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Small launch platforms for micro-satellites

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Abstract

The number of small satellites launched into orbit has enormously increased in the last twenty years. The introduction of new standards of micro-satellites has multiplied the launch demand around the world. Nevertheless, not all the missions can easily have access to space: not all kinds of micro-satellites have granted a deployer system and, furthermore, once a micro-satellite is able to reach it, it cannot usually choose its final orbit. Recently two new platforms have been introduced for the release of micro-satellites as piggy-backs. These platforms are totally operative spacecrafts that act like *motherships*, and allow to select some parameters of the final orbit of the piggy-backs. They provide a solution for three different nano-satellites standard, and at the same time they are being developed in order to reach more powerful orbital release capabilities in the future. The design and the mission of these platforms are described in this paper.

Keywords: small satellites; launch systems; cubesats

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1. Introduction

The last twenty years have seen a tremendous increase in the number of small satellites launched into orbit (Bouwmeester, & Guo, 2010). Small satellites are employed in several applications, ranging from educational

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projects to remote sensing, science and communications (Heidt, Puig-Suari, Moore & al. , 2000; Sandau, Brieß & D'Errico, 2010; Sandau, 2010; Simms, Jernigan, Malphrus & al. , 2012; Manghi, Modenini, Zannoni & Tortora , 2017). This versatility can be better exploited by creating constellations of small satellites, which have been recently proposed for several purposes, such as Earth observation, atmospheric measurements, and disasters management (Boshuizen, Mason, Klupar, & Spanhake , 2014; Gill, Sundaramoorthy, Bouwmeester & al., 2013; Santilli, Vendittozzi, Cappelletti & al. , 2018). Of course, this poses more specific requirements on the in orbit release.

In a spacecraft project, the launch is one of the most critical phases; furthermore, it is troublesome for the launch provider to interact with a large number of small satellites customers. Several space systems and payloads have never been tested in space due to the limited budget for launch procurement.

The majority of small satellites are launched as secondary payloads in a so-called *cluster launch* and they do not have much choice about the selection of their orbit. Furthermore, until some time ago, some micro-satellites did not either have the possibility to be launched since no launch systems able to deploy them in orbit were available. This was the case of PocketQubes and TubeSats, two recently proposed micro-satellite standards (Gill, Guo, Perez Soriano & al., 2016; Cappelletti , 2018).

Considering these restrictions, two new platforms have been developed by the italian company GAUSS (Group of Astrodynamics for the Use of Space Systems), namely the UniSat and the Tu-POD (Truglio, Rodriguez, Cappelletti & Graziani , 2015; Djamshidpour, Cappelletti, Twiggs & Biba , 2017), which can launch different kinds of micro-satellites and, at the same time, allow them to select some parameters of the final orbit. These platforms are small satellites themselves, acting like *motherships* that carry inside them smaller customers satellites. They can accommodate multiple types of micro-satellites, i.e. CubeSats, PocketQubes (UniSat) and Tubesats (Tu-Pod). The possibility to integrate a number of micro-satellites in a single platform has been one of the key factors in the success of this solution in the last years, allowing to obtain reasonable prices for the launch and simplified interactions between customers and launch providers. Furthermore, since the satellites on-board the mothership can be placed in orbit at a desired time instant, it is possible to avoid being close to other spacecrafts at release. This results in simpler identification procedures from ground and lower chances of collision with other satellites from the same cluster launch (Pontani & Cappelletti, 2013).

This paper describes the design of these platforms and the missions performed in the last years. It is organized as follows. Section 2 describes the main launch platforms for micro satellites worldwide; Section 3 presents the UniSat platform, its deployer systems and the in orbit results of the missions launched so far; Section 4 describes the Tu-Pod satellite, the release mechanism and its in orbit results; conclusions are given in Section 5

2. Launch platforms for micro-satellites

Standardized deployers were one of the reasons for the success of CubeSats. Small satellites were already launched in the decades prior to 2000, employing different launchers for orbital insertion. Nevertheless, they all differ by the capability of payload delivery and the employed deployment actuator. The standardization of the interface with the launcher, therefore, has certainly been one of the most important factors in the large increase in launches of micro satellites. The deployer must protect the launcher from any interference with the satellites, minimize the spin and collision possibilities at release and work as a mechanical interface between the launcher and as many spacecrafts as possible (Nason, Puig-Suari, & Twiggs , 2001).

