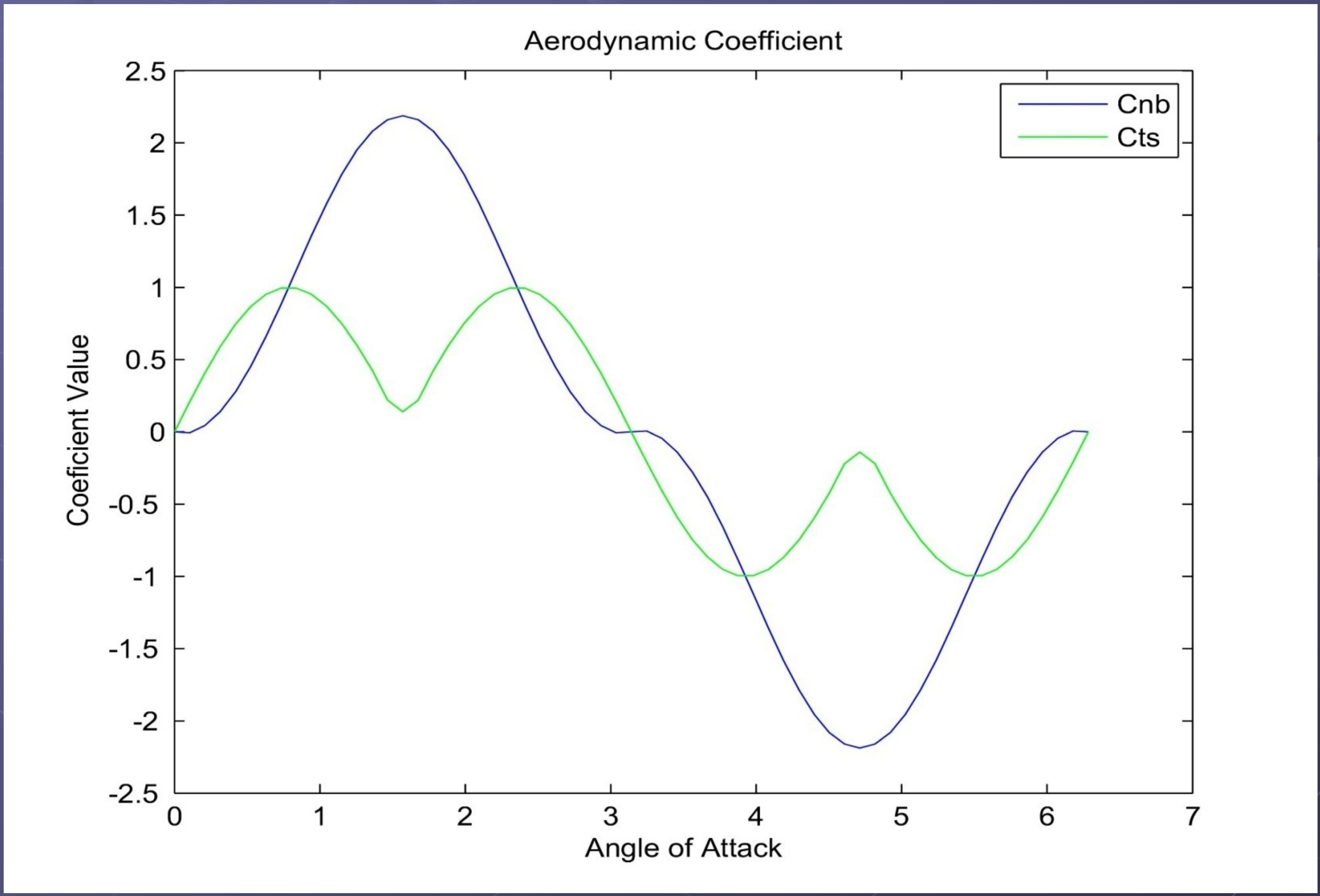
UNICubeSAT implementation

- The satellite and drag balance aerodynamic forces:



Aerodynamic coefficients

- Aerodynamic coefficients are odd functions of the angle of attack



Drag balance displacement

- The drag balance equation of motion is:

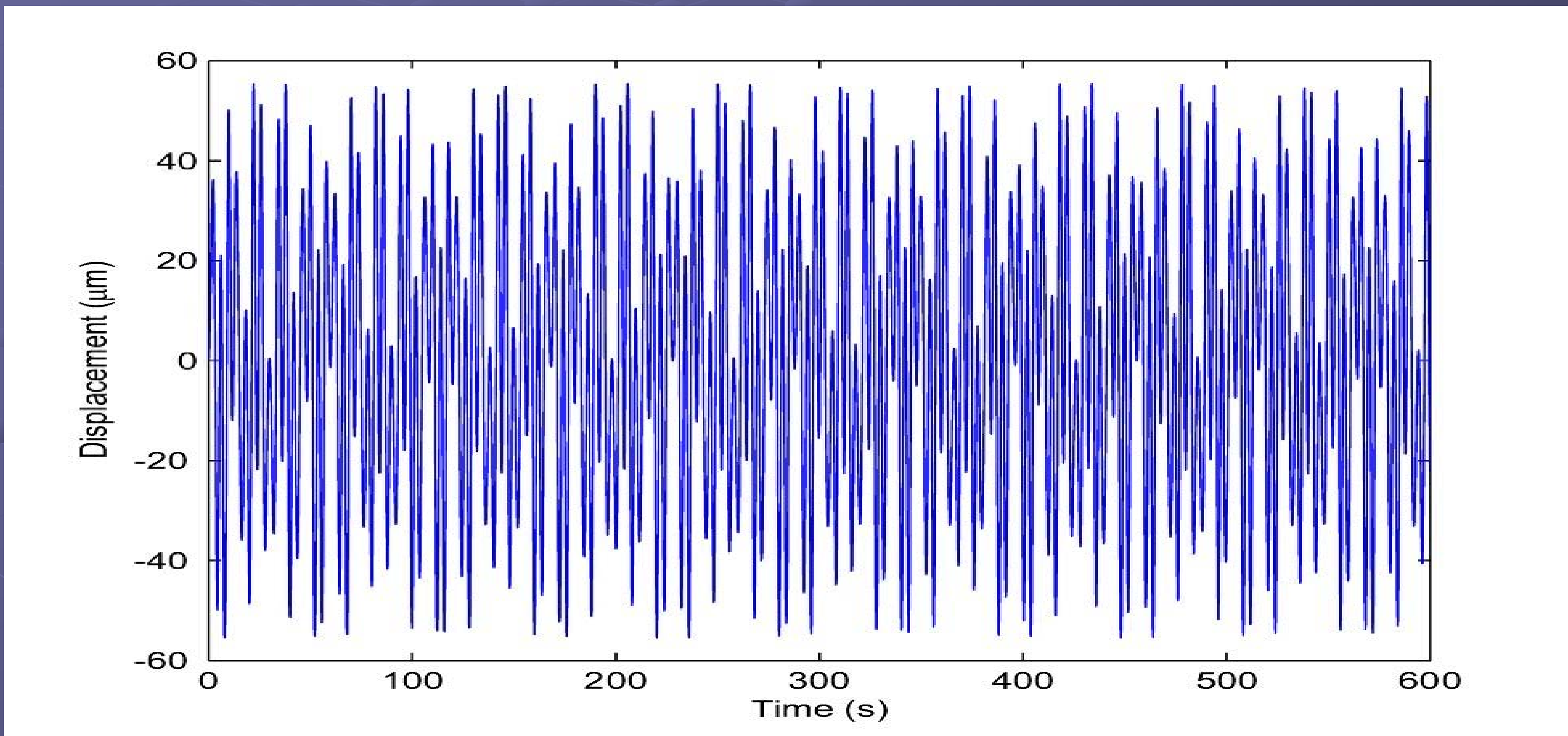
$$\ddot{x} + \omega_n^2 \; x = \frac{1}{2}\frac{\rho v^2 S}{m_{BAL}(1-\mu)}\left[C_{BAL}^{(N)}(r_0 t) - \mu C_{SAT}^{(T)}(r_0 t)\right]$$

$$\mu = \frac{m_{BAL}}{m_{SAT} + m_{BAL}} << 1 \qquad \omega_n^2 = \frac{k}{m_{BAL}(1-\mu)} - r_0^2 \approx \frac{k}{m_{BAL}}$$

