Stratospheric balloon platform for experiments at altitudes up to 40 km

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ABSTRACT

The Earth's atmosphere at altitudes between 20 and 40 km is relatively understudied due to the challenging access to this atmospheric layer. Airplanes rarely reach these altitudes, and sounding rockets travel too quickly to remain at this altitude for sufficiently long periods. The only effective way to study this atmospheric layer is through stratospheric balloons. This paper describes a system developed by a team of students from the Instituto Tecnológico de Aeronáutica (ITA, Brazil), consisting of a system (telemetry, onboard electronics, and data acquisition and storage subsystems) carried by stratospheric balloons to conduct scientific experiments and also serve as a testing platform for systems and components intended for use in nanosats. A balloon flight using this platform, which carried a Geiger-Müller counter, is also described.

Keywords: Ballooning, Radiosonde, Ionizing radiation.

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INTRODUCTION

Humanity has always dreamed of conquering the atmosphere. The invention and development of balloons (manned or unmanned) were the tools that allowed humans to travel at high altitudes and explore the atmosphere for the first time. The history of ballooning spans over three hundred years. In the Western world, Bartolomeu de Gusmão demonstrated in 1709, through a prototype, how a hot air balloon could achieve flight (Visoni and Canalle, 2009). The Montgolfier brothers successfully launched a hot air balloon carrying domestic animals in 1783; the first manned balloon flight occurred just 2 months after the Montgolfier brothers' flight and had 2 crew members, Rozier and François Laurent d'Arlandes (Gillispie, 2014). The first manned hydrogen balloon was also launched in 1783 by Jacques Charles and the Robert brothers (Watson, 1946). Scientific ballooning began in 1804 when Gay-Lussac reached an altitude of 8,000 m, measuring air temperature, pressure, and humidity during the flight (Yajima et al., 2009). In 1902, V. F. Hess ascended to 5,000 m and, with a simple ion chamber, measured how the number of cosmic rays varied with altitude (Riggi, 2023). Compact and autonomous systems designed to probe the atmosphere were introduced with the invention of the radiosonde in 1929 by R. Bureau. Radiosondes are typically used to measure atmospheric parameters such as temperature, humidity, and pressure as they ascend through the atmosphere. State-of-the-art radiosondes are now produced by a number of manufacturers in different countries (Ingleby, 2017)

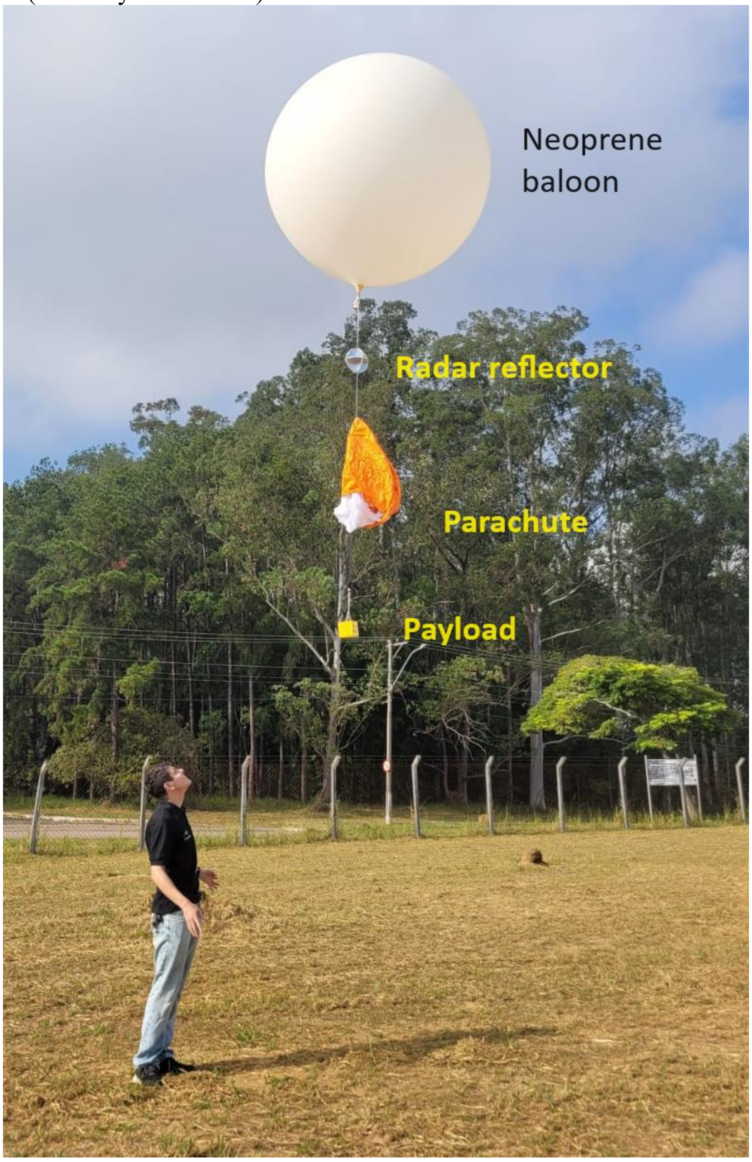
Due to the increasing miniaturization of components, the reduction in their costs, and greater access to information, university and high school students have ventured into the activity of launching balloons for research (e.g., Voelzke and Pereira, 2022; Lee and Conklin, 2016; Coleman and Mitchell, 2014). Usually, the main interest of the students is focused on obtaining pictures of the Earth from high altitudes, to visualize the Earth's curvature, and to perform a series of environmental measurements, such as ionizing radiation and meteorological parameters. Other experiments may consist of studying the effects of ionizing radiation and low temperatures on animal and plant cells and tissues as a function of altitude.

