THE AURORA EXPERIMENT: OVERVIEW AND PRELIMINARY RESULTS

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ABSTRACT

AURORA-Stratosphere and Magnetic Field Polar Explorer is a student experiment from the Scuola di Ingegneria Aerospaziale of the Sapienza, University of Rome. This experiment flown on board the stratospheric balloon BEXUS-7 in the framework of the educational program REXUS-BEXUS (Rocket and Balloon Experiments for University Students) of the European Space Agency (ESA) in order to allow students to participate in all phases of a real mission, starting from the proposal through the mission requirements definition, design, building and ground test campaign, and ending with data analysis and presentation of the results. The results of the preliminary thermal tests performed in the laboratory of the Group of Astrodynamics of the Sapienza, University of Roma (GAUSS) have been compared with those obtained performing thermal-vacuum tests at the Mechanical System Laboratory (TEC-MCV) of ESA-ESTEC in Nordwijk (The Netherlands).
The data analysis and results of the AURORA experiment have been presented in the paper.

1. INTRODUCTION

Aurora Stratosphere and Magnetic Field Polar Explorer is a student experiment developed to fly on board of BEXUS-7 Balloon [1]. The original experiment scope was the measurement of high atmosphere plasma perturbations related to Polar Light phenomena. From this the experiment name: AURORA. The results of the detailed feasibility study, which is part of the REXUS-BEXUS program, showed that these phenomena could be measured at heights not reached by the stratospheric balloon. Then it was decided to change the experiment, exploiting the BEXUS-7 flight for experiments in satellite high resolution imaging, testing a commercial off the shelf telescope and camera (CANON EOS 400 D) for potential use on a future UNISAT mission. To monitor the telescope performance, data related to temperature and attitude have been collected.
The goal was testing the telescope, obtaining during the flight :
· Temperature measurements, using three different kinds of sensors for comparison (Diode,LM335,PT1000);
· Magnetic Field Intensity measurements;
· Earth surface pictures (eventually clouds);
· Telescope testing.
A system diagram of AURORA is presented in “Fig. 1” to present the experiment architecture .

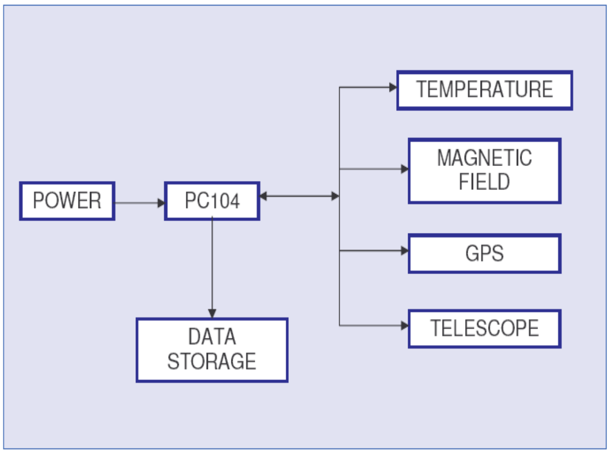

Figure 1 - Experiment Architecture

During the flight, data have been stored on a hot redundant solid state memory, and the whole system was driven by a PC104 embedded computer.
All data were stored on board, with no telemetry link.
An independent GPS module was mounted on the system in order to achieve a better accuracy during post flight data process, in which spatial data have been interpolated with data collected by the sensors. GPS data from EBASS [2] have been used for validation, once a synchronization on initial time have been performed.
A commercial off the shelf (COTS) telescope and camera [3] have been used to take pictures looking downward from the gondola. Two pictures per minute were been taken to test the optics and system performance in the vacuum and low temperature environment.
A thermal protection system has been designed, in order to let the system operate in the stratosphere environment; an analytical model has been developed to estimate temperatures and identify the material with which the passive protection has been designed.