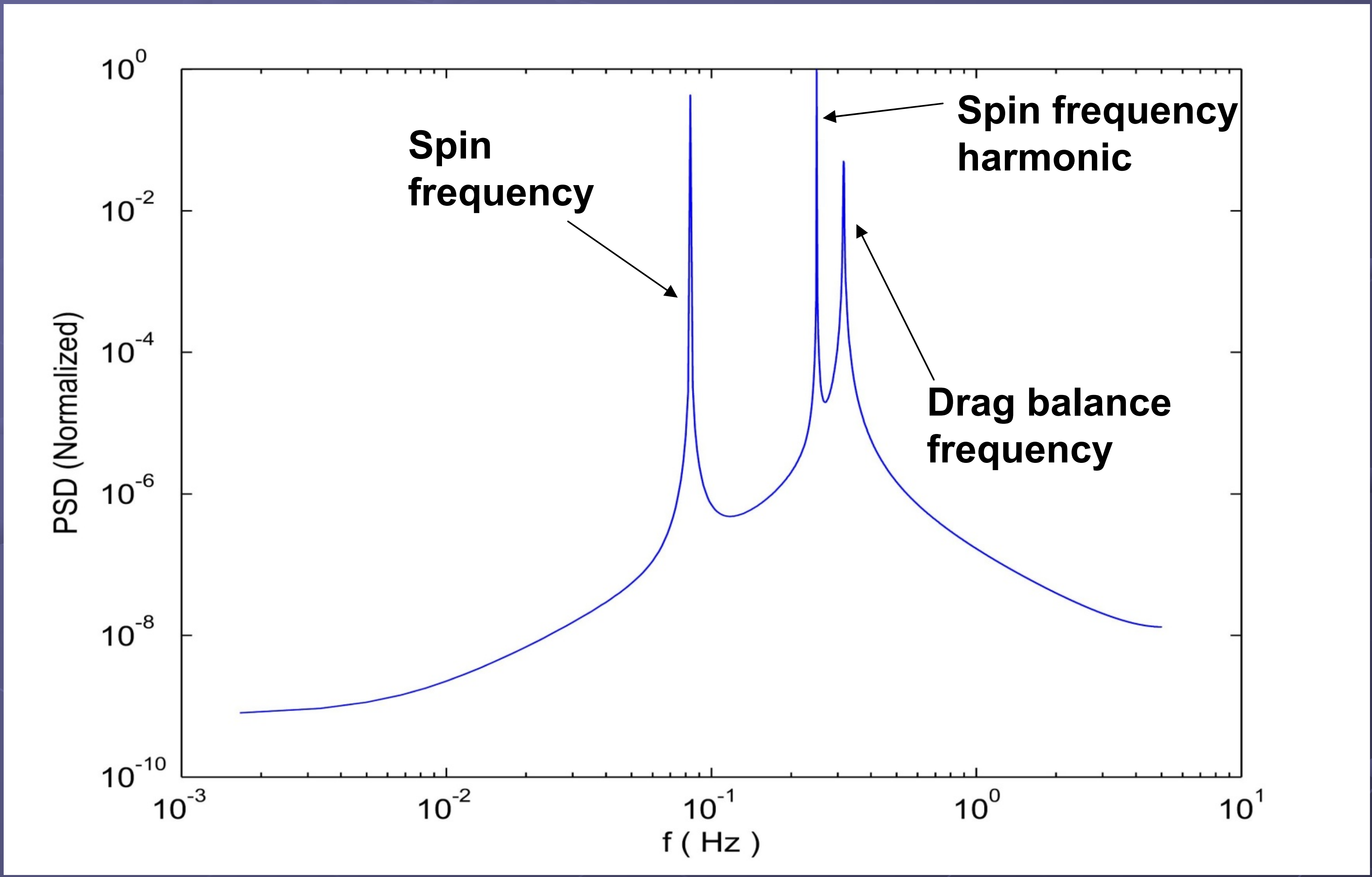
- Second order oscillator where the forcing term contains the drag coefficients, which vary periodically at the spin frequency
- The drag balance displacement contains:
  - Drag balance natural frequency ($\omega_n >> r_0$)
  - Spin frequency + odd harmonics (r_0 , $3r_0$, $5r_0$…)

Numerical simulation

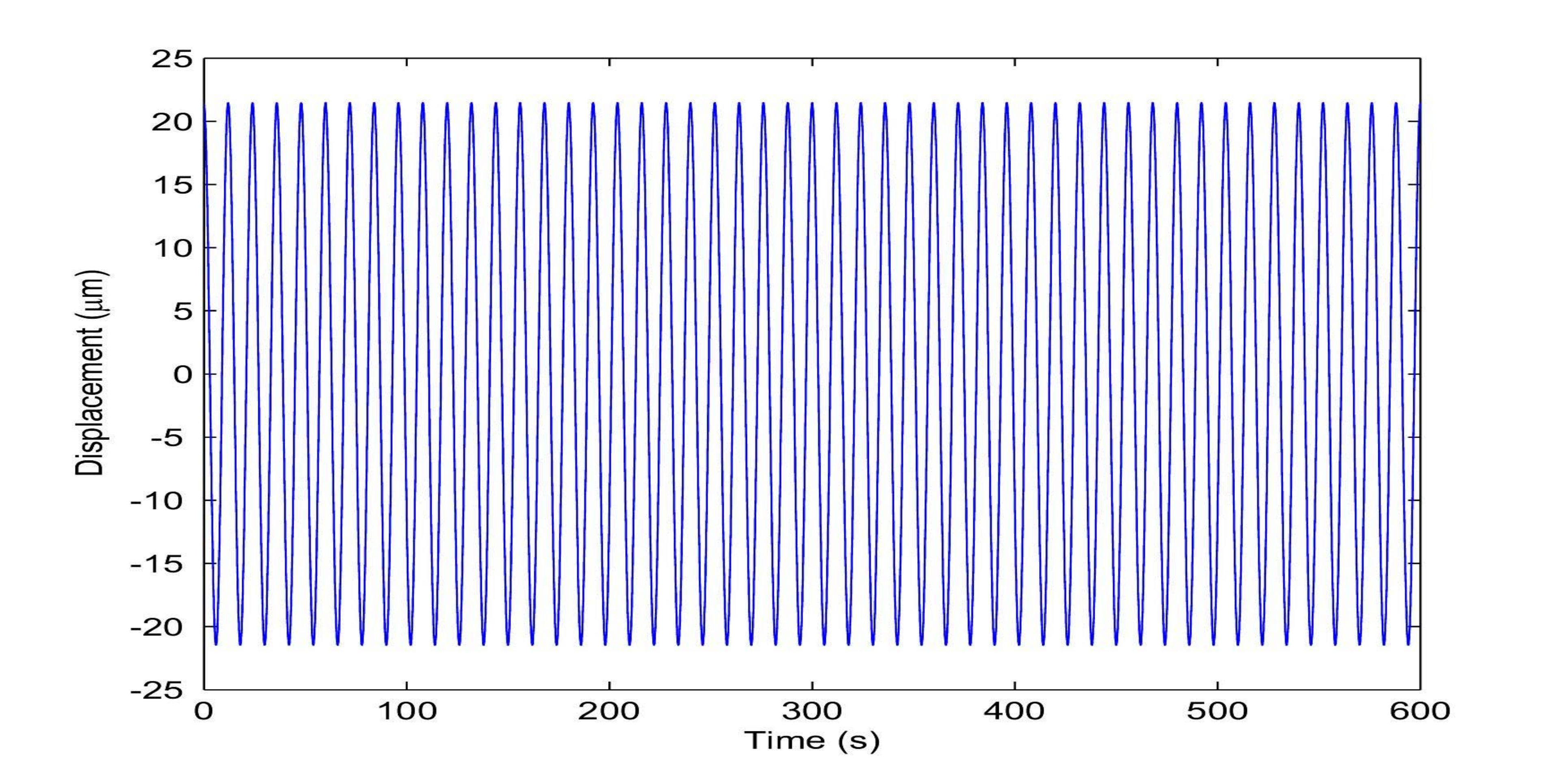
- Displacement



Frequency content of the displacement



Filtered signal at spin frequency



Density evaluation

- Density evaluation from the amplitude of the spin frequency harmonic of the displacement x_1