To conduct these studies, it is necessary to develop a low-cost, easy-to-assemble platform to transport these experiments. This platform should include a GPS system to track the balloon during its flight, a barometer and thermometer to measure atmospheric pressure, data acquisition and storage subsystems, as well as a telemetry system capable of communicating with a ground station at distances of up to 300 km. These balloon launches should occur preferentially during the turn-around period. On these days, the stratospheric winds are close to zero velocities and without preferred directions, causing the balloon to remain almost vertically above its launch point. During this period, the recovery of the experiment is more likely, and the measurement time is greatly increased (Redkar, 1981). In this study, such a system was built, and the results of a flight to measure and record the variation of ionizing radiation in the atmosphere with respect to altitude are presented.

MATERIALS AND METHODS

The platform used, as seen in Fig. 1, is called CurieSat V2, named in honor of Nobel Prize-winning physicist Marie Curie. It was developed in 2023 by the ITACube team, an extracurricular group of ITA students focused on the development of nanosatellites and affiliated with the ITA Space Center (CEI). The system was designed to be a useful, low-cost platform accessible to anyone interested, containing only components available in the Brazilian market. It consists of a 1-kg latex/neoprene TX balloon from Kaymont Consolidate, a radar reflector, a parachute, and a payload containing the electronics and a Geiger-Müller counter. The balloon was filled with approximately 2.5 m^3 of helium. The total mass of the payload was about 1 kg.

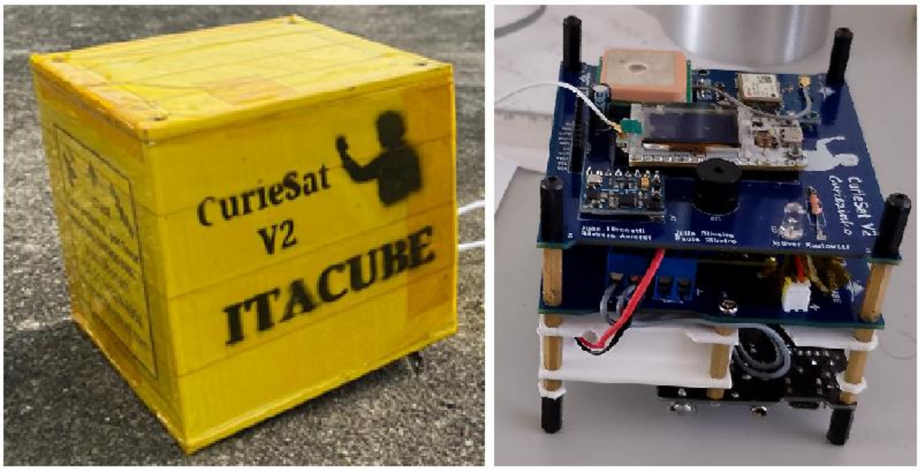
Figure 1. Sounding platform just after its release. Its initial vertical velocity was approximately 5 m/s. This launch occurred on April 29, 2024. (Photo by the authors)



In Fig.2 is shown a detail of the payload container and its interior, with some of the electronics visible.