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2. EXPERIMENT DESCRIPTION

2.1 Mechanical Design

The structure shape was a square box. The box sides were made of L section bars connected by M3 screws in each corner and all the subsystems were located on aluminium plate on one of the box faces “Fig. 2”:

Figure 2 – Subsystems location in the box

The box dimensions were 21.5 x 21.5 x 43 cm without the thermal protection and 39,5x39,5x61 cm considering it.

The imaging system including telescope and camera was fixed to a bar “Fig. 3”:

Figure 3 – Telescope

2.2 Power system

The whole assembly was powered by a custom designed assembled in university laboratory battery pack. The SAFT LSH-14 “light” [4] battery cells have been selected for the low temperature and pressure environment in which AURORA will fly.

The bus voltage is 7.2 V, which requires two series connected batteries (nominal voltage 3.6 V).Two battery packs connected in parallel via a diode has been used for an hot redundancy

2.3 On Board Data Handling

The on board data management consisted of a TS-7800 motherboard, which has an embedded LINUX operative system and allowed to perform complicate tasks in short command line instructions. The experiment data collection has been designed as many tasks running in parallel exploiting the features of the LINUX OS.

All data have been collected on memories: one 2 GB compact flash, 2 SD memories. Images have been stored in the camera Compact Flash. A data budget has been performed, in order to estimate the disk space needed to store all data collected during flight “Tab. 1”

Component	Bit rate (bps)	Data (MB/h)	Data (MB) for 5 hours
ADC (5 channel)	9600	25	125
GPS	9600	3,6	18
APS 539	38400	12	60
		TOTALE	203

Table 1 – Data Budget

Camera stored data on a 1 Gb Compact Flash for a total of 200 photos “Tab. 2”

Compact Flash (1 Mbyte)		1000
Resolution (number of pixel)		1000000
Photo (Mbyte)		5
Number of photos		200

Table 2 – Estimated camera data budget

Software has been developed in C language and bash LINUX, to guarantee the devices initialization such as magnetometer and GPS in order to acquire their telemetry data. It allowed to convert thermal sensors data and to store them on CF memory, SD memory and microSD memory in order to have a three hot redundancy. The software allowed to command the camera remote switch in a prefixed time. This software was also able to switch the motherboard on sleep mode by remote control (Ethernet or serial port). In this way motherboard absorption was at its minimum (93 μA). Once tested the system was working during the pre-launch operations, it has been switched on the sleep mode for 30 minutes, in order to lower the power dissipation,

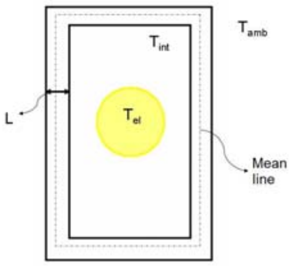
3. THERMAL ENVIRONMENT

3.1 Preliminary Thermal Test

The system operated in a low temperature and rarefied atmosphere environment. There were two conflicting requirements:

- The system must be isolated to avoid low Temperatures;
- The CPU operates in low convection and heat removal was not guaranteed

Proper sizing of the thermal protection design (material and thickness) should take into account both these requirements.



A preliminary thermal test was conducted at university [5] , using a conditioned cell. Results conducted to have a thermal protection of 9 cm of polystyrene to guarantee temperature range functioning for the motherboard.

3.2 Thermal- Vacuum Test

Thermo-vacuum test for the AURORA experiment has been performed at the Mechanical Systems Laboratory (TEC-MCV) of the ESTEC (ESA), in Nordwijk, using the Little Vacuum Facility (LAVAF), “Fig. 4”:

Figure 4 – Little Vacuum Facility (LAVAF)

As suggested in BEXUS User Manual [6] , the required pressure would be below 0.5 mbar, so a pressure of 0.1 mbar has been applied during the test.
In order to recovery the experiment, it has been necessary to wait several hours.
Thermo-vacuum test results are shown in “Fig. 5”: in this graph it is possible to appreciate the maximum temperature reached by the processor SBC TS7800: its value is limited at +60°C, within the operative temperature range required by the mother board. The cooling rate for the SBC 7800 and Daughter board is about 4.5°C/h, whereas for an inner components (for example the telescope) the cooling rate is about 7°C/h.

