Soyuz-CanSat Project

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***Abstract*–We have planned two main purposes for our CanSat: launch the CanSat from both Planète Science's balloon and from a fusex, a 1/25 replica of the Soyuz which is being built by a team composed of Russian students from Samara State Aerospace University, led by Maksim Korovin. This led us to design parts of our CanSat specifically to take into account extra constraints due to its integration in the fusex.**

I. Introduction

OUR school, ISAE-ENSICA, has competed in the CanSat France Competition through the former club *Budstar*, since 2009. This year, we plan to build two CanSat, an International one and an Open Class one. Since summer 2012, the former Budstar team [1] has become an association (under French law 1901) called N6K'nSat. N6K'nSat was created to promote our study and work on CanSat, since over the last few years, more and more students have participated in the CanSat project. Indeed, ENSICA students have won CanSat France Competition every year since 2009 and one Spanish contest. Currently, the association has around 15 members. Our team is EnsiCansat. Our work on an Open Class CanSat follows several earlier studies, nevertheless we will build the first CanSat which weighs 1kg and whose dimensions must fit in a cylinder of 80mm in diameter and 200mm high. We have thus defined 3 missions:

- Integration in the Soyuz
- Come-back mission
- Telemetry

We started studying the previous CanSat made at ENSICA and then we worked towards correcting weaknesses and developing a new system to achieve our goals. We worked hard on mechanical issues, building a strong structure validated by numerical simulations on Samcef software; we also developed telecommunications as we must ensure a signal range of about 700m, the altitude of the delivery from the rocket. This is the main contribution of our team as mechanics and telecommunications will be the critical design and development steps.

II. Context of Development

A. Club

We have two teams working on CanSat and one team is developing testing equipment to enable real balloon delivery which will prepare us for the competition. For now, the main solution remains a solar balloon that the team in charge created on their own. The project is fully-funded: in part by the school itself, with the remainder coming from the ISAE-Supaero Foundation.

Within the team, Vincent Laquerbe is the team leader in charge of the integration in the Soyuz rocket and the parachute, Carlos Hervas is in charge of telecommunications between the CanSat and the ground station, German Orgueira is in charge of the structure and Othman Chabi is in charge of the electronics. All of us are second year aeronautical engineering degree students at ISAE-ENSICA (see Fig 1).

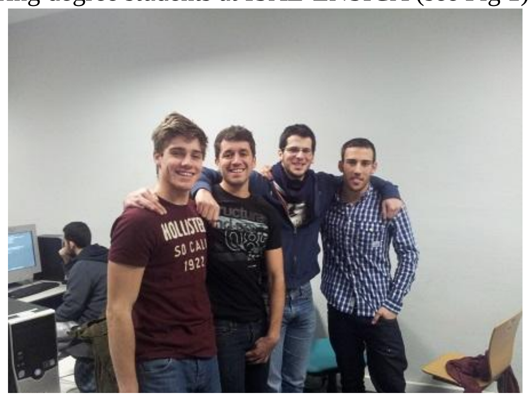

Fig. 1. Picture of the EnsiCansat team.

B. Work plan

We started working on the CanSat in November 2012. A few weeks later, we contacted the Russian students. As our project was ambitious and demanding, we quickly drew up a first draft, pointing out missions and specific work we had to do. By early 2013, we had already determined the tasks which each of us would face: Integration, Electronics, Structure-Parachute and Guidance-Control system. Below we examine each of those parts:

Integration concerns the delivery from the Planète Science tube and the delivery from the Russian rocket. As the rocket constraints are more stringent, we designed the CanSat according to the room we have in the rocket. At the end of April, we visited the Russian team in Samara to check and validate the interfaces we had been working on for months (see Fig 2).

Fig. 2. CanSat Prototype and its location inside the Soyuz.

The electronics closely resembles the configuration used last year, only some components, such as the antenna, have been changed. We bought the components early (February) to check volume constraints. We have been designing a patch antenna for a long time, but as we had it manufactured in a workshop near Toulouse, we received it within a reasonably short time. This part required dozens of hours as we had to understand how each component works with the microcontroller and check its function.

Since we will launch our CanSat from a rocket this year the structure must withstand a great deal of stress. We therefore decided to strengthen the whole structure to resist the stress of takeoff. The main part of the structure was designed on Catia and printed with a 3D printer (see Fig 3 the latest version); this part required small changes to optimize the space inside the CanSat. The parachute is from a wing studied last year by ENSICA students in our wind tunnel (Fig 4).