The payload is equipped with an inertial sensor system consisting of an MPU6050 and a QMC5883L magnetometer, a Neo-6m GPS locator, and a BMP280 barometer. Additionally, the system carries a payload consisting of a circuit and a Geiger counter operating a J305 tube, of Chinese origin. The data from these sensors are collected and processed by a Heltec LoRa Wifi v2 board, which contains an ESP32 microcontroller. The system has the capability to record data on an SD card and transmit it directly via a 915 MHz LoRa radio link with a transmission power of 100mW.

Figure 2. Payload box (left) and electronics boards (Photos by the authors)

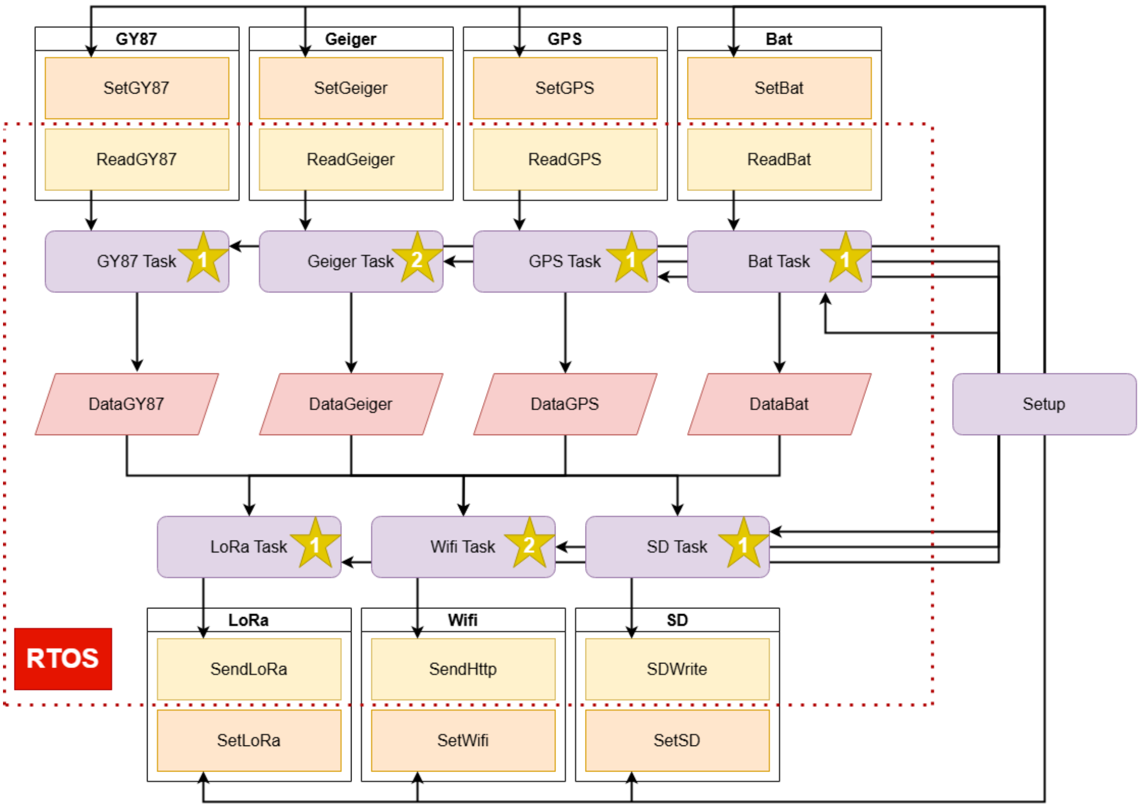


The payload box is made of polylactic acid plastic (PLA), with internal insulation made of extruded polystyrene (XPS) and externally coated with Kapton. A 1000 mAh lithium polymer battery provides 6 hours of autonomy to the satellite and is stored in a separate compartment from the satellite, also made of PLA with additional XPS insulation. It is important to note that the structure completely protects the J305 Geiger tube in the payload from sunlight, preventing potential interference with the measurements.