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

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

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

0.1% + 1% + 1% + 2(5%) +0.5% + 15% = 28%

$$\frac{dA_1(C_{BAL})}{A_1(C_{BAL})}\simeq\frac{dC_{AER}}{C_{AER}}$$

Temperature effect on drag balance spring stifness

Drag balance displacement measurement error

Thermospheric winds

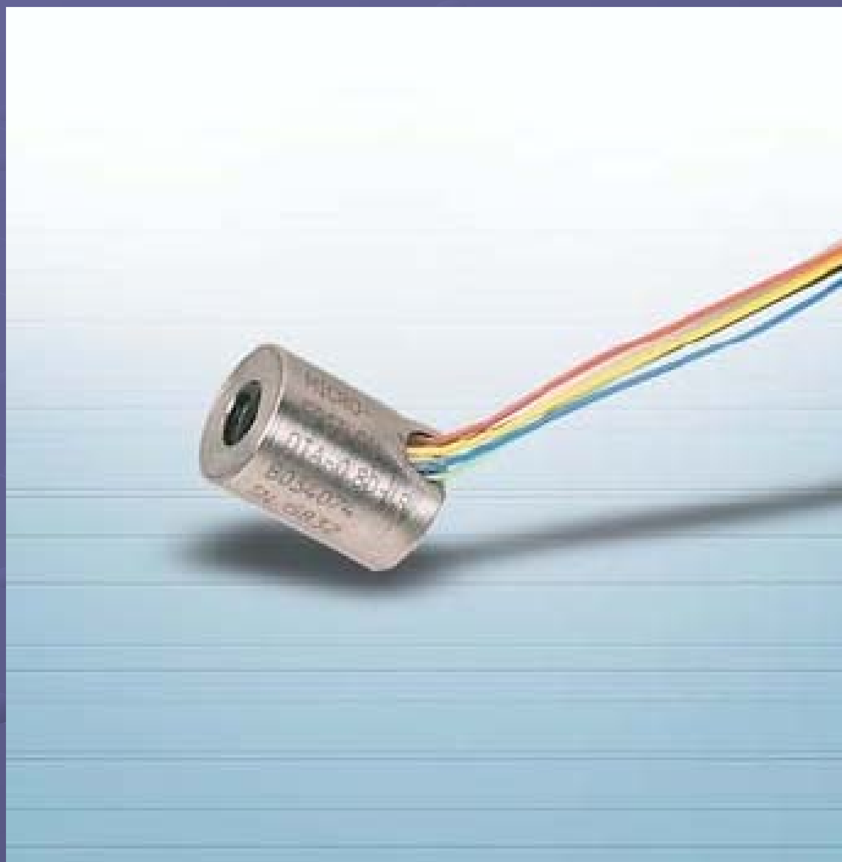
Attitude

- Temperature
- Accommodation coefficients (diffuse vs. specular reflection)
- Gas species (height dependent)

Crirical aspects of the experiment

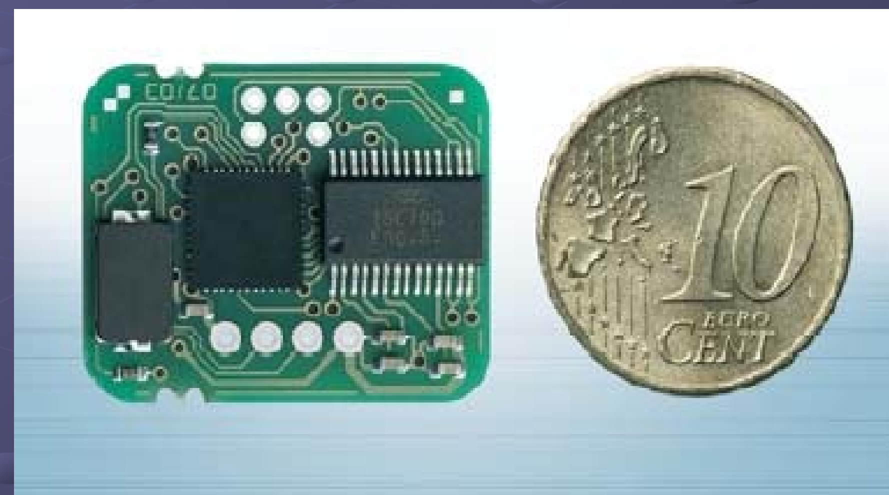
- Scaling down the drag balance implementation from the original 200kg satellite, down to 1kg
- Drag balance release mechanism
- Drag balance and satellite attitude motion coupling: center of mass position and principal axis of inertia orientation (balancing procedure)
- Reconstruction of dynamic pressure from raw data (filtering procedure) and uncertaities in aerodynamic coefficients introduced by the cube shape and monodimensinal 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