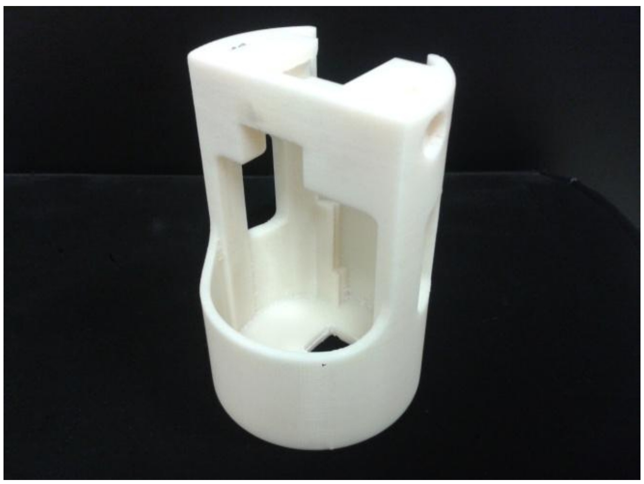

Fig. 3. CanSat (end of May) and parachute (in the wind tunnel).

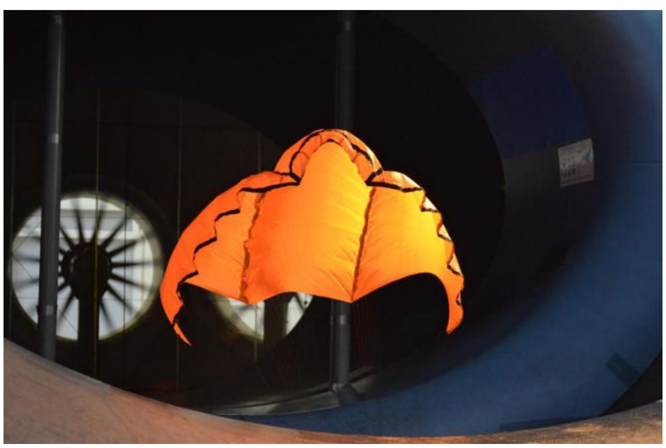

Fig. 4. CanSat (end of May) and parachute (in the wind tunnel).

Concerning the guidance system, we wanted to control the wing in order to land in a precise spot. We will use a proportional gain to specify the path to follow, based on its previous position and behavior. The gain is determined by empirical analysis. This part was the hardest since we had little information about the wing's behavior, only what we could learn from experiments.

Fig 5 below shows the budget, early 2013, of the EnsiCansat team.

Components	Q	Tot
Camera	1	40,00 €
Battery 3,3V	1	-
Battery 7,4V	1	12,00 €
Memory Card micro SD 16 Go	1	20,00 €
Xbee Pro S2B 10 mW	2	110,00 €
Adaptator R-SMA to SMA	2	25,00 €
Emission Antenna	1	
Ground Antenna	1	
Epoxy Resine	1	50,00 €
Actuator HS-55	1	11,00 €
Microcontroller Arduino Mini 3,3V	1	-
Pressure Sensor	1	-
Temperature and Hygrometry Sensor	1	-
Breakout Board for microSD	1	-
GPS EM-406A	1	-
FTDI Basic Breakout	1	-
SUB-TOTAL 1		268,00 €

Fig. 5. Global Budget

III. Definition of the Missions

Our CanSat is organized around 4 main missions during the flight: Atmospheric probing, guidance and accurate landing, pictures and videos, and successful launch from the Soyuz rocket.

A. Scientific Mission

The scientific mission consists of 3 atmospheric probes of hygrometry, pressure and temperature. We use two different sensors whose characteristics [3] are:

- Hygrometry: accuracy 2%
- Temperature: accuracy 0.3°C
- Pressure: accuracy 0.03hPa from 300 to 1100 hPa

All data measured by these sensors will be sent to the ground station in real-time and stored onboard on a micro SD Card.

B. Free Mission 1: Guidance and accurate landing

The purpose is to choose the CanSat trajectory by controlling the parachute's behavior. At the end of the flight, the CanSat must land on a specific target defined by GPS coordinates. An actuator therefore moves the span of the wing to enable rotation. This actuator is controlled by the Arduino pro mini [2], an inexpensive microcontroller. Since only few spans can actually control the wing's behavior, we attached the "working" spans to the actuator whereas the rest are held by screws inside the structure.