The embedded software in the system uses the ESP-IDF framework, leveraging the functionalities of FreeRTOS. The system is based on two sets of tasks, as shown in Figure 3: data collection tasks and data consumption tasks. The first group contains tasks that read data from the sensors and store it in shared memory between processes. The second group reads the shared memory and either transmits the data to the ground station or stores it on an SD card. The software also implements error checking at startup and a system watchdog to enhance robustness.

The ground station used for tracking the balloon consisted of a Yagi antenna with a 915 MHz transmitter, a Heltec LoRa Wifi v2 radio, and a personal computer. Using the GPS data received via radio from the platform, the ground station calculates the azimuth and elevation of the balloon for manual adjustment of the directional antenna. The platform also included, as a redundant measure, a Sinotrack car tracker for location via GSM network to assist in recovering the experiment on the ground.

Figure 3. Diagram of the system's instruments and associated electronics

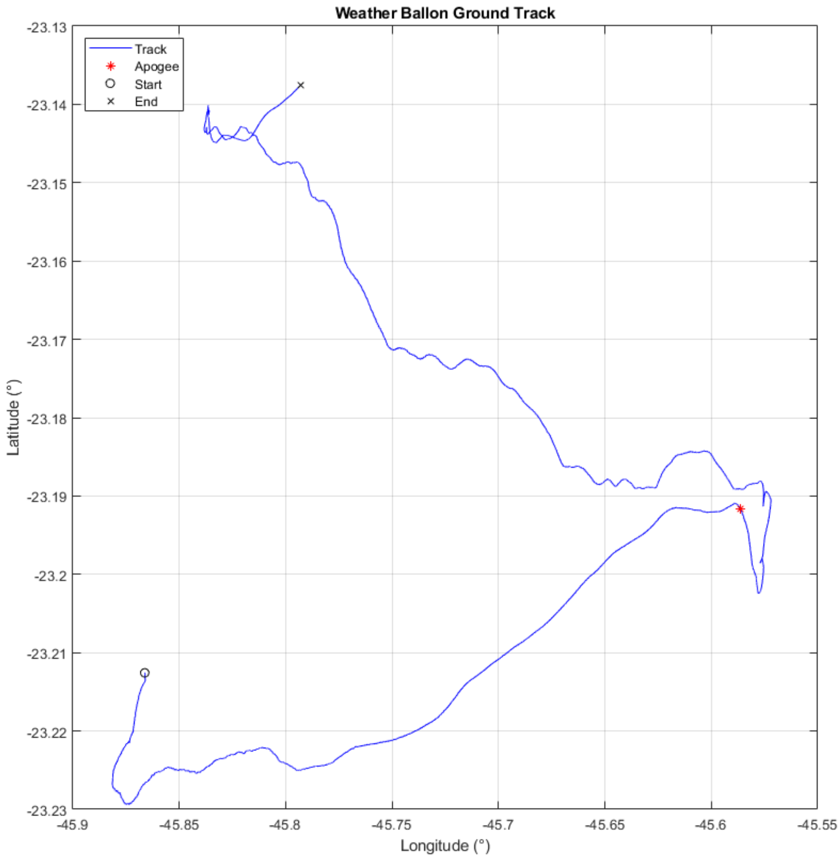


RESULTS AND DICUSSION

Figure 4 shows the projection on the Earth's surface of the path traveled by the balloon over time. This graph is determined by the GPS signal and the pressure sensor located on the balloon. Figure 5 plots the pulse count values measured by the Geiger counter as a function of altitude relative to the ground. This profile of ionizing radiation intensity with respect to altitude and location provides information about the radiation dose at the flight point, which is an important parameter that should be known across Brazil. The measurements of the ionizing radiation profile with respect to altitude and time could help verify the presence of external agents, such as nuclear experiments, that may introduce this type of radiation into the environment. Additionally, large solar explosions can produce extensive secondary nuclear radiation in the Earth's stratosphere, resulting in an increase in the ionizing radiation

in Earth's atmosphere. In Fig. 5, it is clearly visible the Regener-Pfotzer Maximum at an altitude of approximately 16 km (Regener and Pfotzer, 1935).

