

# MORPHEUS 3 – returns

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**Abstract**–MORPHEUS 3 is one of the two BUDSTAR’s third-year CanSats. It participates in the French Championship 2011 alongside with NEO 3, which is the second version of BUDSTAR’s rover CanSat. This can-sized autonomous drone is able to reach a GPS target on the ground after having acquired and sent in real-time atmospheric data during its fall. It also follows-up its parachute deformation in order to analyze its very complex in-flight behavior.

## I. INTRODUCTION

Taking over from its two elders, MORPHEUS completes three missions during its fall: atmospheric sounding, “come back” and parachute deformation tracking.

The two first ones are logical evolutions of the previous versions of MORPHEUS. The third one is a 2011 innovation that aims to give a simplified answer to the extremely complex question of the parachute aerodynamics. The goal is to get the draft of a model to improve scientifically the performances of the parachute in the next years.

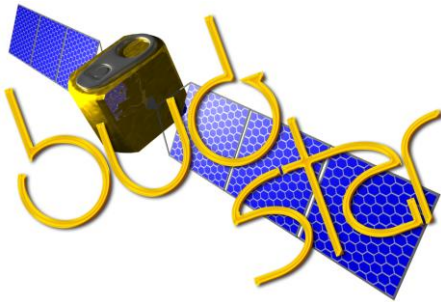


Fig. 1. BudStar logo

## II. CONTEXT OF DEVELOPMENT

### A. The team

BUDSTAR was born in 2009 as a university club of the French Institute of Aeronautics and Space (ISAE) in Toulouse. Since 2010, it is an autonomous association led by ISAE students.

French championship 2009 was the team’s first CanSat competition – and victory. In 2010, the second version of MORPHEUS won the International Competition in Madrid.

This year, BUDSTAR is composed by 4 students in 4<sup>th</sup> and 5<sup>th</sup> year, specialized in computer sciences, control theory and aerodynamics. It has concluded a partnership with the Institute for design and building, and with the Parachute Flight Test Center (CEVAP) for tests.

Each team member has his field of expertise:

- Louis Perrot-Minot, team leader, and Antoine Basset are programmers;

- Mathieu Archen is responsible for structure and electronics;
- Suk-Kee Courty-Audren is in charge of the design & building of the parachute.

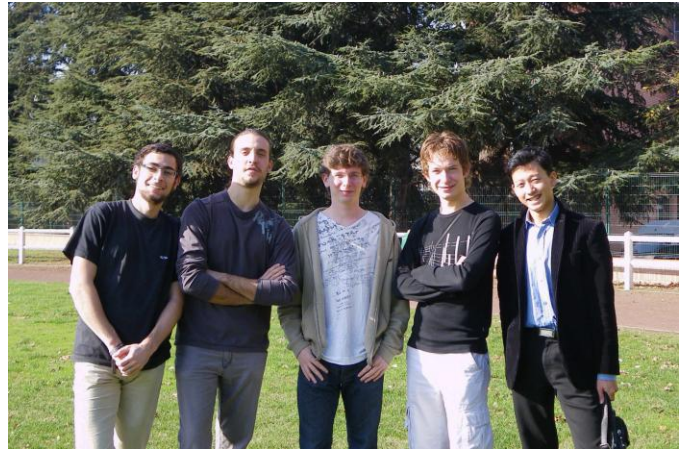


Fig. 2. BudStar 2010 team

### B. Year organization

The year is divided in three parts:

- drafts;
- research & development;
- full-scale tests.

The first months of the year are dedicated to sketches. Each chosen mission is firstly considered independently. Therefore in the case of MORPHEUS it represents three specifications. In this research time, the goal is not to make a final CanSat, but to find the technical answers that will be chosen for the final version.

TABLE 1. FORESEEN CALENDAR



Each mission is firstly independently designed, built and tested. Once these drafts are satisfying – which means fulfill its specifications – it is time to begin final design. At that time, technical solutions and equipments are definitely chosen. This

second phase goes alongside with integration: the missions have to cohabit inside the CanSat, both in terms of physical limitations and programming.

The last part of the year is dedicated to full-scale tests. The CanSat is assembled and ready to fly, but is very far away from being ready for the Championship. This is the most important phase and the one that was lacking on previous years. The main part to be settled is the parachute since there is no satisfying theoretical model – that is the reason for being of the free mission. The team has concluded a partnership with the CEVAP for launching CanSat from a thirty-meter-flight test tour, which allows to quickly set up tests and get nearly live results.