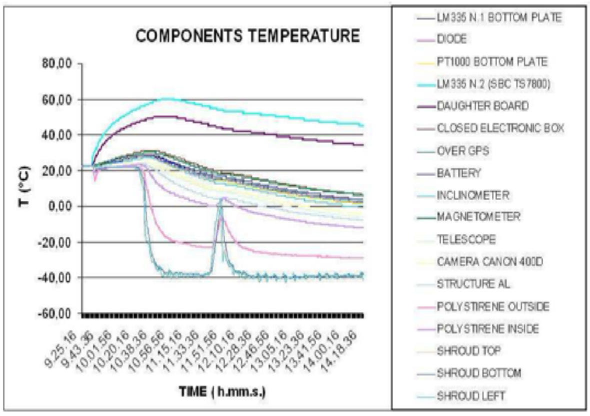


Figure 5- Results of the AURORA experiment thermal-vacuum test

This test confirmed results given by a preliminary thermal test conducted at university and it demonstrated that a single layer of polystyrene (with 3 cm thickness) guarantees a thermal gradient of about 20° C. For this reason, AURORA experiment has been thermally protected using three polystyrene layers, which assure a thermal gradient of about 60 °C.

3.3 TV Results

TV tests validated thermal model evaluated and confirmed thermal protection dimensions; a very good agreement has been detected between preliminary and TV testing.
After test, two polystyrene plates resulted deformed due to the outgassing phenomenon as shown in “Fig. 6”; this different behaviour among the polystyrene plates depended on the different kind of compression of the polystyrene. So the more compressed polystyrene has been used to realize thermal protection.

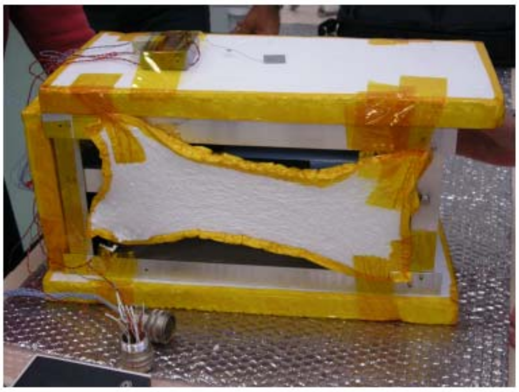


Figure 6*- Polystyrene outgassing*

3. FLIGHT PERFORMANCES

Since the system had no telemetry link, during all the flight (and then until the recovery) any information about system performance were received until the decovery . Once the recovery has been done all the data collected on board during the flight (about 1,2 Gbyte + 4 Gbyte for pictures) have been managed.
Bexus 7 was launched on at 15:37 LT and the landing occurred at 19:30 LT, on October 8th 2008.
Payload recovery happened on October 10th, 2008 at 9.00 LT. AURORA has been recovered without any damages and although the system was still working with a battery voltage of 5,4 V, there was not an acquisition because a voltage of at least 7 V was required. The last acquisition was at 16:58 LT on October 9th.
The flight consists in the following phases reported in the flight profile in “Fig. 7” created by ESRANGE GPS DATA:
1. Ascending phase
2. flight
3. cut down
4. descending phase

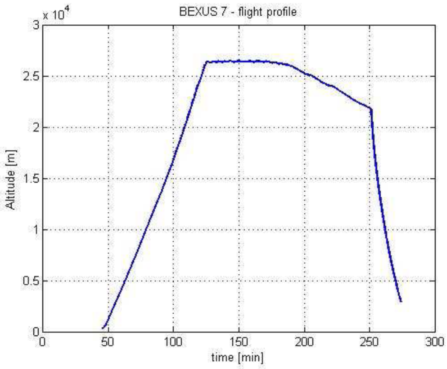


Figure 7- Flight Profile created by ESRANGE GPS DATA

3.1 Magnetometer Results

In "Fig. 8" data collected during the ascending phase are reported. The figure shows an initial quite profile, from the starting time measurements until the release time for the balloon. Then X and Y components of the Earth magnetic field show oscillations until the landing, when their values goes to a constant values .