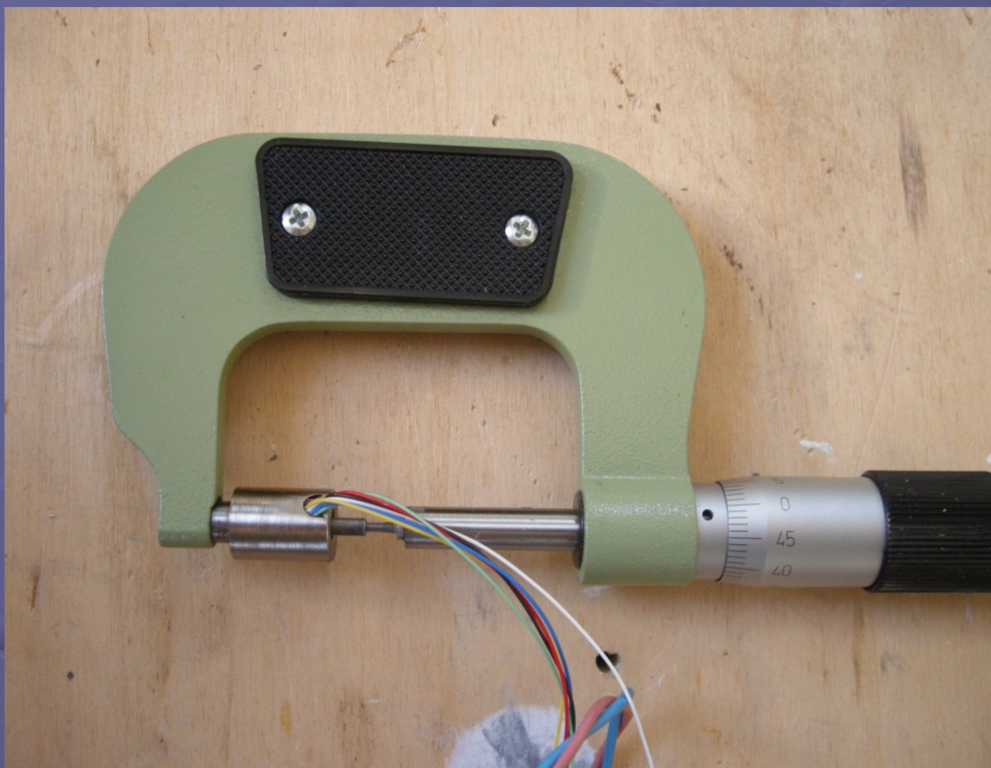
Measurement range ±0.8 mm

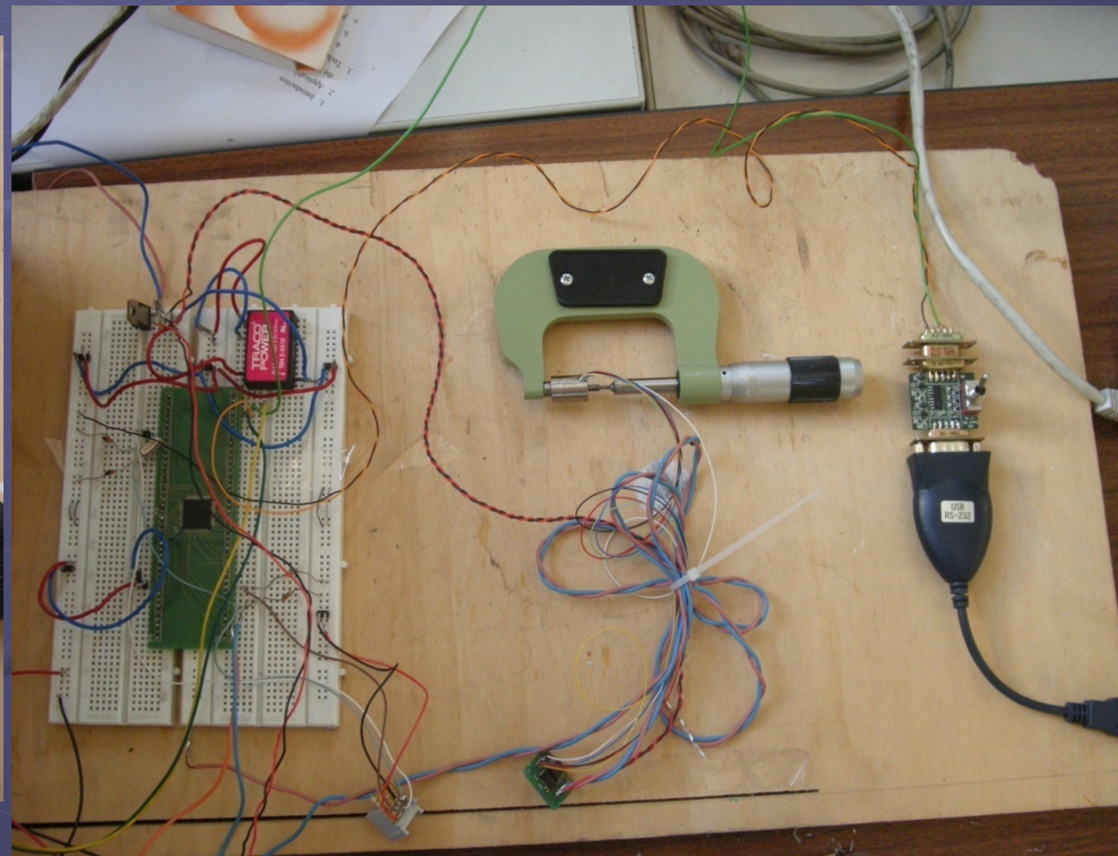
Accuracy: 2 µm



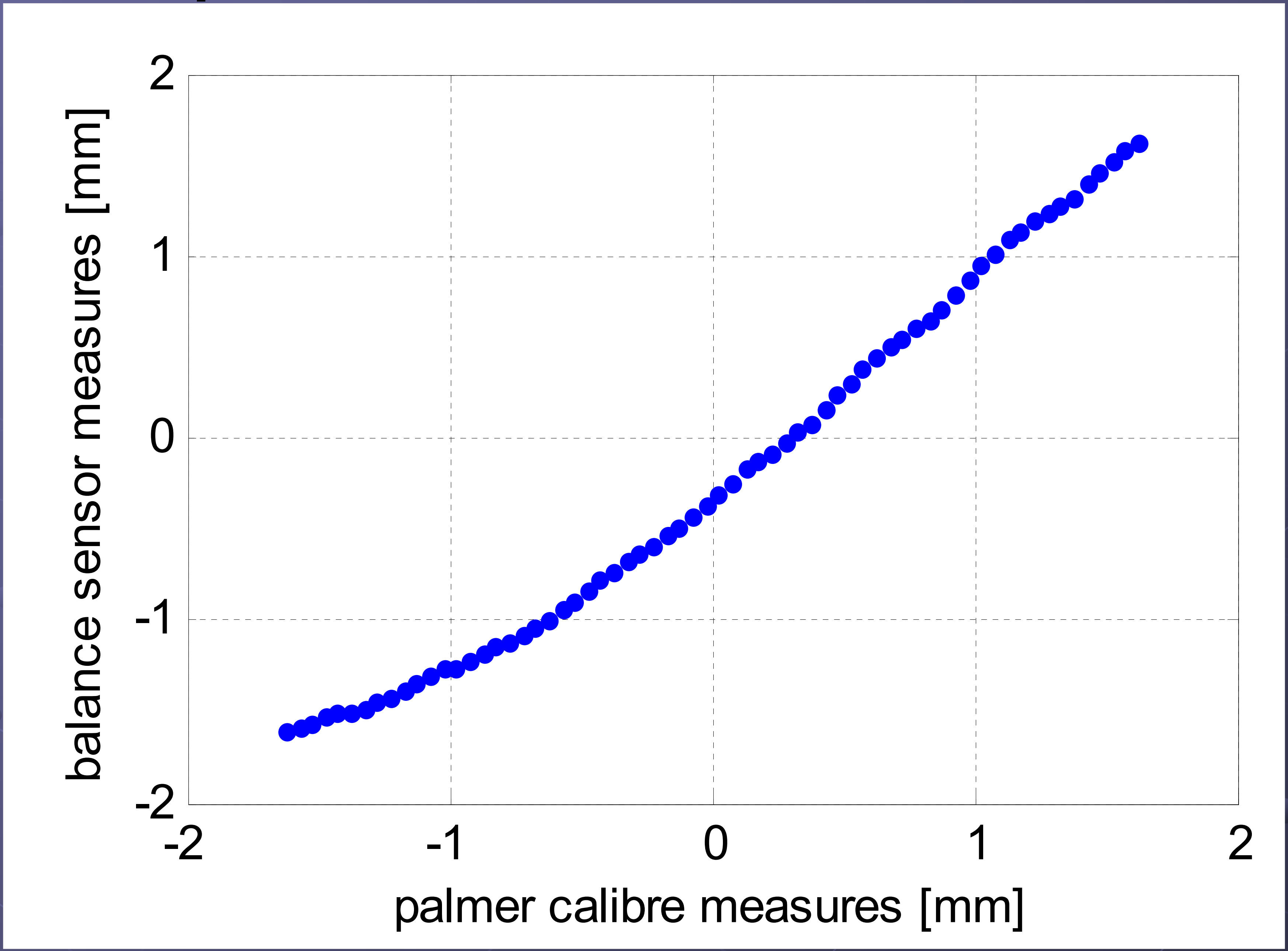
Subminiature controller

Sensor calibration

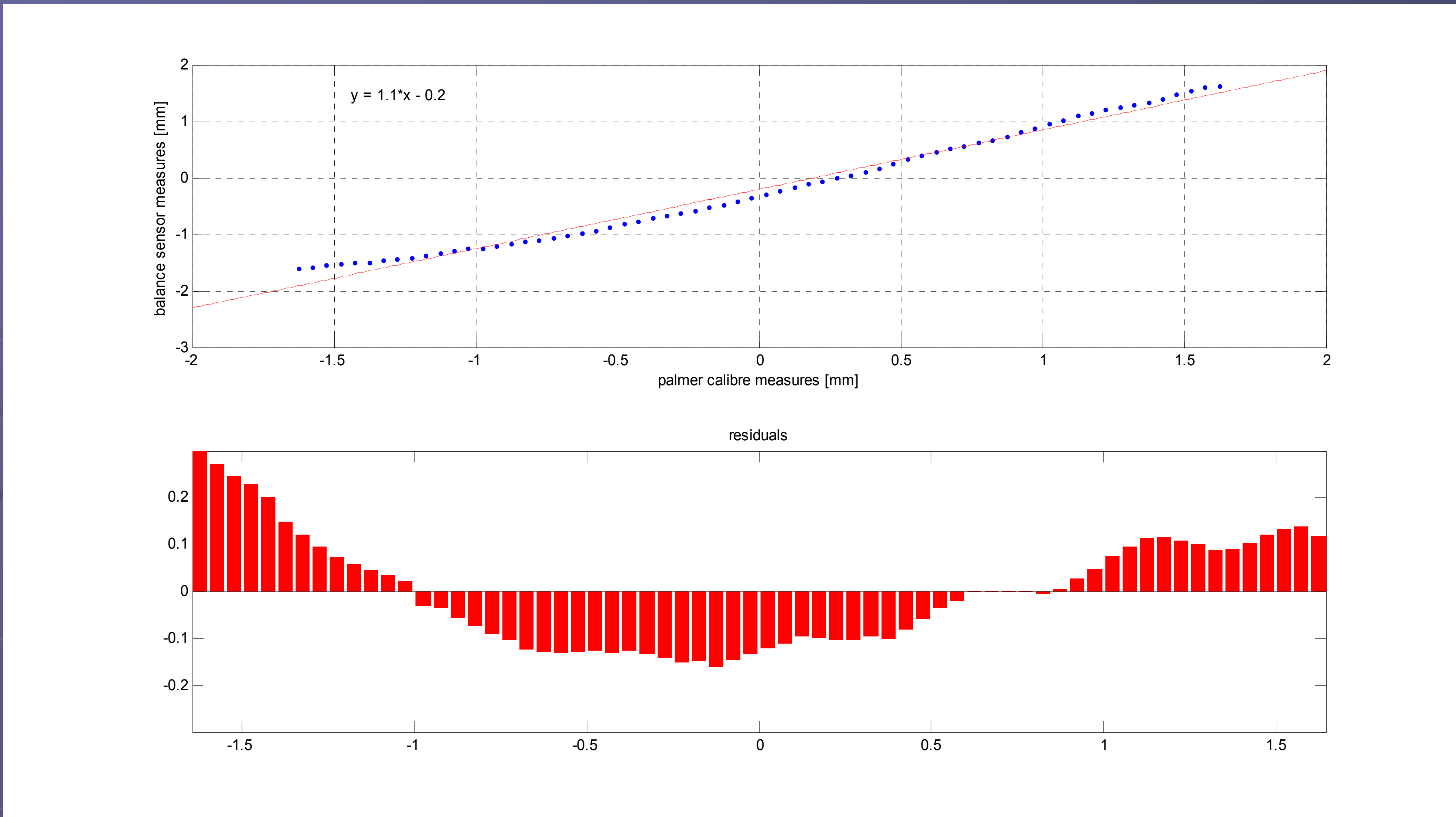




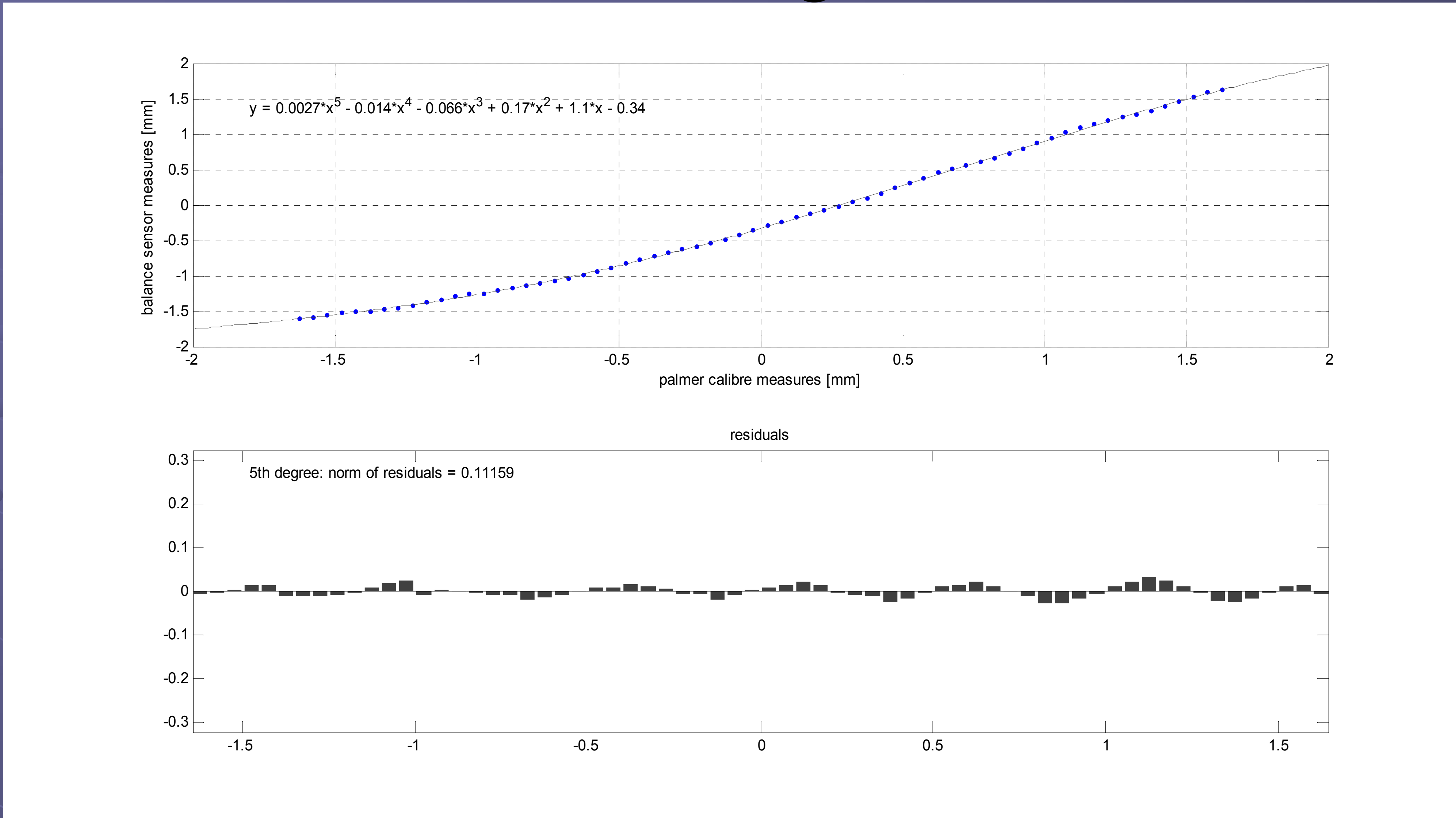
Displacement measurements



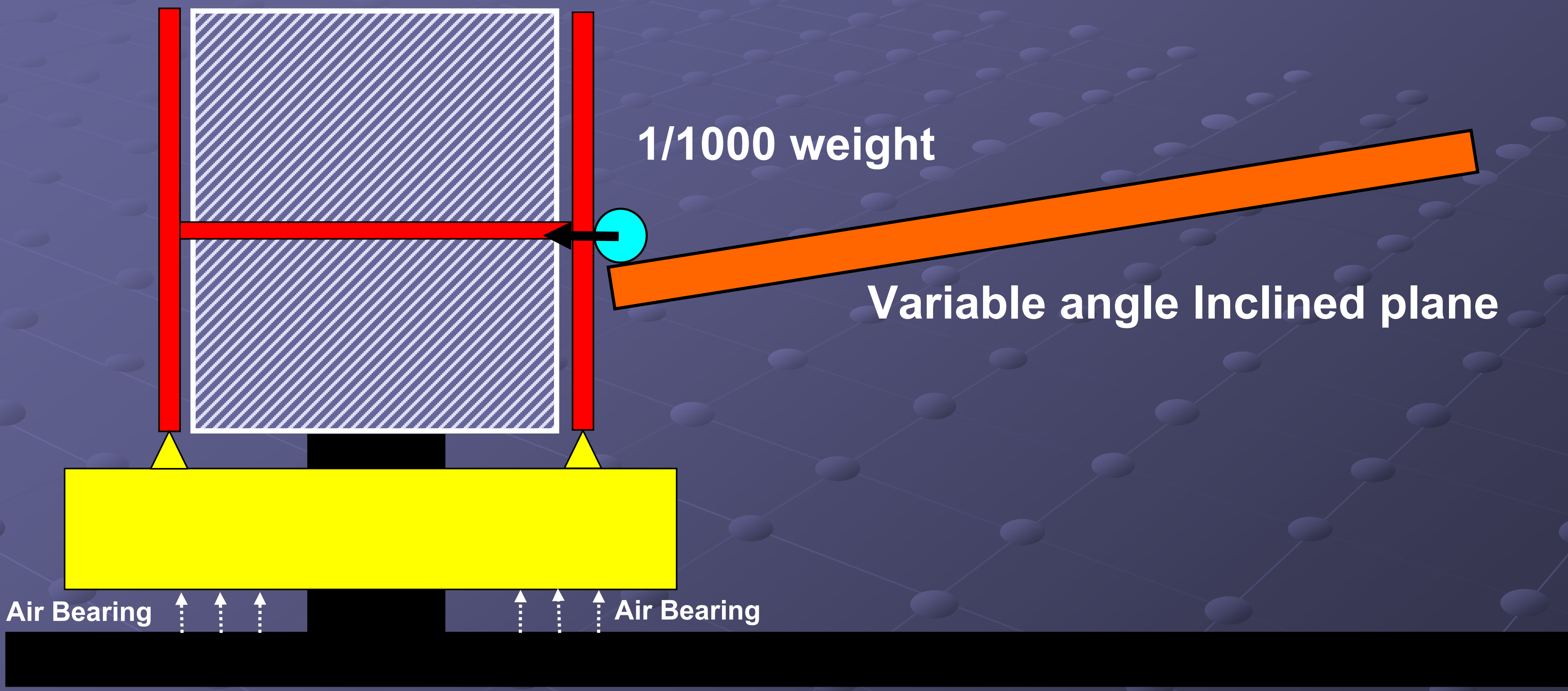
