Educational Test Bench for Attitude Control of 1U Cubesats

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Abstract— **In this paper, we present a test bench intended to test attitude control of 1U Cubesats. This platform, based in air bearing principle, is intended for educational purposes. It is designed according to the principles of modularity, low costs and usability. We have built the frame and the cubesat model using additive manufacturing techniques. Our design is affordable, easy to reproduce and based in COTS. We also present a basic 1U cubesat frame that fits inside a sphere, allowing a full 360º movement around all axis. The cubesat model is equipped with reaction wheels and manetorquers.**

Keywords— cubesat, attitude control, education, Project based learning, opensource

I. INTRODUCTION

A deficiency in the teaching of spacecraft technology is the lack of hands-on practical sessions that quite often rely on computer simulations only. This approach offers to the students a limited understanding of the complexity of the full system and miss some important hardware related aspects such as EMC, limited availability of power, physics time constants, communication latency, manufacturing tolerances, etc. The only way to highlight all this issues is to use real engineering models in practical sessions. However, the use of flight-qualified components for this purpose is limited by its high price, limited availability, lack of documentation and complexity of use. On the other hand, the integration of both open source resources (for software and hardware as well) and COTS (Components Of The Shelve) offers a wide range of possibilities to address this challenge. These resources are available at low price (or even for free!) and are popular among engineering students, so the learning time is really short. This approach is not only useful for educational purposes but for technology demonstrators and validations of actual systems for flight in early stages of development.

Several works follow this line. For instance, in [1] a 1DoF testbench for testing attitude control algorithms of a 1U cubesat with flexible apendages, which represents the deployed solar arrays of the spacecraft. In [2], a reaction wheel assembly is developed from scratch in the frame of a cubesat developed by students. Finaly, [3] shows a similar initiative focused in teaching activities at Master level.

In this paper, we present a test bench intended to test attitude control of 1U cubesats. This work is the result of a final project of double engineering degree (Mechanics and Electronics) conducted in our Faculty and follows the same approach that all abovementioned works. As in [4], we demonstrate that outstanding and high motivated students from other disciplines can successfully develop space related projects.

Although the main purpose of both the test bench and cubesat model is the test of attitude control, we can easily perform many experiments related with other subsystems of the spacecraft, such as power management, communications, control algorithms, software engineering, actuators design, packaging, etc. Moreover, this platform can be easily used to foster educational space related activities among high school students and STEM subjects as well.

This paper is organized as follows. In sections II.A II.B we describe the air bearing and the cubesat model respectively. In section III we suggest some practical sessions that can be conducted with the proposed test bench. Finally, we outline the conclusions and future works.

II. SYSTEM DESCRIPTION

A. Airbearing Test Bench

It is worth to mention the arrangement of the cubesat under test. Instead of lying on top of a platform with a limited range of movement, as the most common case is [5-6], the cubesat model fits inside a sphere that "floats" on top of the air bearing, as it is shown in Figure 1. This arrangement allows a free rotation of 360º in all axis. However, if it is necessary, we can fit the EUT, a larger cubesat arrangement of 3 or 6 units, on top of a hemisphere, according to the most common arrangement.

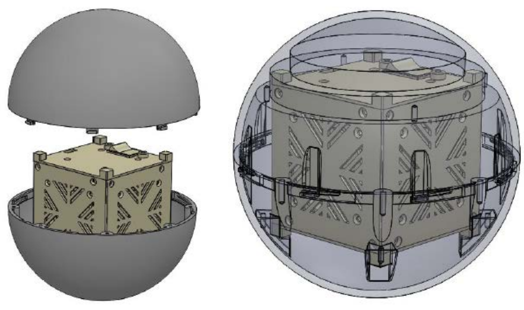

Fig. 1. Cubesat fitted inside the sphere

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We can operate the testbench in three ways. The first one is to fit the 1U cubesat under test inside the sphere, thus allowing a 360º of freedom in all directions, as it has been already mentioned. In this mode, we have the opportunity to test ACS in a complete range of movements. However, we need to balance the sphere in order to compensate uneven mass distribution of the cubesat under test. In the second mode, we can remove one half of the sphere. In this case we have a range of movement limited to 60º of inclination. For instance, this is the configuration that should be used to test suntracking algorithms. Figure 2 illustrates this arrangement. Finally, in case to test a larger spacecraft, we ca attach a solid platform to one of the hemispheres.