C. Free Mission 2: Flight Recordings

The CanSat will store flight recordings in .avi format video. We use a spy camera located inside the CanSat and shoot through openings in the structure.

The video file size will be too large to be sent in real-time so we will collect the file after the flight from an independent micro SD card. The video could be used to analyze the behavior and the stability of the CanSat during the flight.

D. Free Mission 3: Launch from the Soyuz

This consists in integrating our CanSat in a fusex. The CanSat will be launched from the rocket during the flight, a few seconds after the rocket's parachute opens.

IV. CanSat Architecture

A. Electrical architecture

All electronics, except the camera, are controlled by the Arduino. Our electronics mainly include two sensors for atmospheric probing, an actuator to control the wing, a GPS module, an emitter to send data to the ground station and a microcontroller which is the core element (see Fig 6 the controller and components).

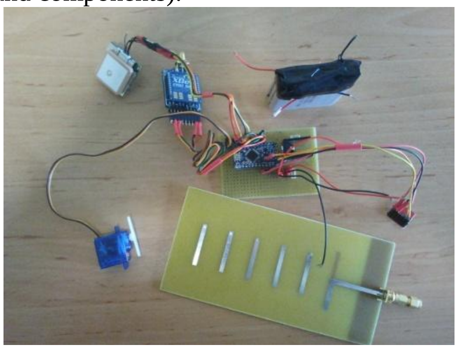

Fig. 6. Components

Our CanSat also contains a camera which works independently, an antenna that we have designed and tested throughout the year and a battery to supply power. The battery has been modified to provide both 3.3V and 7.4V voltages. However, almost all the components are powered by the Arduino microcontroller which delivers stabilized voltage. Most components are soldered on the same electronic board, making it smaller. We will use an umbilical called a jumper to save power during takeoff; the electronics part of the CanSat will not function properly until this jumper is cut.

B. Mechanical parts

As the CanSat is heavier, the stress will be greater. We thus strengthened the structure which is composed of 3 parts:

- A plastic skeleton, designed on Catia Software: this part supports the electronics and all embedded systems.
- A carbon reinforcing tape: the tape will help the skeleton during moments of critical stress (takeoff and parachute opening) preventing CanSat from splitting in half.
- An outer layer (most likely composed of fiberglass but yet to be defined): this layer will close the CanSat to protect the inside and we will put stickers here.

C. Telemetry

The CanSat includes a Xbee Pro Serie2 emitter which supports the ISM-Band: e.g., from 2.4GHz to 2.5GHz. Sixteen channels (5MHz bandwidth) can be chosen; we will use channel 0x17 (2.465GHz), based on our antenna's features (studies are examined below). Data collected by the CanSat will be transmitted to ground during flight.

V. Technical Details

A. Structure

Our project is the first time that a "big" CanSat has been developed at ENSICA. In spite of the difference in mass (300g maximum in 2012 vs 1kg in 2013), the size is close (R = 33mm h = 98mm in 2012 vs R = 37,5mm h = 112mm respectively). Thus, we based our structure on the previous year's and we decided to adapt it and optimise it. This meant designing it to be resistant enough and with enough space inside to carry all the electronic devices and respecting the limitations imposed by the contest.

In order to find possible mistakes or aspects to improve upon last year's structure, we decided to analyse the critical phases of the mission and the behaviour of the structure during them (take off from the Soyuz rocket, opening of the parachute and landing). We made simplified models of the forces and tensions that the structure would undergo to determine their order of magnitude and to be able to model studies on different programs such as Catia V5 or Samcef.

Before designing our first structure, we studied the behaviour of the 2012 CanSat when the modelled forces were applied on Catia V5. Through the analysis, we tried to find the weakest points and the parts that could be improved.

Two new holes were introduced in the upper part of the cylinder (see Fig 7). These were designed to be part of a new system to decrease the tension on the structure due to the threads that attach the motor to the parachute. This system consists of connecting the threads that are not used for controlling and guiding the CanSat to a different part of the structure with the aim of distributing the loads.

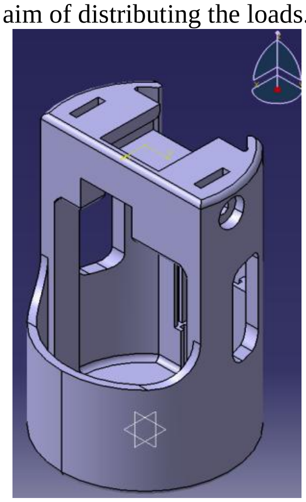

Fig. 7. Catia, May 2013 version

Finally, the three different studies modelled at the beginning were carried out on Samcef in order to verify that the structure could resist and complete the mission. The following figures (Fig 8) show the stress and displacement distribution during takeoff.