### C. Budget

TABLE 2. FORESEEN BUDGET (MARCH 2011)

MORPHEUS	Unit price	Quantity	Total
Batteries*	25	2	50
Microcontroller	20	1	20
XBee transmitters (1 spare)	40	2	80
P/T sensor	50	1	50
GPS antenna*	60	1	60
Hygrometric sensor	35	1	35
Camera	10	1	10
MicroSD card writer	20	1	20
<b>Total</b>			<b>325</b>

GROUND STATION	Unit price	Quantity	Total
Microcontroller interface*	15	1	15
XBee transmitter	60	1	60
<b>Total</b>			<b>75</b>

<b>TOTAL</b>			<b>400</b>
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\*Shared with Neo

## III. DEFINITION OF THE MISSIONS

### A. Scientific mission: atmospheric sounding

During its fall the CanSat records atmospheric data like temperature, hygrometry, pressure... Measurements are sent in real-time to a ground station.

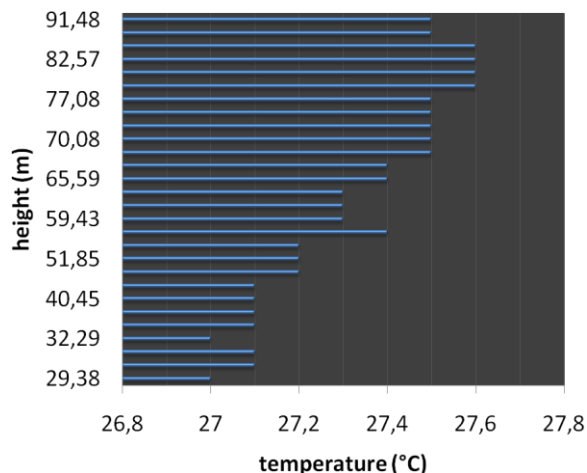


Fig. 3. Temperature results obtained in 2009

### B. “Come back” mission

The CanSat must land on a target defined by its GPS coordinates. MORPHEUS is equipped with a controllable parachute that allows it to head to the target.

### C. Free mission: parachute deformation tracking

The sail is the only vital part of the CanSat. It ensures the safety of the flight and is the only means of heading. Performance of the CanSat depends first and foremost on parachute performance.

The goal of the free mission is to work on its behavior, by filming it in real conditions. For this purpose, the CanSat is equipped with a camera pointing upwards to track parachute deformations.



Fig. 4. Parachute deformation during an opening test

## IV. TECHNICAL DESCRIPTION

### A. General electronic structure

The brain of the CanSat is a microcontroller on which several components are plugged. Most of them are sensors, which capture data during the flight – a servomotor, a transmitter and the battery come on top.

Each component has a role to play for a given mission, described in the following paragraphs.

### B. Atmospheric sounding

For this mission the CanSat uses three sensors:

- a temperature sensor;
- a hygrometric sensor;
- and a pressure sensor, thanks to which the height is calculated.

Measurements are made roughly every second and sent in real-time to a ground station – a software running on a computer equipped with a receiver – which processes, saves and displays them in real-time too.

In the same time data is saved to an on-board memory card in order not to lose it in case of dysfunction of the transmitter or the ground station.

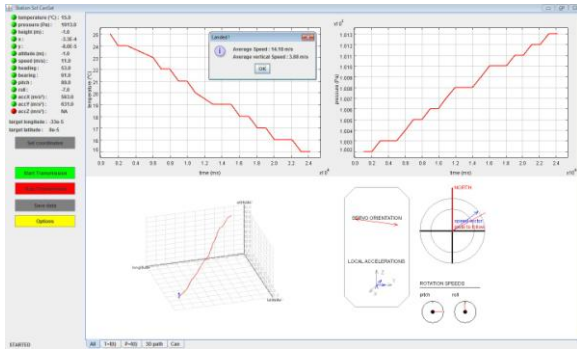


Fig. 5. Screenshot of the ground station software

### C. “Come back” mission

In addition to the microcontroller in which the autopilot algorithm is programmed, guidance of the CanSat is provided by two components:

- a GPS receiver, which gets geographical coordinates every second;
- a servomotor, which acts on the parachute to rotate the CanSat.

The route to follow is reevaluated at every coordinates’ acquisition, and the servomotor is then moved to make the heading match the route to follow.

In order not to spend too much time, the algorithm is very simple and can be expressed this way:

$$\Delta = r - h$$

$$c = \lambda \times \Delta$$

$$\begin{cases} c < c_{\min} \Rightarrow c = c_{\min} \\ c > c_{\max} \Rightarrow c = c_{\max} \end{cases}$$

where:

- $c$  is the command to be applied;
- $r$  is the route to follow;
- $h$  is the current heading;
- $\Delta$  is the trajectory correction;
- $\lambda$  is a constant empirically established;
- $c_{\min}$  and  $c_{\max}$  represent the aerodynamic limitations of the parachute (also empirically established).

Thus, for guiding there are already three constants that must be established thanks to the full-scale-tests.

### D. Parachute deformation tracking

Key points of the parachute are marked in order to be spotted and followed when replaying the movie after the flight.