Along with the introduction of the CubeSats, it came the development of the first dedicated deployer, the P-POD (Puig-Suari, Turner & Ahlgren , 2001). This system is attached to the launcher upper stage and allows the accommodation and in-orbit release of up to three CubeSats at the same time. The deployer activation time is previously scheduled and the spacecraft is released on the same orbit of the upper stage of the launcher. A small ΔV, guaranteed by a spring, provides the separation between the CubeSat and the launcher. Various similar systems have been introduced by other companies in the last years: the ISIS-POD, the RailPOD, the PSL-TPL, the XPOD, the NanoRacks and the J-SSOD are other examples of CubeSats deployer employed on several launchers and on the International Space Station. The modularity of these systems allows to realize bigger deployers that can launch up to 28 3U CubeSats.

All these deployers share the same main features and, therefore, the main advantages. CubeSats can be integrated on any deploying systems, provided that they respect the CubeSat standard from the mechanical point of view. This allows the possibility to have late swappings of satellites from one deployer to another, in case of necessity, without many difficulties. The cost of access to space is reduced since small satellites launch providers can negotiate higher volumes of mass on board the launchers. On the other hand, these systems are not ready yet to perform more complete missions that would require specific in-orbit release conditions, like time-delayed release or small orbital maneuvers, for example.

Micro satellites constellations pose more strict requirements on the release systems. Therefore, there is a need for different, more autonomous deployers that could guarantee placing a satellite on the needed orbit and not just release it when and where it is possible. Another necessity that arose in the last years is to provide access to space to other platforms besides CubeSats, such as PocketQubes and TubeSats, even though the latter still have a smaller market than that of the former. The next sections will present two platforms that represent a first attempt to solve the issues of common micro satellites deploying systems. The UniSat and the Tu-Pod platforms are two versatile, completely autonomous satellites that can release in orbit different kinds of micro satellites.

3. The UniSat platform

The history of the UniSat platform dates back to the end of the 1990s, when the first satellite of the series was designed, manufactured and launched by the Scuola di Ingegneria Aerospaziale di Roma. After four satellites launched from 2000 to 2006, the newly-established company GAUSS took over in 2012 and UniSat became a private project whose main goal was to serve as a platform for launching other micro-satellites. The mission of UniSat-5 in November 2013 was the first ever commercial launch in which a satellite carried on board and released in orbit other piggy-back satellites for commercial use. Furthermore, this was also the first time that PocketQubes were flown in space.

One of the next objectives for the UniSat platform will be to have the capability to perform small orbital maneuvers, both in and out of plane. In this way, it will be possible to release the micro satellites on different orbit conditions from those of the launcher. As a mission example, by changing the argument of perigee, it would be possible to distribute several micro satellites on the same orbit; another possibility could be that of changing the RAAN so as to modify the local solar time of a Sun-synchronous orbit and creating a constellation of spacecrafts that would pass over the same portion of the Earth at different times during the day (Marinan, Nicholas, & Cahoy ,

Feature	**G-POD**	**Other deployers (3U)**
Mass	1.9 kg	1.3-2.0 kg
ΔV	1.1-1.3 m/s	1.5 m/s
Temperature range	-16° to +7°	NA
Deployment	On demand	Fixed

Table 1: **G-POD and other deployers main features**

2013). Nowadays, UniSat is one of the two platforms for the release of micro-satellites that is looking forward to achieve this capability (Andrews , 2012). A necessary condition for performing these orbital maneuvers with the UniSat platform is the availability of an on-board attitude determination and control system (ADCS). The first step in this direction was the implementation of a passive magnetic control system on board UniSat-6. An active ADCS has been proposed for boarding in the future UniSats (Battistini, Cappelletti & Graziani , 2016).

In the following, the design of the UniSat spacecrafts will be presented, as well as the two missions of UniSat-5 and UniSat-6.

3.1. Design of UniSat-5 and UniSat-6

UniSat-5 and UniSat-6 are two spacecrafts whose main mission is the in-orbit release of smaller spacecrafts. Their design is deeply influenced by this task. Both spacecrafts have almost a cubic shape and most of the internal room is reserved to host the deployers of the piggy-back satellites. UniSat-5, shown in Fig. 1, hosted both Cubesat and PocketQube deployers, namely G-POD and MRFOD, which occupied almost 3/4 of the platform overall volume; UniSat-6 boarded only CubeSats deployers, whose doors can be seen on the top panel in Fig. 2. The first version of MRFOD was designed and implemented by Morehead State University students with the supervision of prof. Twiggs. Actually, GAUSS is working on a new version called GPQOD, that will be boarded inside the UniSat. The G-POD main features are resumed in Table 1 along with the common values of other deployers, found in the literature. Comparing the two columns, one can say that the performance of the GPOD are similar to those of other deployers, its main advantage being the possibility to perform on-demand in orbit release.