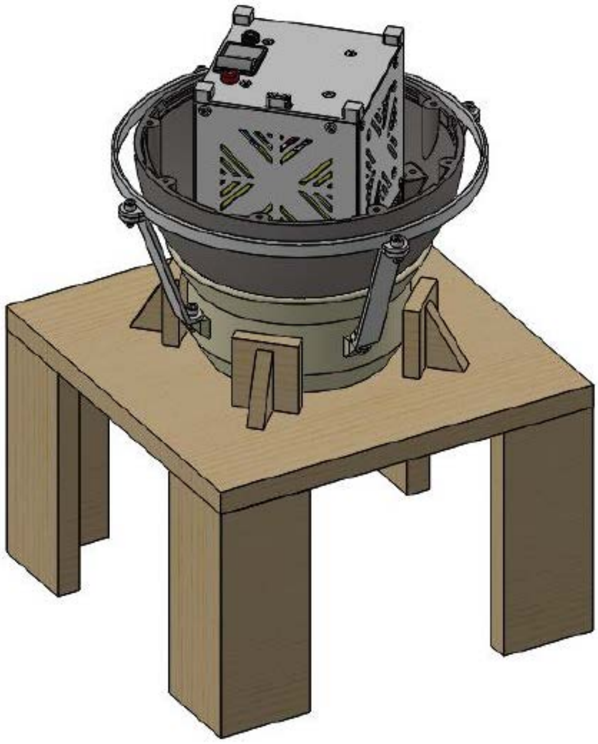

Fig. 2. General view of the test bench. The ring outside the hemisphere limits the movement to 1 DoF

Additionally, we have designed an attachment that reduces testbench DoF to one in order to tune a single controller at once. We have used FlowSimulation-SolidWorks to simulate airflow and the distribution and diameter of holes in the base frame as well [7]. Figure 3 shows a view of the air bearing base.

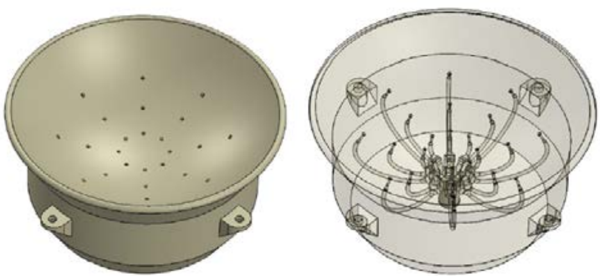

Fig. 3. Detailed view of the base of air bearing and air channels

As we have used plastic materials for the 3D manufacturing process, this testbench is suitable to attach some coils in order to produce a magnetic field and, therefore, test ACS based on magnetorquers.

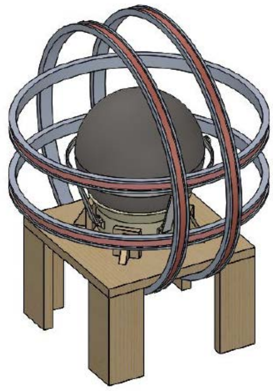

Fig. 4. Test bench with coils to test ACS based on magnetorquers (for the shake of clarity one set of coils are not shown)

B. Cubesat Engineering Model

Moreover, we have designed a 1U cubesat frame using a modular approach, in such a way that it is easy to replace the equipment on board. In this way, you can test flywheels or magnetorquers of both simultaneously. Regarding the cubesat model, Figure 5 shows the basic configuration that consists of 3 flywheels, a 9 DoF Inertial Measurement Unit (accelerometer, gyroscope and magnetometer), a wireless communication board, battery pack and 3 light sensors.

