CUBESATS: A COST-EFFICIENT WAY TO VALIDATE TECHNOLOGICAL BRICKS

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I. ABSTRACT

The main reason for miniaturizing satellites is to reduce the cost of deployment. CubeSats accomplish several high-level goals, offering opportunity to test components in space within a short time for instance. Suitable for launch in multiples using excess capacity of larger launch vehicles, the CubeSat design specifically minimizes risk to the rest of the launch vehicle and payloads. They are relatively cheap and easy to build which allow them to be an interesting solution to improve TRL of new technologies.

In this paper we first give a brief description of CubeSats. Then we explain how to develop your own CubeSat with details about electrical, mechanical and software interfaces.

Finally, two study cases in the context of the FISICA (Far Infrared Space Interferometer Critical Assessment) program will be shown: the implementation of a high sensitive accelerometer and a miniaturization of the hypertelescope concept.

II. INTRODUCTION

Offering the advantages of low cost and rapid development, CubeSats are considered excellent platforms for space-born testing of key technologies. This is why the development of such a mission is included as part of the FISICA study, aiming to improve the Technology Readiness Level (TRL) of key technologies for a future large infrared space missions, such as FIRI (Far IR Interferometer), up to TRL 9.

The use of accelerometers on board of the formation flying satellites offers the opportunity to implement control loop algorithms keeping the satellites in the appropriate positions with the necessary precision during the observation periods.

While the critical technology brick that was selected for implementation on such a platform was an accelerometer developed by Assist in Gravitation and Instrumentation (AGI) in Rome, it was decided to also implement a miniature, non free-flying, demonstration of the hypertelescope concept.

III. CUBESAT DESCRIPTION

A CubeSat is a standard of nano-satellite for space research combining 1, 2 or 3 satellite units (U), having a volume of exactly one liter (10 cm cube), has a mass of no more than 1.33 kilograms, and typically uses commercial off-the-shelf (COTS) components for its electronics. CubeSats offer the advantages to be developed in a very short time-scale with low cost and they are usually launched in 'piggyback', using excess capacity of launch vehicle.

Beginning in 1999, California Polytechnic State University (Cal Poly) and Stanford University developed the CubeSat specifications to help universities worldwide perform space science and exploration.

In 2004, with their relatively small size, CubeSats could each be made and launched for an estimated $65,000–$80,000. This price tag, far lower than most satellite launches, has made CubeSat a viable option for schools and universite. Because of this, a large number of universities and some companies and government organizations around the world are developing CubeSats — between 40 and 50 universities in 2004, Cal Poly reported.

The standard 10x10x10 cm basic CubeSat is often called a "1U" CubeSat meaning one unit which can be stacked in order to increase the resources available for the payload.

Following a thorough study of available COTS components and their cost and performance, the table below defines available resources for the payload hosted by 1, 2 or 3U allowing us to choose the one suited for our technology validation experiments should meet these specifications.
### Table 1 – Resources available for payload

<table>
<thead>
<tr>
<th>Type</th>
<th>1U</th>
<th>2U</th>
<th>3U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload mass</td>
<td>390 g</td>
<td>1310 g</td>
<td>2650 g</td>
</tr>
<tr>
<td>Payload height</td>
<td>44 mm</td>
<td>110 mm</td>
<td>210 mm</td>
</tr>
<tr>
<td>Available power</td>
<td>0.6 Watts</td>
<td>1.8 Watts</td>
<td>3.5 Watts</td>
</tr>
<tr>
<td>Mission examples</td>
<td>Educational</td>
<td>Technology demonstration</td>
<td>Amateur radio</td>
</tr>
<tr>
<td></td>
<td>DTUsat – 1</td>
<td>Rincon – 1</td>
<td>Delfi – C3</td>
</tr>
</tbody>
</table>

### IV. INTERFACES

1. **Mechanical interfaces**

Since CubeSats all have cross-section 10x10 cm regardless of length, they can all be launched and deployed using a common deployment system. CubeSats are typically launched and deployed from a mechanism called a Poly-PicoSatellite Orbital Deployer (P-POD), also developed and built by Cal Poly. The P-POD is a rectangular box with a door and a spring mechanism, as shown in Figure 1. P-PODs are mounted to a launch vehicle and carry CubeSats into orbit and deploy them once the proper signal is received from the launch vehicle. P-PODs have deployed over 90% of all CubeSats launched to date (including unsuccessful launches), and 100% of all CubeSats launched since 2006.