Sensor measures linear fitting



Sensor measures polynomial fitting

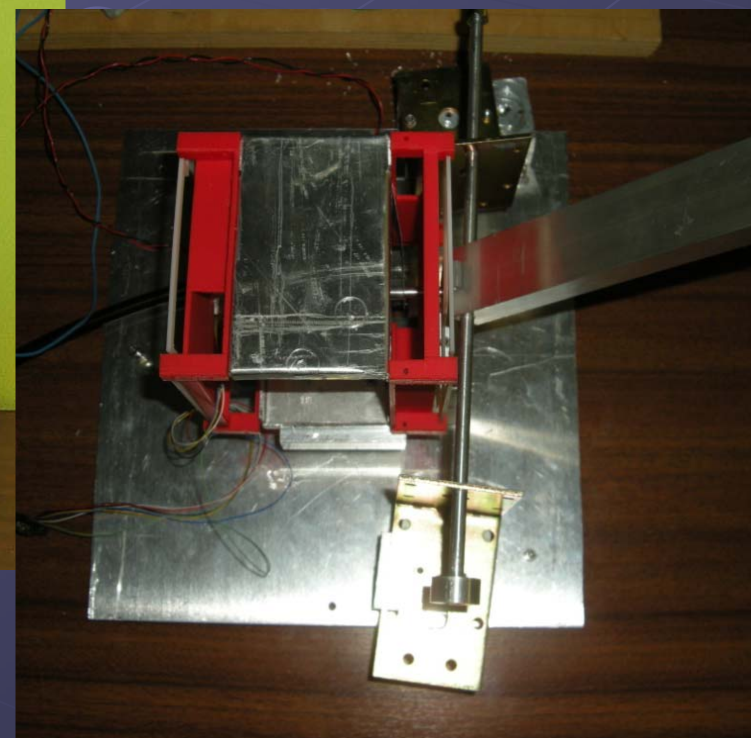


Drag balance ground calibration set-up



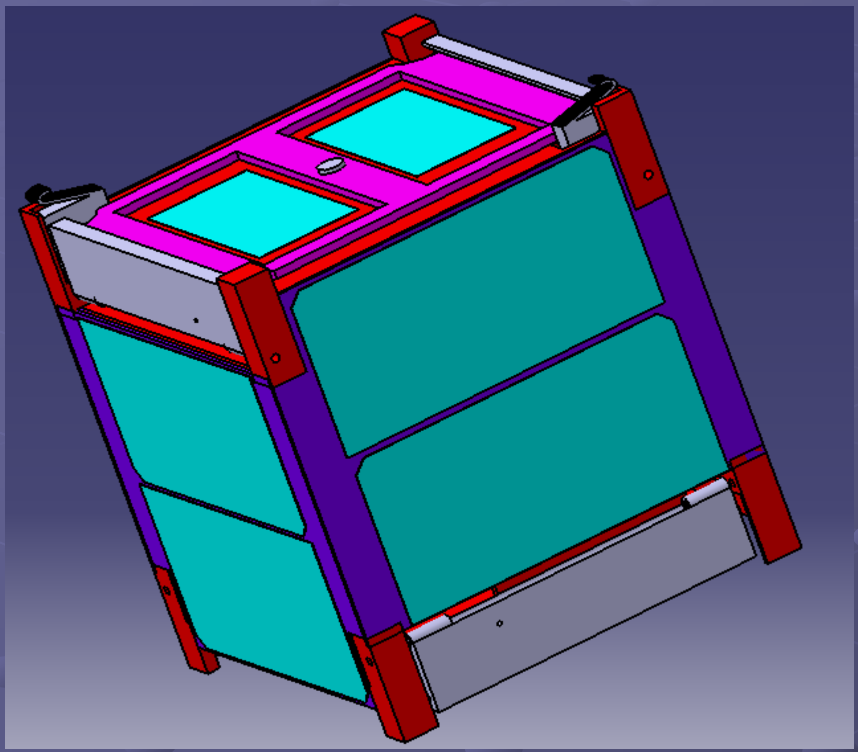
Compressed air bearing reduces friction

Drag balance ground calibration set-up

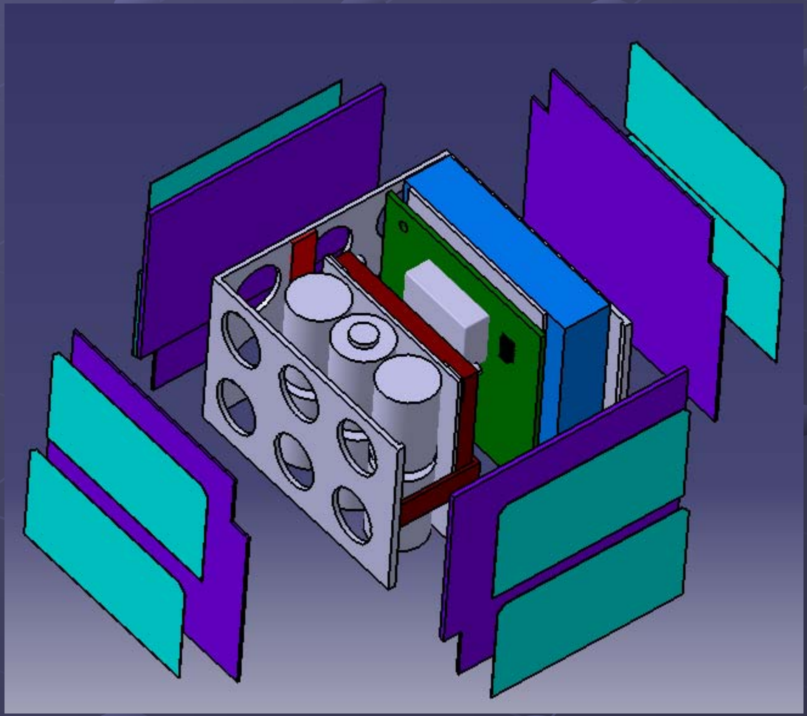


UNICubeSAT configuration

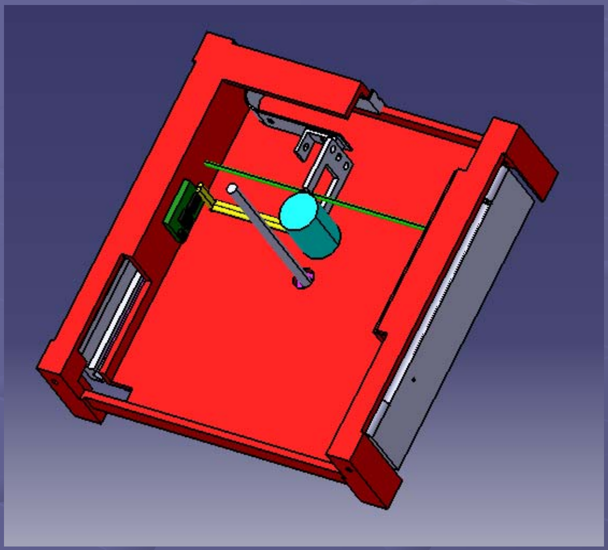