Due to the large amount of information needed, the movie is not wirelessly sent, but saved on another on-board memory card. Once the CanSat has landed, the movie is manually analyzed on a video tracking software to get the key points movements and then the dynamic parachute deformation.

### E. Telemetry equipment

The CanSat is equipped with an Xbee Pro emitter transmitting on 2.5GHz at a power of 10mW, which allows the

CanSat to communicate with the ground station from at least 300m.

Every second, the CanSat sends a frame containing all collected data to the ground station: time, pressure, temperature, coordinates, command...

The ground station is equipped with a Java home-made application that receives and plot all measurements in real-time. Once the transmission ends, it is possible to save the data table in order to replay the flight later.

### F. Structure

The structure of the CanSat is composed in two parts:

- an intern plastic skeleton, containing “rails” where components are plugged;
- an extern aluminum shell covering the intern structure to increase solidity;

The intern skeleton is a 3D-printed piece, computer designed on Catia software.

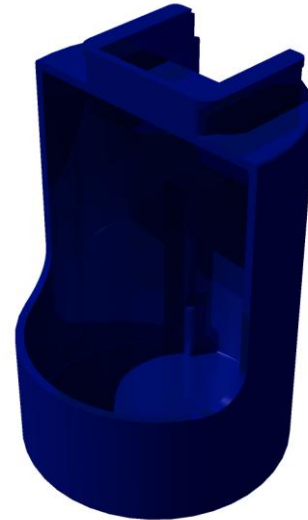


Fig. 6. Catia designed structure

## V. PARACHUTE DEVELOPMENT & TESTS

### A. Foreword about velocity

The electromagnetic surrounding inside the CanSat is to high to get the current heading with a magnetic compass, so it is calculated from the two last GPS coordinates acquisitions. This implies that the velocity is relative to the ground and not to the air. In these conditions, it is interesting to note that the guiding algorithm only converges if the wind is slower than the CanSat. That is one more reason why the parachute is the most critical part. It has to be faster than the regulatory maximum wind, *i.e.* 5m/s.

### B. Type of parachute

The key word of the parachute is “reliability”. This implies it has to be as simple as possible. The parachute must fulfill three requirements:

- it has to open in 100% cases;

- it must fly at least at 5m/s;
- it must be controllable.

The finally chosen configuration is NASA ParaWing 5, a single layer sail developed in the 60's by NASA for Gemini capsules. It is very simple and easy to build and to modify according to tests results.

The control is made with a single servomotor that rotates the CanSat below the parachute: it reacts like a tilting microlight, by shifting its center of gravity.

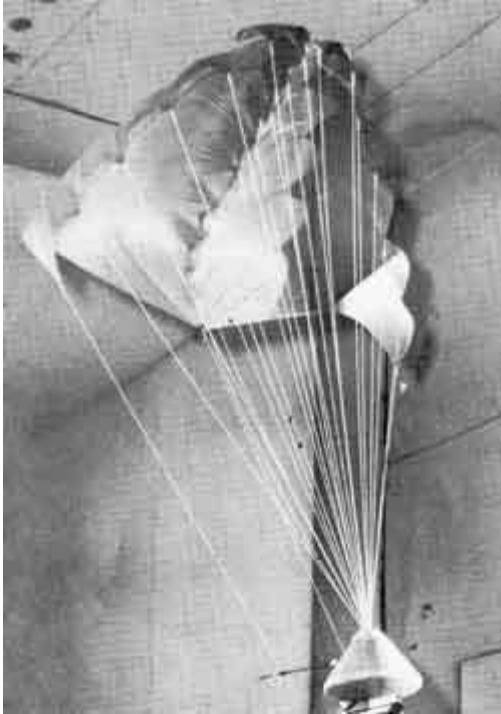


Fig. 7. Original NASA ParaWing for Gemini capsules

### C. Tests

The quality of opening of the parachute nearly exclusively depends on the folding. The optimal one is found drop after drop. Thanks to the simplicity of the ParaWing, once the optimal folding has been found, it is easy to be repeated.

The sink rate of the parachute is relatively easy to settle: there are quite precise formulas to determine speed versus surface area. Horizontal velocity adjustment is made by modifying empirically the angle of attack thanks to shroud length corrections. This is also the technique used to improve flight symmetry.

The controllability of the parachute is the ability to rotate without stalling or folding, and to stabilize it after a turn. The tests consist in rotating the servomotor step by step until the parachute stalls or folds. The constants  $c_{\min}$ ,  $c_{\max}$  and  $\lambda$  are determined by successive drops.

## VI. CONCLUSION

In two years, two versions of MORPHEUS and three competitions, the team never managed to complete the “come

back” mission and land on the target. These failures were principally attributable to the parachute.



Fig. 8. 2010 integrated Morpheus

This year the calendar is more test-oriented than ever and the free mission should dramatically simplify the parachute improvement – at least for next years. This new mission can be considered as a foundation for future CanSats.

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