Simple-1: Development stage of the data transmission system for a solid propellant mid-power rocket model

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Abstract. This paper presents the development stage of a communication module for a solid propellant mid-power rocket model. The communication module was named Simple-1 and this work considers its design, construction and testing. A rocket model Estes Ventris Series Pro II\textsuperscript{\textcopyright} was modified to introduce, on the top of the payload, several sensors in a CanSat form factor. The Printed Circuit Board (PCB) was designed and fabricated from Commercial Off The Shelf (COTS) components and assembled in a cylindrical rack structure similar to this small format satellite concept. The sensors data was processed using one Arduino Mini and transmitted using a radio module to a Software Defined Radio (SDR) HackRF based platform on the ground station. The Simple-1 was tested using a drone in successive releases, reaching altitudes from 200 to 300 meters. Different kind of data, in terms of altitude, position, atmospheric pressure and vehicle temperature were successfully measured, making possible the progress to a next stage of launching and analysis.

1. Introduction

Colombia has an incipient aerospace sector, with only one satellite in orbit named Libertad 1, designed by Universidad Sergio Arboleda between 2004 and 2007 for academic purposes [1]. In the same way, at industrial level, the situation is not very different, as there are few companies working on space exploration, there is not yet a critical mass of initiatives to enter into the demanding aerospace industry. Mostly advances in aerospace topics are in academy, which is the case of Proyecto Uniandino Aeroespacial (PUA) planned by Universidad de los Andes [2] and most recently the Universidad de Antioquia with the undergraduate program in Aerospace Engineering [3].

There is a gap in the aerospace thematics in Latin America [4]. Space exploration has allowed the creation of new market prospects and new technologies that have improved our global economy and have achieved improvements in our lifestyle [5]. A way to close the gap in countries without previous research on these issues is throughout CanSat missions [6] and the experimentation with rockets projects, as an useful strategy to educate people by training...
in hands-on experience activities. Training of people will also help in the development of multidisciplinary skills useful in more complex missions such as project management, teamwork abilities, manufacturing process, design of experiments, communications subsystem development and big data analysis [7, 8, 9].

CanSat is a standard form factor of a nano-satellite with a volume around 350 ml and a mass about 500 g, that has a shape of a cylindrical rack structure [10, 11, 12]. All basic functions of a satellite are represented in CanSats, such as the Energy Power Supply Subsystem (EPS), the Communications Subsystems, Command On Board & Data Handling (CO&DH) and Payload Subsystem. A CanSat could perform several experiments such as altitude control measurements, image capture, downlink of several sensors [13, 14, 15], and differential GPS measurement.

Electronics applications such as flight instrumentation, avionics or communications subsystems can be tested in sounding rockets or even in some commercial rocket models, because they provide a practical form to test extreme conditions such as thrust, vibrations, acceleration, atmospheric pressure and thermal variations.

Figure 1: Simple-1 CAD model distribution detail

The Simple-1 mission was created as an initial step to contribute in the development of aerospace topics in our universities and region. The objective of this mission was to learn about the manufacturing processes of components for the emergent aerospace industry in our country. The total integration scheme of the mission is shown in Figure 1. The name of the mission was not selected by a deliberate consensus, it was just a curious way of referring to the mission, in an attempt to appropriate design methods that reference the KISS principle (Keep It Super Simple [16]), by means of selecting items that using low power transmission, low consumption and easy to get.

In the first part of the paper the critical aspects of electronic design of the mission, and the technical specification of the components used are documented. Secondly the results are exposed. Finally the last part of the paper the conclusions, the discussions and future work recommendations for the following stages of testing and launching of the Simple-1 mission are given.

2. Methodology
Dynamic and structural factors of the rocket were considered to make the selection of the components according to the characteristics of useful weight and its trajectory. The Simple-1 is divided in four subsystems: The communication, the Energy Power Supply (EPS), the Command on Board & Data Handling (CO&DH) and the payload subsystem. For the communication subsystem the radio module were selected and the antenna were manufactured. The EPS was designed considering the power requirements of all the components and the operation time of the mission. The CB&DH was selected taking into account the microprocessor capabilities. When
the basic subsystems were established, the payload, consisting of several sensors, was designed and integrated.