UNICubeSAT in stowed configuration



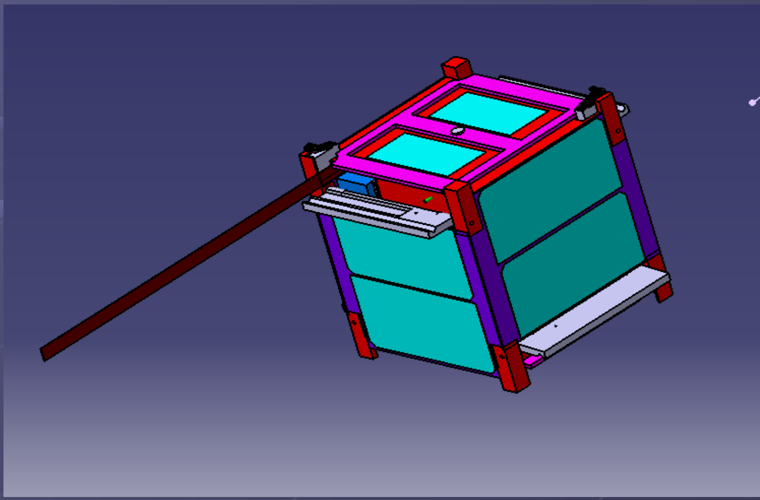
UNICubeSAT electronics packs assembly

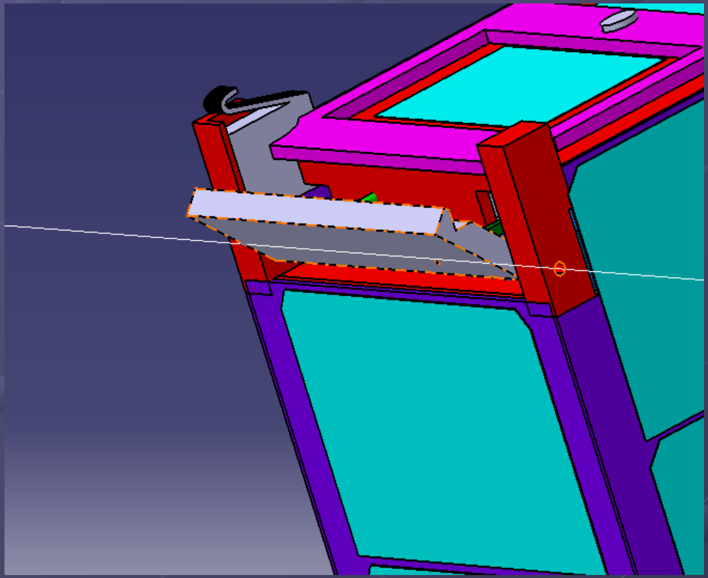


UNICubeSAT drag balance and antenna release system

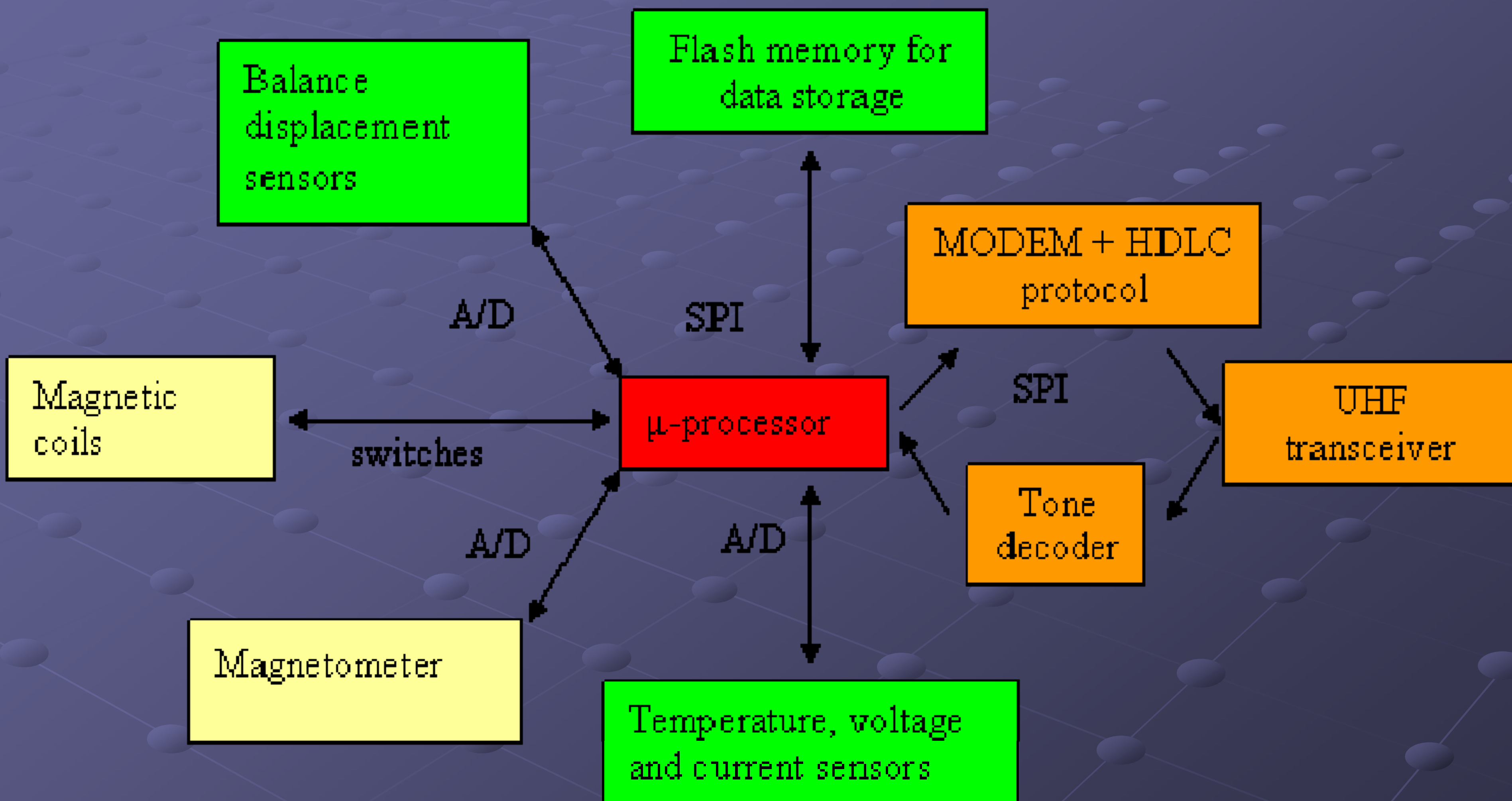


Thermal cutter system already qualified for flight on DNEPR LV

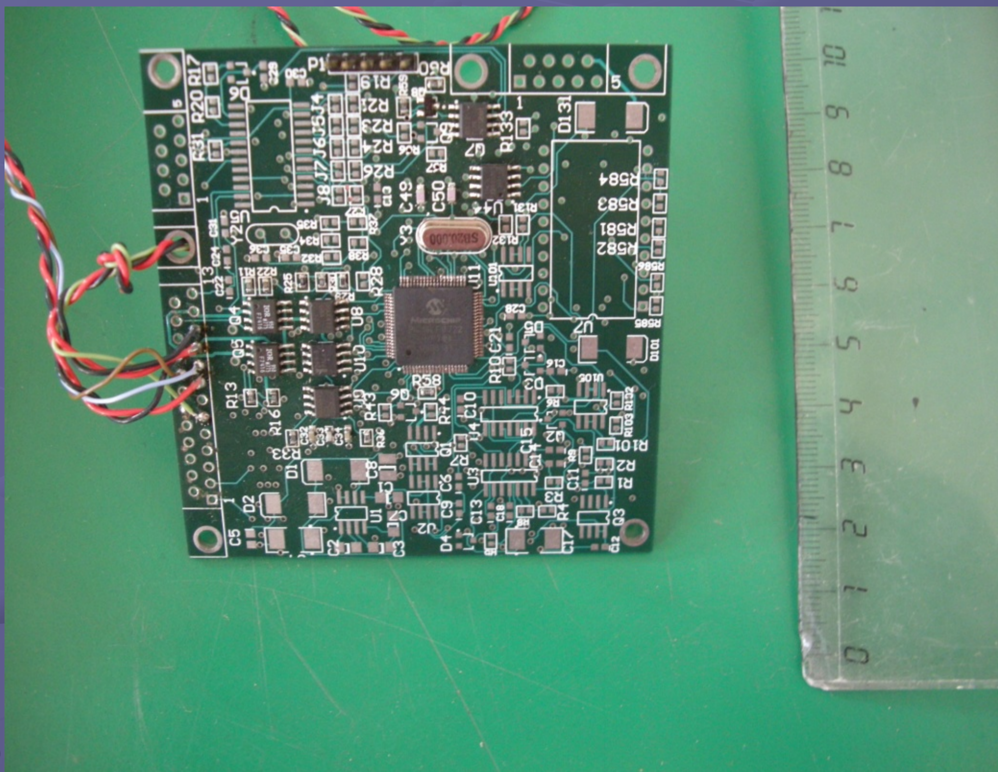




UNICubeSAT OBDH scheme