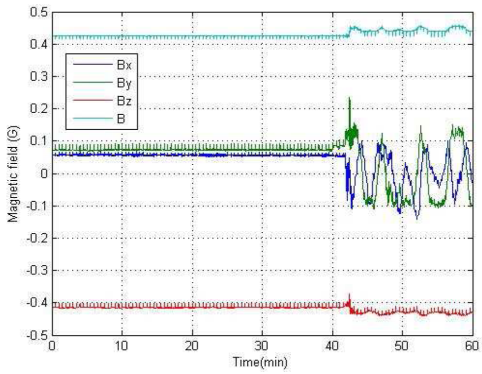


Figure 8 – Magnetometer Measurements during Ascending Phase

The short time oscillation visible in "Fig. 9" were due to the presence of the reflex camera shooting every 30 seconds. In fact during the shot, a 180° rotation of an internal mechanism, influenced instantaneously the magnetic measurements.

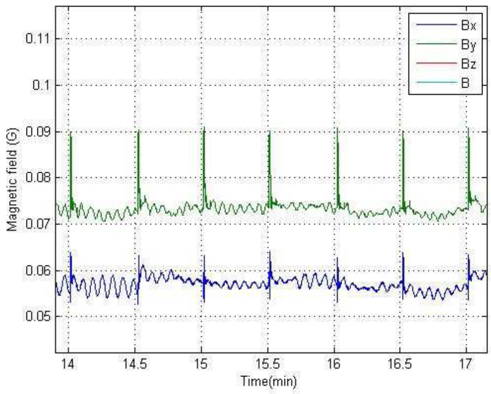


Figure 9- Short Period Oscillations

As shown in "Fig. 10" the balloon cut down occurred about 247 minutes after the switch on of the system; the landing happened about 275 minutes after the system was switched on.

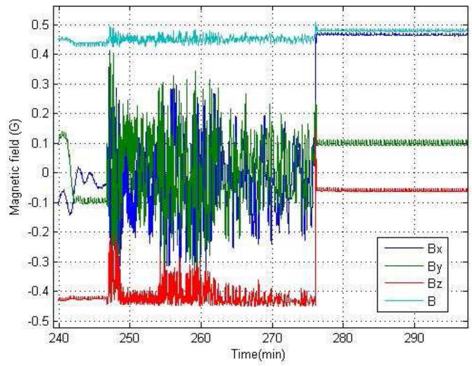


Figure 10 - Magnetometer Measurements

3.2 Inclinometer Results

It was included an inclinometer in the experiment in order to evaluate pitch-roll movement of the gondola. Excluding some little oscillations (about 10-1 deg in amplitude), a constant value for pitch and roll angle during all the flight can be observed in "Fig. 11":

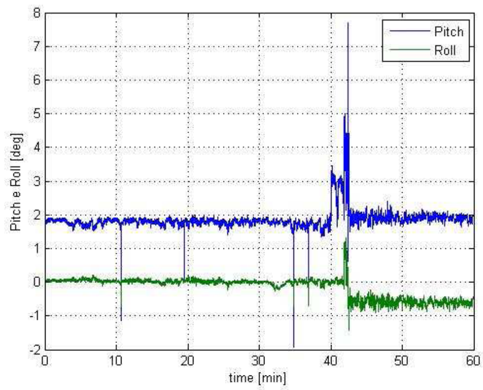


Figure 11 - Inclinometer Measurements

During the descending phase the observed oscillations become more important (about 5 deg of amplitude). Once the gondola have been crashed, pitch and roll angles change their values, giving the final attitude of the gondola as shown in "Fig. 12":