![Figure 1 – CubeSat deployment system P-POD](image)

2. **Electrical interfaces and connectors**

Like bigger satellites, CubeSats have to be equipped with several modules:

- an EPS (Electrical Power System) which handle power consumption inside of the CubeSat
- an OBC (On-Board Computer) which is the head of the mission
- a communication module to connect to the ground station

These modules are available off-the-shelf and the standard version is the PC 104 electronic board. They can be stacked through the PC 104 stack connector. Many features are available through this stack connector to connect a payload to an electronic card: CAN bus, SPI channel, UART, 3.3 V or 5.5 V input, Ground (GND),… and connection can be achieved by using a simple pin connector.

In addition of this stack connector, picoblade connectors are also available to connect the payload as shown on the Figure 2.
A1 to A6, USART and PC are picoblade connectors and H1 and H2 compound the stack connector.

With COTS components, the payload shall operate using unregulated power, 3.3V or 5.5V.

3- Software implementation

One of the most important technological evolutions that make CubeSats so interesting is the development of smartphone technologies during the last ten years. The smartphone drastic requirements for powerful processors operating on tiny batteries have provided unprecedented processing power to consumptions ratios. For instance, this allows our Cubesat CPU board to run at 40MHz while only sipping 70mA of current.

The same technological evolution has also been beneficial on the software side as embedded development has become something much more streamlined than what it used to be. As such, integrated development environments like Eclipse are now available for space-worthy systems, running free real-time operating systems and using standard compilers like gcc for C/C++ code. This does simplify drastically the development for flying systems, admittedly at the cost of reliability and redundancy.

From a practical standpoint, writing software for a Cubesat is now similar to writing software for any embedded platform. However, embarked software remains one of the most critical aspects of a Cubesat mission. As resources devoted to a Cubesat are relatively low it is all the more important to be able to rely on stable and efficient drivers for all the subsystems so that application engineers can focus on the instrument.

V. PAYLOAD IMPLEMENTATION

Taking into account the dimensions of our payloads (accelerometer and hypertelescope), a 2 Units CubeSat will be required for this mission. The following standard avionics will be on board:

- NanoPower P-series for the power module, which will provide photovoltaic power conversion up to 10W with an on board 1.8 Ah lithium ion batteries, allowing up to 6 hour autonomy for the CubeSat.
- Nanomind A712D for the on board computer with its high-performance 32-bit ARM7 RISC CPU and 2GB MicroSD card support for data (especially for pictures)
- Nanocom U482C for communication system, providing up to 4800 baud uplink and 9600 baud downlink for data transfer

1- Accelerometer payload

The cube-sat implementation of a single-axis version of such an accelerometer is designed to demonstrate the Technology Readiness Level (TRL) of this key element for a Far-Infrared interferometer, i.e. the functionality
of an accelerometer that can be the fundamental element to be used in a control loop of the interferometer to control its dynamic.

Custom interfaces have been made for the accelerometer. The electronics part was split in two and set next to mechanical part in order to cut down the payload height, as shown on Figure 3. Electrical and data physical layer drivers are done by standard PC/104 pin connectors and data transfer will follow the CubeSat Space Protocol.

![Figure 3 – Accelerometer implementation](image)

2. Hypertelescope concept

We propose a miniature demonstrator of a multi aperture Fizeau interferometer based on the hypertelescope concept which could be flown on a nano satellite platform for Sun observations. The optical design and the data processing pipeline have been demonstrated on a ground testbed (see N. Baccichet and A. Caillat presentation).

In order to minimize the size and the weight of this optical bench, we expect to use the Nanocam, another off-the-shelf components, as detector. This allows to implement this interferometer into our 2U CubeSat together with the accelerometer as shown on Figure 4 since we win a factor 15 the weight and 5 on the size of the optical bench compared to our ground testbed.

Figure 4 (a) shows the flight model concept of the CubeSat, shipping all the navigation system (antenna, computer, transceiver, power module) and payloads (reaction wheel, accelerometer and hypertelescope concept) Figure 4 (b) shows a sectional view of the optical bench of the space Fizeau interferometer concept.

![Figure 4 – Hypertelescope concept implementation](image)
VI. CONCLUSIONS

We have described the design of a CubeSat platform optimized for validation of key technologies for a future far infrared interferometer mission such as FIRI. The proposed platform is a 2U CubeSat, and we have described its design in terms of standard CubeSat avionics, navigation components and communication software.

Two payloads are included, one for testing of a high-precision accelerometer, a fundamental element for the dynamic control loop of a space-based interferometer, and one allowing miniaturized demonstration of a multi-aperture Fizeau interferometer in space.

The development of a flight model will be the next step in order to perform space tests and validate the TRL 8 for the accelerometer and to acquire scientific data in space with our interferometer.

ACKNOWLEDGEMENTS

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REFERENCES


V. Iafolla et al, “FISICA (Far Infrared Space Interferometer Critical Assessment) Metrological problems and system requirements for interferometric observations from space”, in: Metrology for Aerospace, IEEE 2014.