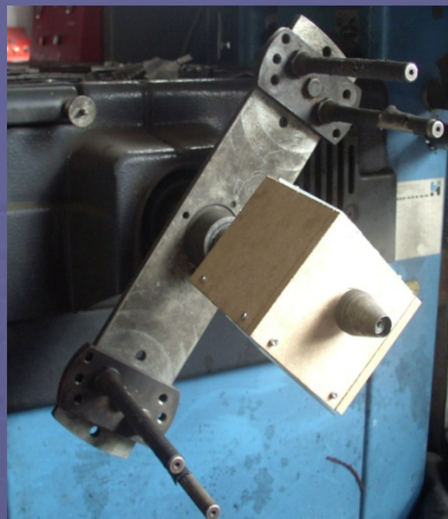


UNICubeSAT OBDH electronics board



Tested on BEXUS 7 flight
October 2008

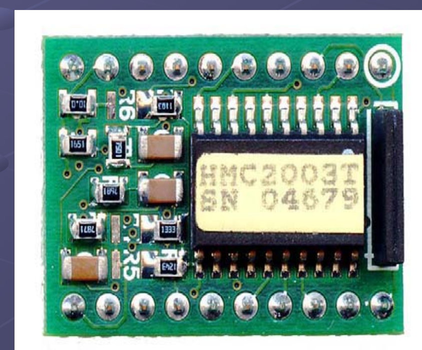
Attitude Determination And Control / 1

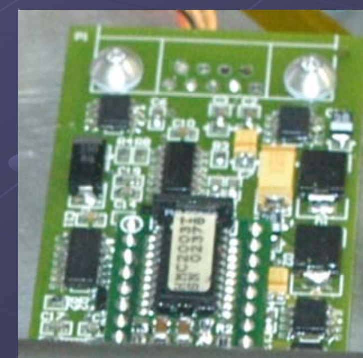


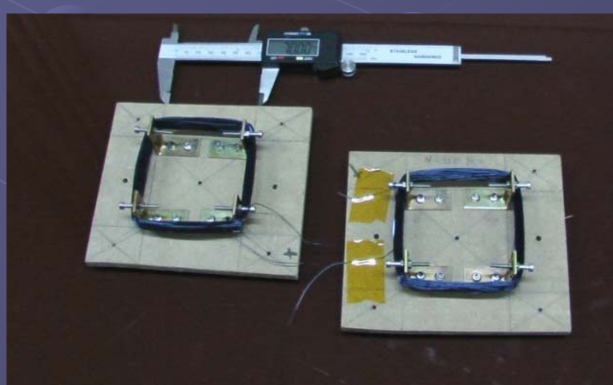
Wooden mock up of UNICubeSAT on the balancing test system

- Center of mass position