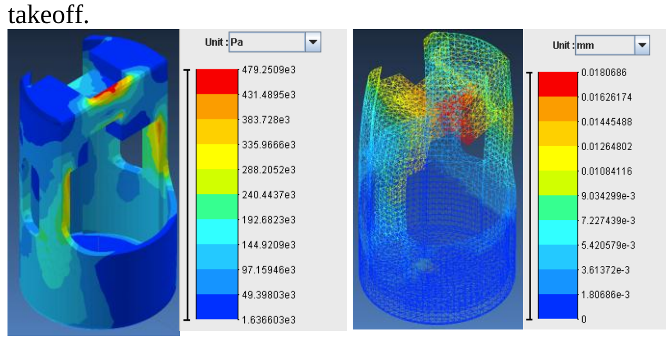

Fig. 8. Numerical simulation of the take off on Samcef

B. Antenna

The launch from the Soyuz rocket necessitates a 700m to 800m signal range to transmit data to the ground. As a first approximation, we assumed that the electric fields follow an isotropic propagation; this way, the Friis equation gives us the power received:

$$P_{received} = \frac{\lambda^2}{(4\pi R)^2} P_{emitted} G_{emission} G_{reception}$$

Where:

- P: power received and emitted
- R: distance between the CanSat and the ground station
- λ: wave length (2.465GHz means 12.17cm)
- G:represents both antenna gain at emission and reception

Since the emission power is limited to 10dBm, the only way to increase the power received is to improve the two gains. Thus, we decided to design our own patch antenna [4]. We will place it below the CanSat, facing the ground to maximize the gain and minimize the loss. The antenna is composed of a dielectric substrate, a ground plane and an excited patch. It is supplied by a coaxial wire which crosses the whole antenna (Fig 8).

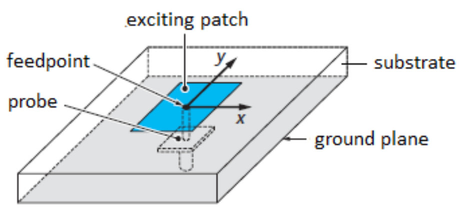

Fig. 7. Patch Antenna

The gain and the overall performances are determined by the patch and substrate dimensions and features. A complex system of equations defines a unique dimension for the patch. Our antenna is a circle with the same diameter as the CanSat itself (75mm) and the patch is a 31.5mm square. To validate the theoretical model, we conducted several numerical simulations on HFSS software to calculate gain and antenna to circuit adaptation (Figure 8 shows the gain, in function of the orientation for several geometrical parameters).

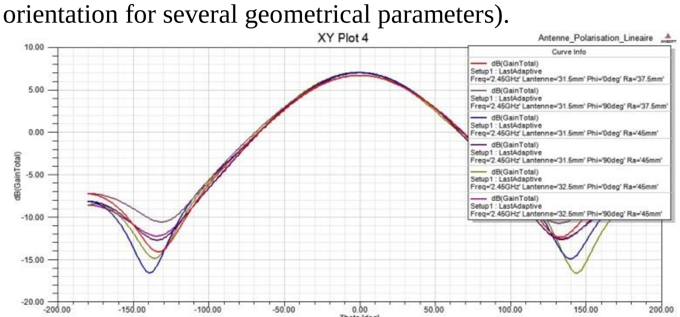

Fig. 7. Antenna gain

Next, we designed a specific geometry to simulate the real antenna that will be used during the C'Space. We perforated the antenna's substrate to hang the antenna on the rest of the skeleton.

Moreover, we also studied circular polarization. The problem here is that the calculus required to solve multiple systems of equations with dependant unknown variables. Several days were needed to obtain results.

VI. Conclusion

This year we built an Open Class CanSat which can be launched from both balloon and rocket. We have designed a new transmission system to improve on previous ones in order to ensure the 700m range required for the rocket's flight. For now, we are conducting final tests (all embedded systems) with the whole CanSat to prepare for the competition in August.

Acknowledgment

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- The Planète Sciences and CNES teams
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References

[1] http://budstar.free.fr/
[2] http://www.arduino.cc/
[3] https://www.sparkfun.com/
[4] Communication with R. Pascaud, professor at ISAE