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Development of an Actuator for an Airdropped Platform Landing System

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Abstract

This work presents an actuation system that aims at improving the maneuvering capability during the landing phase of the LAICAnSat platform. The LAICAnSat is a low-cost, modular platform for high altitude applications, such as remote sensing, telecommunications, research, development and innovation within the aerospace field. The landing system uses a ram-air parachute that is actuated by servo motors located on a pseudo 2U CubeSat platform. This platform differs from the actual

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CubeSat standard due to the actuation mechanisms on the outside of a 2U standard module. A brake lines actuator is responsible for the directional, speed and glide ratio control. The paper provides details of the design, realization and testing of the actuation system, which represent a first attempt in the development of an autonomous landing system for the LAICAnSat.

Contents

1 Introduction

High altitude platforms are interesting devices for conducting research and perform technological activities. At the same time, they can be used as educational tools in aerospace engineering given their relatively low manufacturing and launch cost. The LAICAnSat is a project with the goal of designing, manufacturing, launching and operating a high altitude platform. The platform is composed of a pseudo-satellite which carries on the payload and all the subsystems needed for the mission (on-board computer, radio, batteries, payload, etc.). The pseudo-satellite is attached to a latex balloon that rises up in the sky until it explodes. The descent of the pseudo-satellite to the ground is controlled through a parachute.
The project started in 2013 [1] at the University of Brasilia and so far several missions have been executed. While the first launched version of the platform was a simple proof of concept of the main elements of the mission, the following launches have involved an ad-hoc designed platform that is being continuously improved and upgraded: the structure and on board computer have been designed in accordance with the CubeSat standard, the telemetry & tracking system is based on the APRS technology [5]. The platform has been employed in a scientific mission that successfully filmed the solar eclipse of August 2017 from the stratosphere in the framework of the NASA ballooning initiative [4]. One of the future goals of this project is to develop a control system for safely landing the platform by automatically steering the parachute. Preliminary studies of the aerodynamic model [2], the guidance strategy [3] and of an altitude control

system for floating the balloon [6] have been realized in previous stages of the project.
Automatic steering is a very important feature for the realization of unmanned

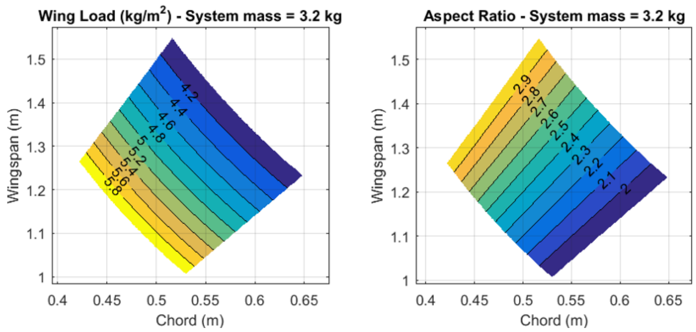

Figure 1: **Envelope of the wingspan and chord of the canopy.**

airdropped platforms. Models of equations describing the motion of a parachute & payload system have been proposed in the past [7]. Proposed methods of control include glide-slope control [8], model predictive control [9] and optimal control [10]. Steering can be obtained through the deflections of several surfaces, such as canopy spoilers, and trailing edge left and right brakes (either asymmetrically or symmetrically).
The contribution of this paper lies in the complete description of the design, realization and testing of an actuation system for the lines of the parachute to be implemented in future flights of the LAICAnSat project. The actuation system is composed of a steerable parachute and the servo mechanisms that are used to pull the left and right edges of the parachute to provide the directional, speed and glide ratio commands. Fig. 2 shows a schematic of the main elements of the actuation system.

The detailed design of the actuation system is made with the definition of

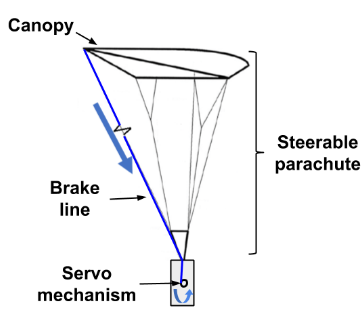

Figure 2: **Schematic of the main elements of the actuation system.**

specific solutions that meet the project requirements. The system has been

manufactured and tested in laboratory trials as well as in flight tests.
This paper is organized as follows: Section 2 describes the design and manufacturing of the actuation system; Section 3 describes the realized tests; conclusions are given in Section 4.