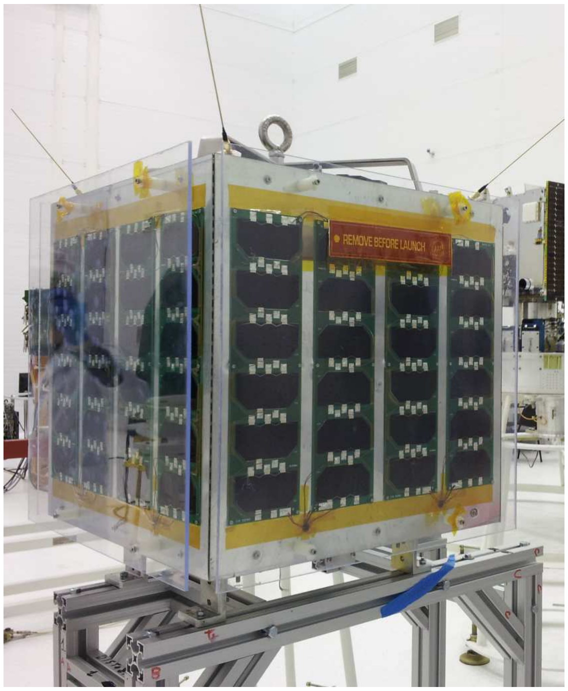

Figure 1: The UniSat-5 spacecraft at the integration

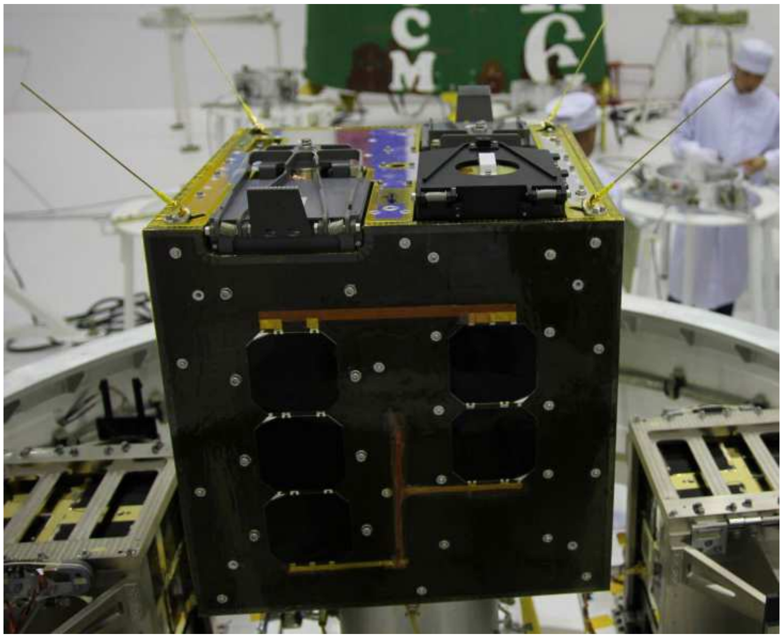

Figure 2: The UniSat-6 spacecraft integrated on the launch platform

Both satellites used the same communication system, consisting in a UHF radio and 4 antennas, and the same OBDH, based on the ABACUS computer (Nascetti, Pancorbo D' Ammando & Truglio , 2013). Both were designed to maintain an internal thermal range between -10°C and 10°C. Power is provided by body-mounted solar panels, which provide from 5 W (bottom panel) to 11 W (4 side panels) of electrical power.

UniSat-6 had a passive magnetic attitude control system, made of a permanent magnet and hysteresis rods; the stabilization of the spacecraft was verified through the data collected from the attitude sensors (magnetometers and rate gyros) (Battistini, Cappelletti & Graziani , 2016). UniSat-6 had also a camera to take pictures of the Cubesats at the ejection from the mothership and for low-resolution Earth observation images. The main features of the two spacecrafts are resumed in Table 2.