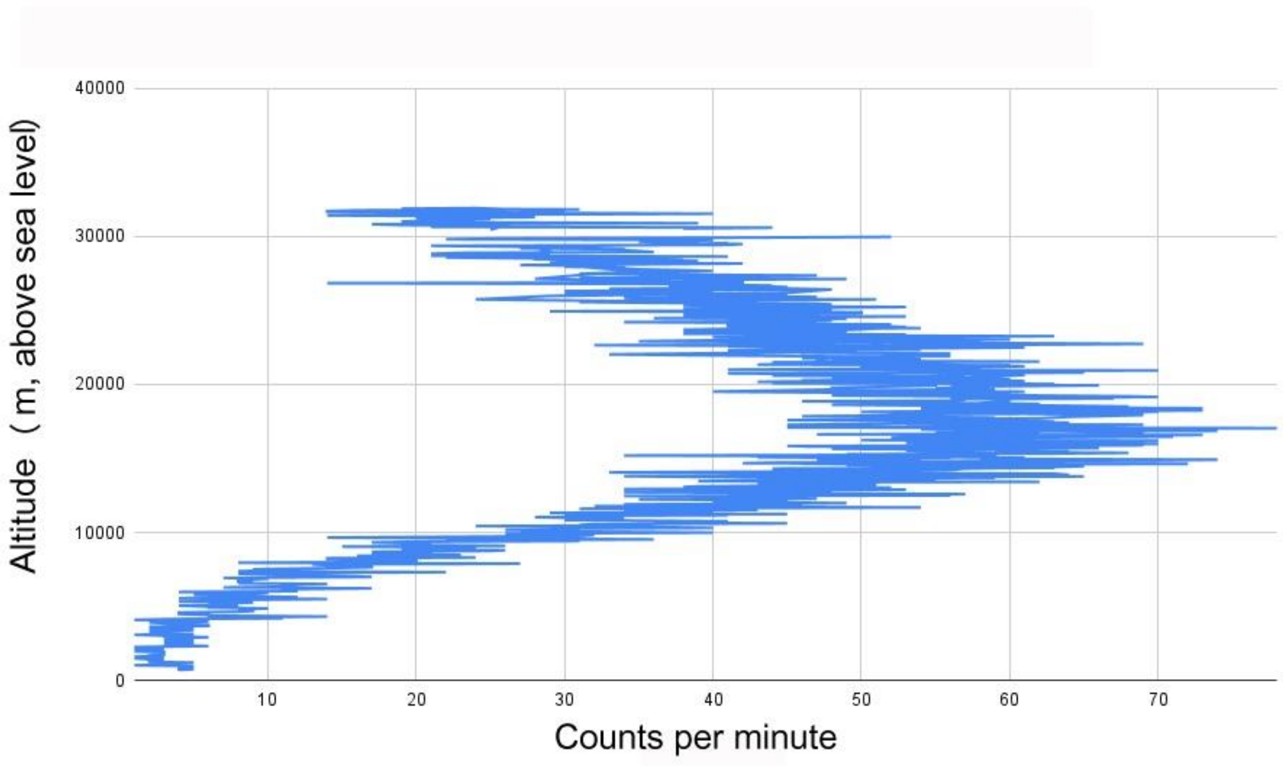
Figure 4. Track of the balloon projected on Earth's surface. The empty circle, the red circle and the "x" mark, respectively the launch site, the position of the highest altitude reached by the balloon and the fall site.



CONCLUSION

This work, carried out by ITA students from various fields, demonstrates a simple yet important system for other groups in Brazil to use for conducting various types of measurements between the ground and 40 km altitude. For such measurements, a reliable telemetry system is essential to maintain a continuous ground-balloon-ground link, even at horizontal distances of up to 300 km. A good GPS receiver and atmospheric pressure sensor onboard the balloon enabled the determination of the balloon's altitude, latitude, and longitude, as well as its recovery on the ground. This successfully tested balloon-ground telemetry system allows interested parties to conduct intriguing experiments in the lower atmosphere of the Earth. Our ITA team utilized this opportunity to determine the ionizing radiation profile between the ground and 40 km altitude in the São José dos Campos region, SP, Brazil, as shown in Figure 5.

Figure 5. Counts per minute of ionizing radiation as a function of altitude measured by the Geiger-Müller counter. The Regener-Pfotzer Maximum is observed at an altitude of approximately 16000 m. The total ti flight time was about 2 h and 30 min.



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