2.1. Rocket dynamic conditions
Once the commercial rocket model and their payload weight capacities were chosen according to the volume available, the geometry of the rocket was subjected to dynamic simulation using open source OpenRocket Software, as shown in Figure 2. This software uses the Runge-Kutta 4 (RK4) integration method as a numerical solver, which is a fourth-order integration method; for this reason, the total simulation error is of the order $O(\Delta t^4)$. This simulation was made with the goal to determine the maximum velocity and acceleration factors in the trajectory estimated for the solid propellant motor [17, 18].

Estes Pro Series II Ventriz (9701) Stock
Length: 117 cm, Max Diamter: 6.98 cm
Mass (with motor): 494 g

Stability: 2.28 cal
CG: 82.2 cm
CP: 98.1 cm

Altitude: 460 m
Max Velocity: 171 m/s (Mach Number: 0.5)
Max Acceleration: 188 m/s²
Flight Time: 91.4 s
Time of Apogee: 7.7 s

Figure 2: OpenRocket simulation view at initial position and orientation the rocket at time $t=0$.

This rocket has a dead weight equal to 500 g and reaches an approximate altitude of 460 m according to simulations using a Estes composite rocket motor (G80-7T) that generates a maximum thrust of 108 N.

2.2. Electronic components selection
According to the design requirements for the mission the electronic components were selected. Some characteristics of the Simple-1 electronic module are shown in Table 1.

2.3. Communication system
The communication subsystem was divided in two groups: The flight segment and the ground segment. The flight segment was composed by the Radiometrix (NTX2-434.650) module, several SMD (Superficial Mounting Device) LED indicators, a SMA (Surface Mounting Antenna) connector and a coaxial antenna cable adapted to the antenna. The antenna consist of quadrupole geometry that works as a ground plane and the antenna radiator which was calculated for the wavelength of the radio-frequency used (16.4 cm). The sensors data is send to the Radiometrix from the Arduino using a PWM signal that assigns a specific voltage level shifting between two values that represent different frequencies from the antenna. The Figure 3 shows the operation schematic of the subsystems on flight.

The second segment is a ground station based on a Software Defined Radio SDR architecture. The radio used was a HackRF. The data was received via a link between the software to receive data from SDR radios named SDR# or GQRX with the decode software DL-FLDIGI throughout a virtual audio cable. The Figure 4 shows a diagram of the operation of the communication ground station subsystem.
Table 1: Electronic Components: Simple-1 Module

| Component                  | Reference                      | Features                                                      |
|----------------------------|--------------------------------|----------------------------------------------------------------|
| Main onboard computer      | Arduino Mini Pro              | • Clock: 16 MHz                                               |
|                            |                                | • Flash Memory: 32 KB                                         |
|                            |                                | • SRAM: 2 KB                                                  |
|                            |                                | • Microcontroller: AT-mega328                                  |
| Data Storage               | MicroSD Data Logger            | • Flash Memory: 8 GB                                          |
| Data Transmitter           | Radio Metrix NTX2              | • Frequency: 434.650 MHz                                      |
|                            |                                | • Channel Spacing: 25 kHz                                     |
|                            |                                | • Data Rate: 10 kHz                                           |
| Position Measurement       | GPS Ublox NEO 6M GY-GPS6MV2    | • Update Rate: 5 Hz                                          |
|                            |                                | • Position Accuracy: 2.5 m                                    |
|                            |                                | • Velocity Accuracy: 0.1 m/s                                  |
| Inertial Measurement       | 3Ch Accelerometer LSM303       | • ±2, ±4, ±6, ±8, ±16g at 16bits                              |
| Unit IMU                   | 3Ch Magnetometer LSM303        | • ±2, ±4, ±8, ±12G at 16bits                                  |
|                            | 3Ch Gyroscope L3GD20           | • ±245, ±500, ±2000°/s at 16bits                             |
|                            | Barometric Pressure BMP180     | • +9 – 0.5 at 16bits                                         |
|                            | Temperature Sensor BMP180      | • 0to65°C at 16bits                                          |
| Energy Storage             | Battery LiPO                  | • 7.2V, 200mA                                                |

2.4. Energy Power Supply subsystem (EPS)
The EPS subsystem is composed by two LiPo batteries joined in series, a mini DC-DC Buck Step Down power conversion module, a switch and a capacitive element to reduce the noise rate level of the power input signal to feed the Arduino. A connector to charge the battery and to access the payload inside the rocket structure is part of this subsystem. A structure to hold the batteries in place was manufactured using a 3D printer.