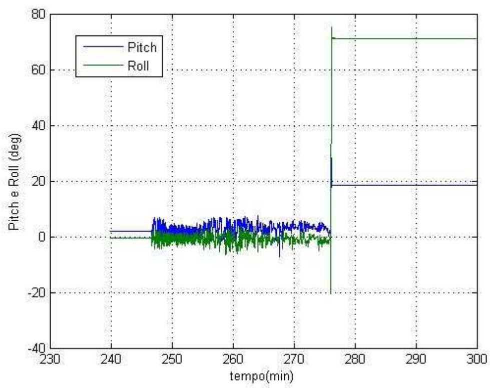


Figure 12- Inclinometer Measurements during Ascending Phase

It was expected a more oscillator behaviour due to the wind, but in effect balloon attitude was almost quiet.

3.3 Image Acquisition

Telescope and reflex camera have successfully worked during the flight and they came back home without any damage. Camera took pictures shooting every 30 seconds, recording images for about 4 GB.
Due to a postposition of the launch, from the morning to the afternoon, there were not enough light.
For this reason, coupled with an not appropriated camera setting for a low illumination conditions, only a few images were clean.
Otherwise the smaller camera has an automatic focus/light settings and for this reason its pictures were clearer than the telescope ones as shown in "Fig. 13":

Figure 13– Little camera shot

3.4 Integration of GPS Data with GOOGLE EARTH MAP

From the GPS data (NMEA format) it was possible to monitor the ascending and descending phase, with the support of Google Earth map , "Fig. 14":
Due to the features of the GPS employed, the flight phase could not be reported for altitude over 18000 meters.

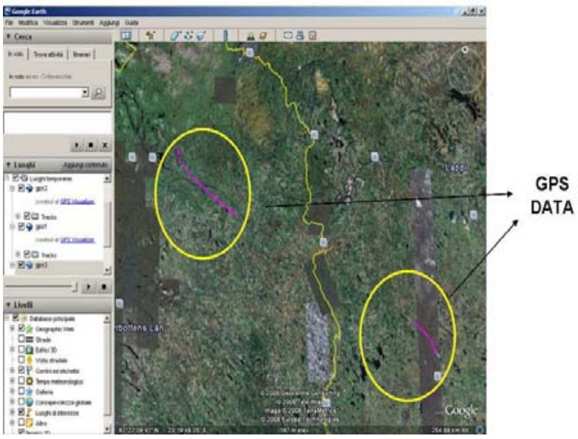


Figure 14-GPS data integration with GOOGLE Earth Map

3.5 Temperature Sensing

Thanks to thermo sensors applied on motherboard and on the smaller camera board, it was possible to affirm their temperatures were within their operative ranges .
In "Fig. 15" and "Fig. 16" the motherboard temperature during all the flight is analyzed: the first one is related to a measurement due to LM335 sensor, while the second one is sensed by an integrated sensor of the CPU.

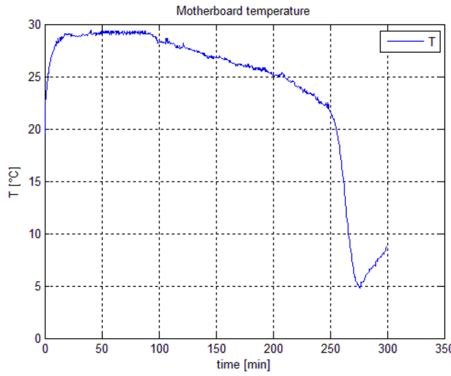


Figure 15-Motherboard Temperature (LM335)

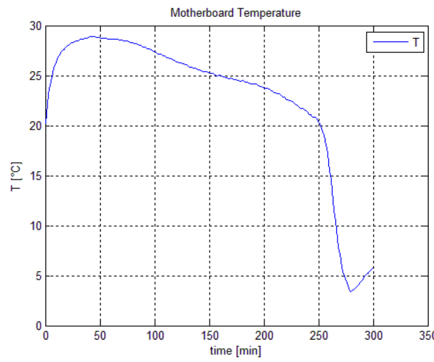


Figure 16- Motherboard Temperature (integrated thermal sensor)