- Principal axis of inertia

UNICubeSAT magnetometer







UNICubeSAT magnetic coils prototype

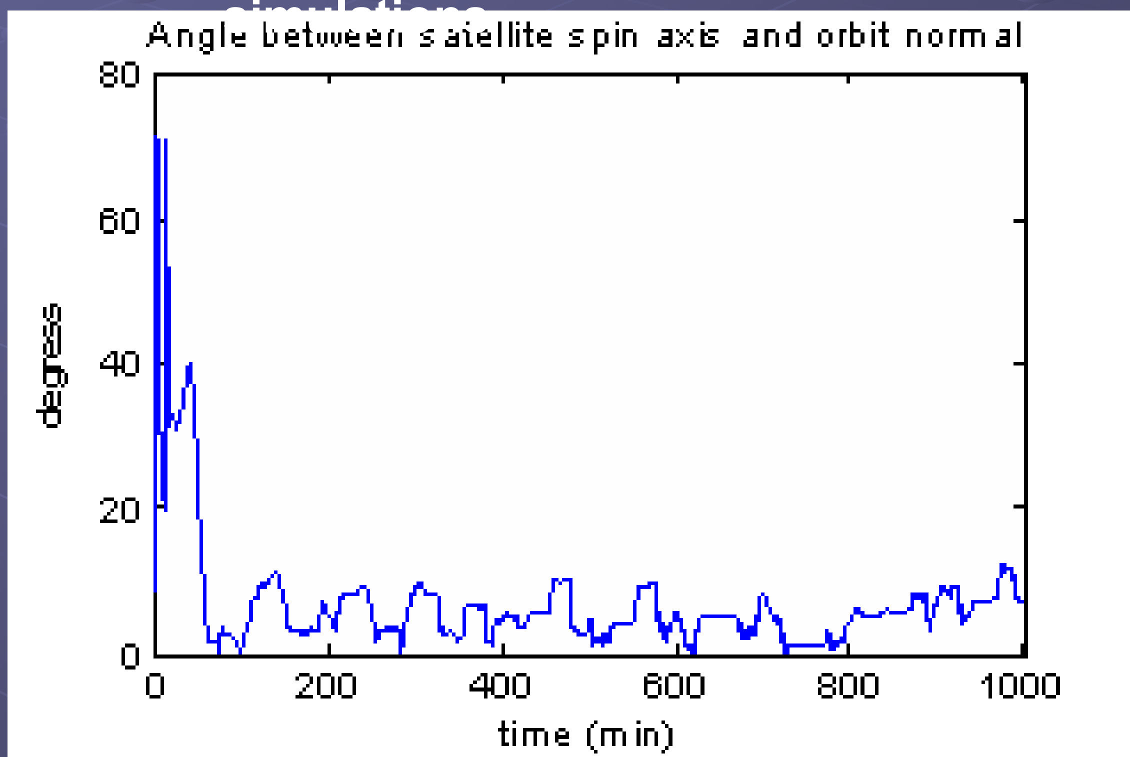
Attitude Determination And Control / 2

Control law: minus B dot

It controls the spin axis orientation and spin angular rate rate

using magnetometer readings only

Attitude Numerical



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