2.5. On Board Data Handling (OB&DH)
The OB&DH subsystem of the Simple-1 was composed by the Arduino pro mini (Atmega168) and a data external storage using a MicroSD Datalogger. The Arduino module receives all the data from the sensors connected and distribute its capacity by saving data into the MicroSD datalogger and sending packets to the Radiometrix module. These two process have different velocities, saving more data per unit of time that the data per unit of time of the Radiometrix channel. The total code size is:
• Program memory used: 27,158 bytes (88%)
• Dynamic memory used: 1,504 bytes (73%)

The use of the 8-bit micro-controller limited the amount of computing capabilities and the libraries were reduced to optimize it. Transmission of information through the output of the Radiometrix at 50 Bd was successfully achieved.
2.6. Payload (Sensors)
Generally, the Cansat missions as rocket’s payload, besides of having internal storage subsystems, are designed to send in the more near real-time possible data transmission from the remote measurements devices in the descent flight. The intention was to test the concept of using a communications subsystem that provides information of different stages of the rocket flight, considering the ascent and descent time and the redundancy that the storage subsystem (SD) provides. The sensors of the Simple-1 compose the Payload subsystem: the analog accelerometer \((x, y, z)\), the Inertial Measurement Unit (IMU), the GPS and the temperature and altitude sensor.

3. Results
3.1. Altitude Simulation
According to the simulation of the rocket with its characteristics and the payload (Figure 5), it was estimated that the flight time is around 91.4 s, reaching a maximum altitude of 460 m. That

![Vertical Ascent vs Time](#)

Figure 5: Plot of the flight simulation trajectory Estes Ventris Series Pro II®

3.2. Payload
The payload was designed from the dimension considerations of the Estes rocket in order to introduce it in the upper internal part. The radiator monopole was assembled in the center of the array ground plane structure. The dipoles of the ground plane were placed in the orthogonal plane to the axis of the rocket what makes them excel from the structure of it. Due to the fact that the antenna ground plane dipoles are attached to the rocket structure, it was necessary to accomplished a Drone altitude test to check the range and stability of the signal transmitted. The chemical etching method was used to generate the tracks of the circuit as a practice to generate some experience in the team about the PCB manufacturing process. First the board was designed using Eagle and then was printed and transferred over the copper with heat, the etching method was implemented. (Figure 6).

This first approach of the module allowed a successful transmission of data from sensors attached on it. This allows the formalization of the electronic design methods, and also allow reduce the cost and time for the next printed circuit using an industrial process. The final board is presented in Figure 7.
3.3. Drone altitude test
Quadricopter tests were made in order to prove the transmission distance and calibrate the payload. The Simple-1 was elevated to altitudes in the range between 200 to 300 m as is shown in the Figure 8.

Figure 8: Simple-1 being tested in a quadricopter

In the first test some noise was detected in the data packets but insignificant. The first experiences were made transmitting at a data rate of 50 Bd.

3.4. Distance test
A long distance test has been implemented, seeking to measure the capacity of the transmission module. In this test two static positions were established, the T position corresponds to point data transmission, and the R position corresponds to the point of receiving the data. Both points will have a range among themselves of 1.3 Km in the city of Medellín. The geographical location of these points is in the Figure 9. This test allowed to verify the distance of transmission of the payload. The Data packets were transmitted at a rate of 300 Bd, with a maximum gain of 43 dB and a minimum gain of 24 dB. The importance of this test is that was conducted in a real environment, with natural and artificial obstacles, which affect the transmission of data. It should be noticed that this type of environment, in terms of radio frequency data transmission, can become an hostile environment for the amount of noise and electromagnetic interference.
4. Conclusions
In order to reduce the volume of this kind of modules is necessary to get experience in the electronic development using Surface Mounting Devices (SMD). The test communication procedures of the CanSat Simple-1 made in the drone flight and in the test between two sight line points allowed to transmit data successfully and check the transmission range of the payload. The system should attempt to shield the circuits in order to prevent different sources of noise. This is a detailed activity that requires knowledge to characterize individually each component to generate the appropriate ground shields for the components that required it and to make the appropriate physical distribution of the components and subsystems for next developments. Is important to understand the frequency noise that generate each subsystem and also understand more about external radiation source to prevent the integrity of the module.