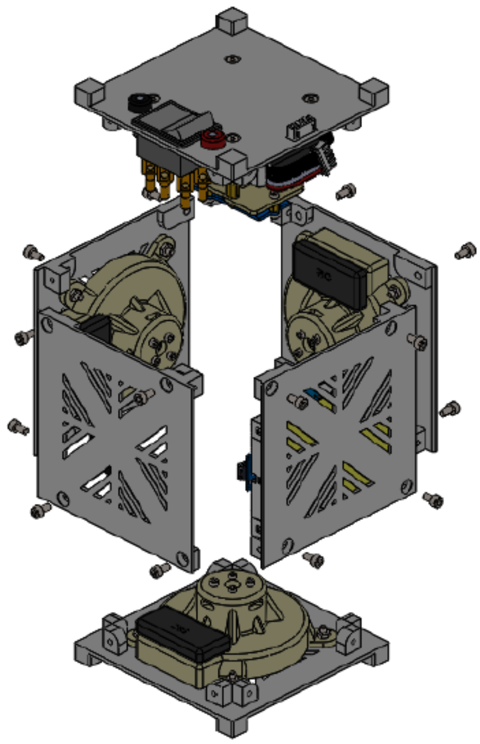

Fig. 5. Exploded view of the cubesat with 3 reaction wheels assemplies, battery pack (upper face) and control board.

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We have also designed some faces of the cubesat equipped with PV arrays. In addition, we have also designed some payloads as cameras or laser pointers. Figures 6, 7 and 8 show a view of the battery pack, an exploded view of the reaction wheel assembly and how it is attached to a cubesat face, respectively.

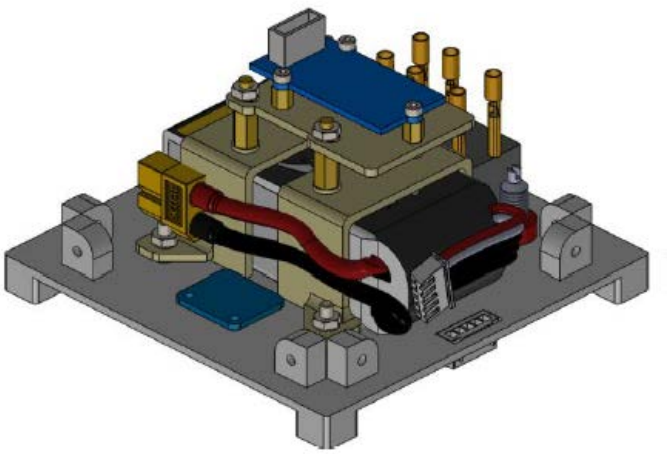

Fig. 6. Detailed view of the battery pack

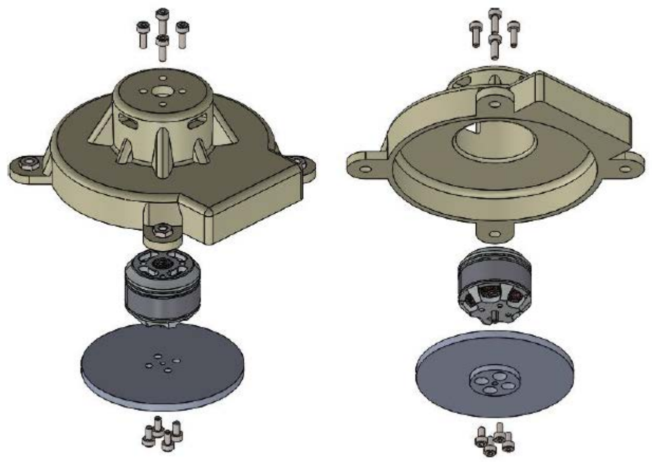

Fig. 7. Detailed view of reaction wheel assembly (brushless motor, inertial mass and housing)