3.2. In orbit missions

UniSat-5 and UniSat-6 were launched from the Dombarovsky Cosmodrome in Yasny, Russia, on board a DNEPR-1 rocket, the former on November

Feature	**UniSat-5**	**UniSat-6**
Dimensions	50×50×52 *cm*	40×40×40 *cm*
Piggy-backs	4 Cubesats + 3 PocketQubes	4 Cubesats
Total mass	28 *kg*	26 *kg*
Dry mass	16 *kg*	16 *kg*
ADCS	None	Passive magnetic

Table 2: **UniSat-5 and UniSat-6 main features**

21, 2013 and the latter on June 19, 2014. The final orbit was in both cases a near Sun-synchronous orbit above 600 *km* of altitude. UniSat-5 carried on board four Cubesats (PUCP-Sat-1 from Perù, ICUBE-1 from Pakistan, HUMSAT-D from Spain, and Dove-4 from USA) and four PocketQubes (QB-Scout, Eagle1 and 2 from USA, and WREN from Germany), while there were other four Cubesats (Tigrisat from Italy/Iraq, Lemur 1 from USA, AntelSat from Uruguay, and AeroCube6 from USA) riding on UniSat-6. All the satellites team involved in the mission demonstrated prior to the launch the compliance of their spacecrafts with the 25-year-rules for space debris mitigation. In both missions, the customers were university groups as well as private companies.

The UniSat-5 mission established some records: it was the first time that a satellite released other satellites into space for commercial purposes; it released into orbit the first peruvian satellite; it was the first time that PocketQubes were flown. With the latter fact, the UniSat platform granted access to space for the first time to a very low-cost platform, which is crucial for researches with minimal budgets. No other systems allows the launch of PocketQubes so far.

Unlike piggy-back launches, UniSat-6 had also other mission objectives, which included the test of payloads and subsystems, such as the new telecommunication system, the solar panels, the new electronic bus and the on-board camera. Since the in orbit release of the satellites, which occurred 25 h and 38 min after the launch, UniSat-6 has been sending communications and data collected on board. Two examples of pictures taken from the camera can be seen in Figs. 3 and 4.

Figure 3: Tigrisat release as seen from the UniSat-6 camera

Figure 4: View of Italy and Northern Africa from the UniSat-6 camera

Figure 5: The Tu-Pod

4. The Tu-Pod

A TubeSat is a hexadecagon-shaped spacecraft assembled from a set of printed circuit boards. It can be classified as a picosatellite, since its weight is less than 0.75 Kg. The TubeSat envelope is almost a cylinder with an external diameter of 8.94 cm and 12.57 cm height. Due to their cylindrical shape, TubeSats cannot be accommodated in a standard CubeSat deployer, nor in any other existing device.

The idea behind the Tu-Pod was to design a release platform for TubeSats which could easily match the dimensions of any CubeSat deployer, so to have access to the well established CubeSat launches market. Of course, being a spacecraft itself, the Tu-Pod allows to release the TubeSats after some time and to perform other kinds of missions, such as the technological test of new space devices. Apart from being the only system able to deploy TubeSats, the Tu-Pod design is remarkable for the employment of an additive manufacturing technology, the so called Selective Laser Sintering (SLS). Additive manufacturing refers to a process by which digital 3D design data is used to build up a component in layers by depositing material. This technology is interesting for small satellites as it provides with a high level of freedom in the design, the optimization and integration of functional features. The additive manufacturing perfectly matches with the design of particular subsystems such as for example antenna deployer mechanisms. Tu-Pod is the results of a joint collaboration between GAUSS and the US company TetonSys.

In the following, the design of the Tu-Pod and the in-orbit results of the first mission will be presented.

4.1. Design of the Tu-Pod

The Tu-Pod is directly analogous to a 3U CubeSat, with external dimensions of $34.5 \times 10 \times 10$ cm, as shown in Fig. 5. It consists of three main parts:

- Main section
- Bottom section
- Pusher system

The main section is made with SLS. The SLS method uses a laser as the power source to sinter powdered material. The material selected was the Windform XT 2.0, a material whose previous uses were mainly for automotive racing. The Windform XT 2.0 is a carbon micro-fiber reinforced polymer material commercialized by the italian company CRP technologies.