2 Design and realization

This section will describe the design and realization of the landing system actuator. The actuator is composed of the parachute and the servo motors that pull the lines of the parachute. The design will be driven by the definition of the requirements. The second step will be the selection of a suitable parachute according to the wing load (WL), the aspect ratio (AR) and the center of gravity (CG) positioning. Then the servo motors will be presented and eventually the manufacturing of the system.

2.1 System requirements

System requirements are mainly defined in accordance with a typical LAICAnSat mission profile. This involves some specifications on maximum touchdown speed and maneuverability of the vehicle, for example. Since this design will be tested in a real mission only in the future, though, some specifications will be related to the validation of the aero-electro-mechanical landing system in a realistic, but controlled flight test. This is the case of the control commands, which will be sent by a human operator, since a complete control system has not been implemented yet.
The system requirements are:

- Maximum touchdown vertical speed: 5 m/s;
- Actuators manually controlled by using a radio control system;
- The landing system must be sufficiently maneuverable to deviate from a tree or other obstacle;
- The parachute canopy must be initially folded and deployed by a remotely controlled actuator.

2.2 Selection of the parachute

The first requirement that must be taken into account when selecting the parachute type is that it must be steerable. The most known steerable parachutes are the Ram-Air [11] and the Cruciform Parachutes [12]. Cruciform parachutes have a great drag coefficient and are largely used for decelerating big payloads, such as land vehicles and aircrafts. This geometry is very stable in pitch and roll, but severely unstable in yaw movements. Cruciform parachutes may spin uncontrollably, so they have a low controllability [13].

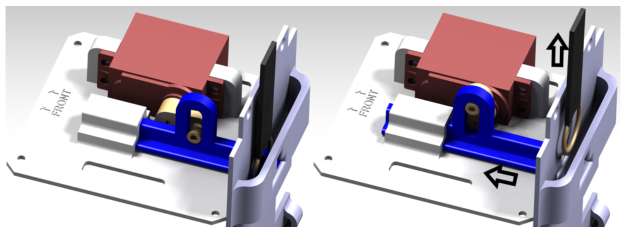

Figure 3: **Canopy deployment actuator.**

Figure 4: **Brake lines actuator.**

On the other hand, a ram-air parachute is roughly an airfoil with an open leading edge, which allows to create an air inlet. The airfoil inflates with air intake and it becomes similar to a wing, generating two aerodynamics forces: lift (vertical) and drag (horizontal). It is the only parachute type that decreases its vertical velocity by using a lift force and not a drag force. This canopy type has a great maneuverability and is used worldwide for civil and military purposes [13]. The Ram-Air parachute is the most suitable when maneuverability is a requirement.
Knowing that maneuverability is an important mission requirement, it is reasonable to use a ram-air parachute. It is then necessary to calculate the geometrical parameters that drive the selection of the canopy. Three parameters will be taken into account: AR, WL and the CG positioning. A suitable AR for a parachute system should be between 1.9 and 3 [13].

$$1.9 \leq AR = b^2/S \leq 3 \tag{1}$$

where b is the wingspan and S is the wing surface.
Next, it is necessary to set the WL limits, which is the load carried by one area unit. Since the payload mass is well defined, the WL is useful to select the parachute surface. The wing load for a ram-air parachute system must be between 4 kg/m^2 and 6 kg/m^2 [14]. So,

$$4 \leq WL = m/S \leq 6 \tag{2}$$

where m is the total mass of the system, including the canopy mass.
Estimating a mass of 3 kg for the CubeSat and 0.2 kg for the parachute system, the total mass is going to be 3.2 kg. Using the AR and WL limits previously defined, it is possible to see graphically the upper and lower envelope for the canopy wingspan and chord. Fig. 1 shows the ideal envelope of the canopy and will help choosing a suitable canopy.
The third geometrical parameter that will be taken into consideration is the CG positioning. It has an important impact on the parachute flight conditions, and initially it will be considered only its influence on the trimmed Angle Of Attack (AOA). During the flight, the payload oscillates as a pendulum around the trimmed AOA, α_{trim}. The trimmed AOA is usually between 3° and 10°, depending on the airfoil profile. If α_{trim} is too small, the canopy may collapse; if α_{trim} is too high, the canopy may stall. The following equation is used to determine α_{trim} [14]:

$$\alpha = \frac{1 + \sqrt{1 + 4\frac{h_0}{d_0}(1 - D_2 a)\left(\frac{h_0 D_0}{d_0 a} + \frac{c_{media} C_{m0}}{d_0 a} - i_0\right)}}{2\frac{h_0}{d_0}(1 - D_2 a)} \tag{3}$$

where h_0 is the vertical distance from the CG to the aerodynamic center, d_0 is the horizontal distance from the CG to the aerodynamic center, D_2 is the three-dimensional induced drag coefficient, a is the three-dimensional lift coefficient

vs angle of attack curve slope, C_{m_0} is the bi-dimensional aerodynamic moment coefficient and i_0 is the bi-dimensional zero lift angle of attack.
Having calculated those geometrical parameters, it is possible to select an off-the-shelf canopy that meets the mission requirements. The selected canopy for the mission is a rectangular canopy, with a chord of 0.6 m and a wingspan of 1 m. It has an AR equals to 1.7, slightly lower than the recommended one (1.9). Therefore, it means that this canopy is marginally less maneuverable than a canopy with the recommended AR. The parachute has a mass of 0.2 kg so the mass of the LAICAnSat for the flight test may be between 2.2 kg and 3.4 kg to meet the recommended WL (between 4 kg/m^2 and 6 kg/m^2).

2.3 Actuation system

To achieve the system requirements, at least two actuators are necessary. Firstly, it is required that an actuator deploys the canopy, which is folded during the initial phases of the mission and must be deployed only in the landing phase. The developed deployment device uses a servo motor in order to create a scotch-yoke-actuator that releases the ring of the deployment bag, which is mounted on the top of the LAICAnSat. The deployment actuator, an exterior wall of the LAICAnSat and the deployment ring are shown in Fig. 3.
The second required actuator must pull up the brake lines of the parachute and so control the direction and the velocity of the system. Two servo motors are used on this actuator, each one having a maximum torque of 13.2 $kgcm$, an angular velocity of 257.1 $°/s$ and a range of motion of 2826°. Fig. 4 shows the brake lines actuator.
Finally, the actuators are disposed on the LAICAnSat stack in order to maintain the system CG as low as possible, because it helps on the system stabilization when deploying the parachute. Fig. 5 represents the LAICAnSat general assembly and the actuator position.

2.4 Realization

All of the actuators - as most of the LAICAnSat - are manufactured using 3D printing technology with PLA (PolyLactic Acid). The assembled structure with the parachute and the deployment bag are shown in Fig. 6.

3 Flight test

The flight test was realized with the support of a paramotor, which flew over a predetermined area and released the LAICAnSat from a height of 243.2 m. After that, the deployment actuator was remotely triggered and the parachute deployed, reducing its vertical velocity. Fig. 7 shows the flight path of LAICAnSat during the flight test, with a top view (a) and a lateral view (b). The line between the blue and the red markers represents the paramotor trajectory before releasing the LAICAnSat and the line between the red and green markers is the

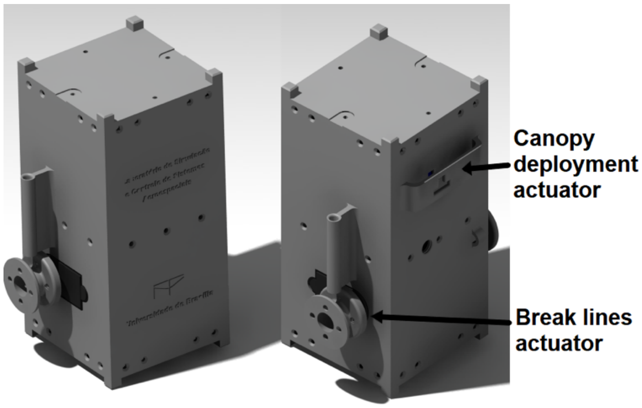

Figure 5: **Position of the actuators on the general assembly of the LAICAnSat.**