Discussions
In future work it is recommend the use of two independent computing modules for the communication, the data reading and storage subsystem because each one needs a critical computing time operation. The use of at least two modules of each sensor or system on board is a good practice to improve the exactness of the measurements.

Is important to improve the fact that the communication module is sensitive to temperature changes increasing or decreasing. A shift in peak frequency is noticed with the temperature variation and this make difficult the signal tracking. Was necessary to track the signal due to the change to keep the transmission stable. Is important to think in temperature stabilization mechanisms for this module in the next future developments.

The pseudo-analog signal sent to the Radiometrix using the PWM of the Arduino probably has big influence to the noise of the signal transmitted because it has a frequency signal of $36 \text{kHz}$ that was chosen over the default low PWM frequency that present an poor performance in the ration signal-noise. Is recommended to ensure a cleaner and stable signal without sacrificing response time between high-voltage and low bit because it could disable communication transmissions, using low pass filters according to the frequency of the RTTY data speed used.

The radio that was used is more commonly suitable for high altitude balloon missions because the data rate transmission are less demanding. It is important to assume considerations like the
data rate transmission before the design of the communication subsystem. If the interest is in the measures during the ascent stage and also transmission is important to think in a radio with more fast data rate transmission, if the focus on the mission is to collect data and not necessary the near real-time transmission the descent period will be enough to collect and transmit some data.

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References
[1] Portilla J G 2012 Revista Académica Colombiana de Ciencias 36 491–500 ISSN 0370-3908
[2] Faculty of Engineering U d l A Pua: Proyecto uniandino aeroespacial pua URL https://pua.uniandes.edu.co/doku.php
[3] Cañas E Nuevo programa de ingenieria aeroespacial
[4] Sarli B, Cabero M, Lopez A, Cardoso J, Jimenez D, Roman-Gonzalez A, Villena G, Vargas-Cuentas N I and Perazzo P 2015 66th International Astronautical Congress-IAC 2015 p 11
[5] Lockney D, Schwerin B and Rademakers L 2010 National Aeronautics and Space Administration: Spinn Off document 2010 Tech. rep.
[6] Bautista-Linares E, Morales-Gonzales E A, Herrera-Cortez M, Narvaez-Martinez E A and Martinez-Castillo J 2015 1–4
[7] Nakasu S, Sako N, Sahara H, Nakamura Y, Eishima T and Komatsu M 2010 Acta Astronautica 66 1099–1105 ISSN 0094-5765 URL http://dx.doi.org/10.1016/j.actaastro.2009.09.029
[8] Yamaura S, Akiyama H and Kawashima R 2011 RAST 2011 - Proceedings of 5th International Conference on Recent Advances in Space Technologies 856–860
[9] Miyazaki Y and Yamazaki M 2013 RAST 2013 - Proceedings of 6th International Conference on Recent Advances in Space Technologies 1081-1086
[10] Soyer S 2011 RAST 2011 - Proceedings of 5th International Conference on Recent Advances in Space Technologies 789–793
[11] Gansmoe T, Mathisen S V, Grande J, Nielsen J F D and Rossing N K 2013 The CanSat Book
[12] Ykis H A, Apacak R Y, Agirbas O, Abur S and Soyer S 794–799
[13] Nehme P H D, Borges R A, Cappelletti C and Battistini S 2014 1–7 ISSN 1095-323X
[14] Gopal G, Harith B, Raj R, Savyasachi J and Umadi C 2016 6 5181–5184
[15] Sivaramakrishnan R 2014 International Journal of Innovative Research in Computer and Communication Engineering 2 2335–2339 ISSN 320 -.9798
[16] Fulcher E and Patil S 1994 Multipitch Modules, 1994. Proceedings of the 1994 International Conference on (IEEE) pp 572–577
[17] Niskanen S 2013
[18] Niskanen S 2009 Helsinki University of Technology