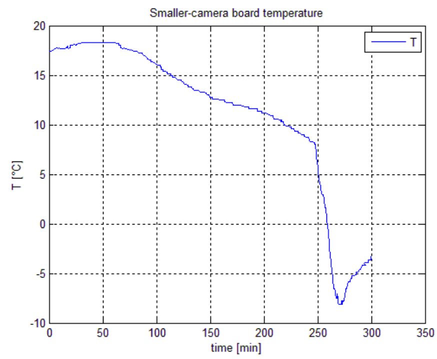


Figure 17-Smaller Camera Board Temperature

In "Fig. 18" temperature profile due to 3 different kind of thermal sensor mounted on AURORA (LM335, PT1000,Diode), and a temperature profile sensed with balloon sensors are shown. During post flight data analysis a difference between our measurements and ESRANGE ones has been observed. This is due to a different sensors placement: while ESRANGE sensors were placed outside the gondola, AURORA thermal sensors were placed at the bottom of the gondola, so these measurements were affected by a thermal coupling with the rest of the experiment.

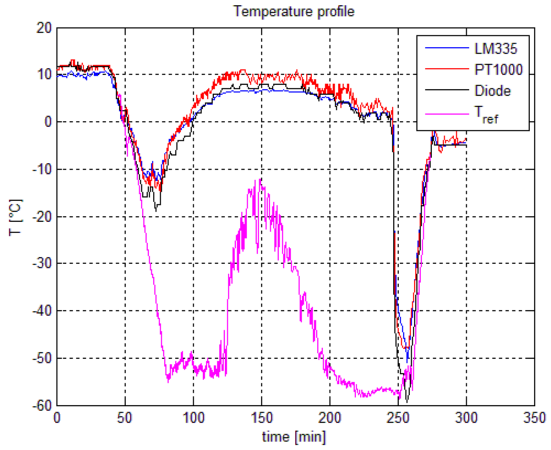


Figure 18- Compared temperature measurements

In post flight data analysis it has been investigated the relative importance among the different kind of heat exchange , "Fig.19":

- natural convective heat exchange;
- forced convective heat exchange;
- radiative heat exchange with the experiment;
- radiative heat exchange due to earth IR emission.

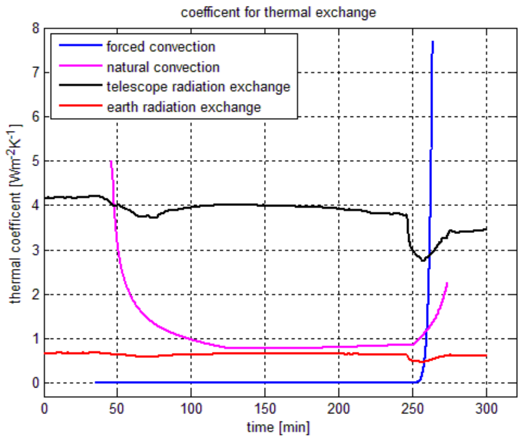


Figure 19- Coefficient for thermal exchange

Radiative exchange between sensors and experiment was the predominant during the most of all the flight except for the ascending phase, where natural convection was predominant, and the descending phase where the prevalence of the forced convective exchange was determined by the high velocity of the falling gondola.

The low contribution of the convective coefficient was due the low density at the high altitude.

4. CONCLUSIONS

BEXUS program provided to students the opportunity to participate in a real project. No malfunction have been detected for the software. The correct dimensioning of the thermal protection guaranteeD all the hardware worked in the right temperature range. This results were anticipated by the thermal analysis conducted at university and then by the thermal test in ESTEC. The over-sizing of the power subsystem ensured the system working during all the flight and after the landing, without any power loss.

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