Figure 6: **LAICAnSat assembled structure.**

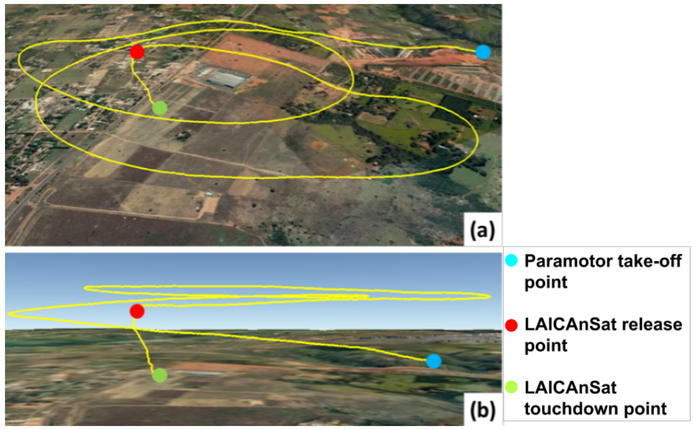

Figure 7: **Flight path of the LAICAnSat during the flight test: top view (a) and lateral view (b).**

LAICAnSat descendent trajectory.
During the deployment, the parachute lines got tangled, probably because the LAICAnSat was spinning when the deployment started. That caused a twisting descent with the canopy barely deployed and it was not possible to control the flight velocity and direction with the brake lines actuator. Because of that, the LAICAnSat landed with a vertical speed greater than the maximum required. Fig. 8 shows the vertical speed of LAICAnSat during the descendent trajectory. The canopy deployed on time 5.7 s, with a vertical velocity equals to 23.13 m/s. The vertical velocity reduction is evident, but not enough, and the LAICAnSat landed with a vertical velocity equals to 11.92 m/s on time 20.5 s. Despite the fact that the touchdown speed was 138.4% greater than the maximum required, the LAICAnSat structure and electronics were not damaged.

4 Conclusions

This article described the development of the LAICAnSat landing system, including a simple methodology for canopy selection. It was also carried out a flight test of the developed system. The deployment mechanism was very efficient and had a quick response. For now it was not possible to evaluate the brake lines actuator behavior in flight. However, it had a good performance during the ground tests.
More tests are necessary for better describing the system behavior, including a high altitude test. That is important because the LAICAnSat needs more falling time for stabilization (to reduce the spinning speed) before beginning the canopy deployment. Also, it is possible to make some physical changes on the LAICAnSat structure in order to mitigate the possibility of getting the parachute lines tangled. An example of physical modification is to make larger

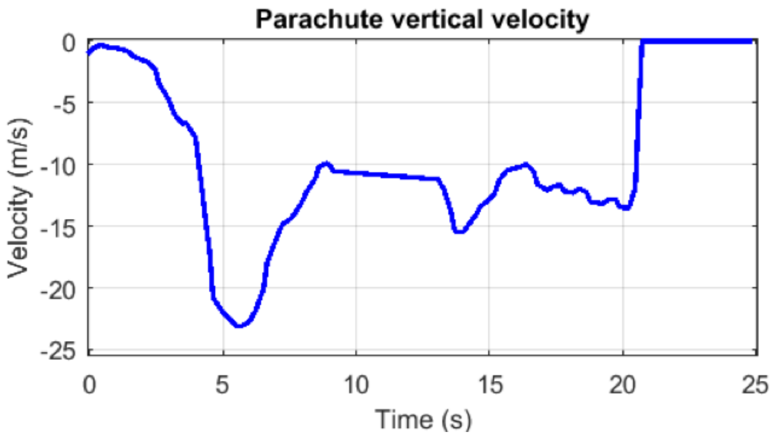

Figure 8: **LAICAnSat vertical velocity during the descendent trajectory.**

conduits for the brake lines on the LAICAnSat side.
Future developments of this research depend on more flight tests and system modifications according to the tests results.

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