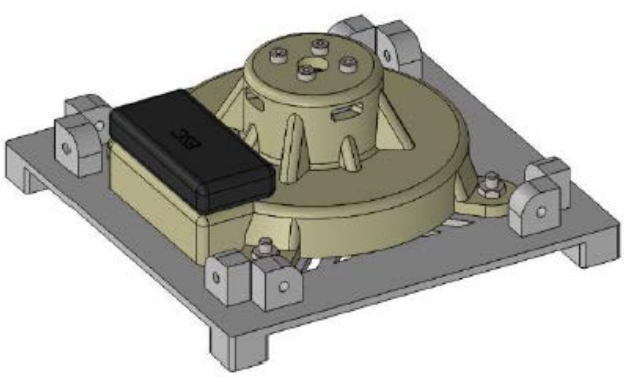

Fig. 8. Full reaction wheel assemply attached to a cubesat face

Figure 9 shows the block diagram of this basic configuration.

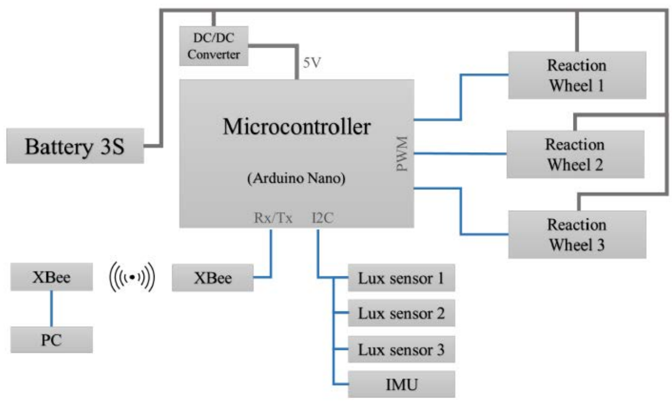

Fig. 9. Block diagram of cubesat engineering model

Table 1 summarizes the main components we have used.

TABLE I. MAIN COMPONENTS

Component	***Qty***	***Features***
Arduino Nano[a]	1	5V ; 16MHz ; 32kB Flash-
TATTU LiPo Battery	1	11,1V ; 3s ; 1550mAh, 45C
MN1806 Brushless motor	3	1400KV
ESC Emax BLHeli	3	-
IMU - MPU 9250	1	I2C, accel, gyro, magnet.
TSL2561, Lux sensor	3	I2C,0.1-40,000lux

III. POSSIBLE PRACTICAL WORKS

In this section, we suggest a set of possible topics that can be studied using this test bench and cubesat model as well. Please, consider this list as a mere suggestion. This list can be enriched by the contributions of the community. With this test bench it is easy to address several basic engineering concepts in different fields such as control, power distribution, communications, mechanical packaging, etc.

A. Control engineering

- Tune a PID controller using the 1 DoF setup
- Compare controllers in terms of different criteria, such as accuracy, power consumption, etc.
- Use different type of controllers (Fuzzy, neural-networks, etc.)
- Use the 3DoF setup to test a full ACS.
- Test ACS for sun tracking.
- Test ACS in the conditions considered [1]

B. Power management

- Test different MPPT (Maximum Power Point Tracking) algorithms for solar arrays.
- Test several power distribution architectures.
- Evaluate the combined performance of sun tracking and MPPT algorithms in terms of energy harvest.

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C. *Communications & Data Mangement*

- Impact of a communications latency in spacecraft performance

D. *Mechanics*

- Impact of tolerance on mechanic performance of the ACS
- Optimization of reaction wheel assembly

IV. Conclusions

In this paper we have presented a testbed based in the air-bearing principle intended for the test of Attitude Control System of 1U cubesats. In addition, we also present an engineering basic model of cubesat that allows the development of a wide variety of hand-on projects. We have used additive manufacturing techniques for mechanical parts, COTS for electronics hardware and open source software. This set is affordable and modular and it can be used for teaching purposes in universities at degree or master level or for STEAM activities in high school as well.

In future works, we want to develop a simulation model of the systems in order to correlate actual behavior and simulation results and thus, highlight the existence of “non-ideal” behavior that are intrinsic to actual systems.

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