The main section intern is completely dedicated to the TubeSats and pusher system allocation. The inner dimensions of the spacecraft allows to host up to two TubeSats in a single mission. The main section hosts also the Tu-Pod door and four rails made in aluminum with anodized sliding surfaces. TubeSats are installed in the unit by the front door. The front door is mounted to the Tu-Pod with a self-opening hinge; the door has a release mechanism consisting of a nichrome wire wrapped around a nylon bolt and connected to the electrical system that allows remote release. When a command is issued by the system logic, the cutter activates and melts through the bolt; then, the door is opened, the spring pulls the pusher plate forward, and the TubeSats are ejected.

The bottom section is dedicated to the Tu-Pod satellite electronic, power and telecommunications systems allocation. The avionics take advantages from the electronics designed and tested for the Eagle-2 mission, a PocketQube previously launched from UniSat-5. The system uses radioamateur frequencies and a very low transmitter power (100mV). Due to the short mission duration an EPS based on commercial primary batteries has been selected for the first mission. In case of future, longer duration missions, it will be possible to upgrade the EPS with the use of Li-Ion batteries and flexible solar cells mounted on the Tu-Pod cylindrical structure.

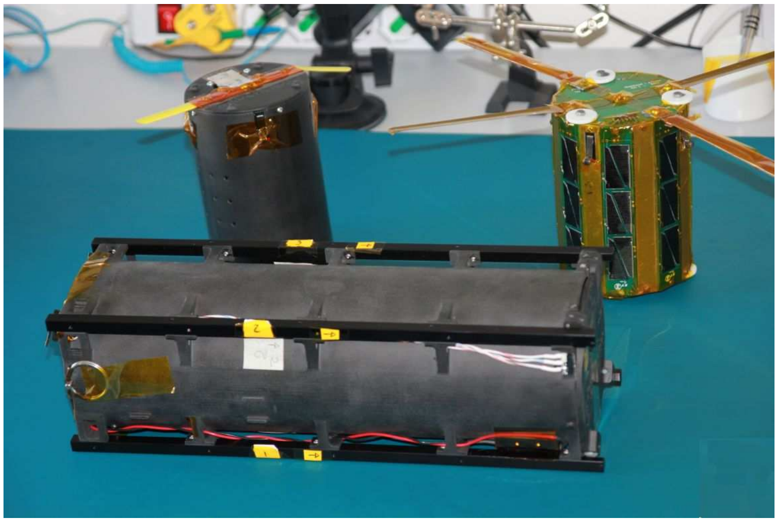

Figure 6: Integration of the TubeSats inside the Tu-Pod

The pusher system is composed of a push plate and a spring. The push plate is a simple, thin Windform XT 2.0 plate that allows the spring to homogeneously push the spacecrafts during the ejection. The plate has a shape that permits to use part of the room dedicated to the push spring to accommodate the TubeSats antennas. The push spring is made in 316 Stainless Steel. The number of coils has been designed so to limit the exit velocity of the TubeSats to 0.5 m/s in accordance with ISS safety requirements imposed by JAXA and NASA for the launch from J-SSOD system.

4.2. First mission in orbit

The first mission of the Tu-Pod was realized in 2016/2017. The main goal was the launch of the first two TubeSats ever, namely TANCREDO-1 and OSNSAT (Tikami, Moura & Dos Santos , 2017). The three satellites right before the integration at GAUSS premises are shown in Fig. 6. The Tu-Pod was first integrated in the J-SSOD deployer from the japanese company JAMSS and then flown to the International Space Station (ISS) on board an HTV-6 rocket on December 9^{th}, 2016. After a month on board the ISS, the Tu-Pod was released into orbit on January 16^{th}, 2017 from the Kibo robotic arm, as shown in Fig. 7. The final orbit was slightly lower than the ISS orbit

The Tu-Pod started operating right after the release, transmitting telemetry and a beacon to the GAUSS ground station in Roma, as shown in Fig. 8.

Figure 7: The Tu-Pod being released by the ISS

The ejection of the two TubeSats successfully occurred after three days from the release. The two TubeSats were regularly transmitting indicating the success of the main mission of the Tu-Pod. The spacecraft continued transmitting until its reentry in the atmosphere, which took place some weeks later, due to the very low orbit in which the Tu-Pod was placed.

5. Conclusions

The number of small satellites launched per year has greatly increased recently. Small satellites are always increasing their functionalities, becoming every time more performant. Along with this growth, a new set of requirements for in orbit insertions has been set. Smaller spacecrafts standards and the possibility of creating constellations of micro-satellites are now realities which the market of launch providers has to face.

Recently the italian company GAUSS has proposed an innovative concept for launching micro-satellites, that of using a mothership satellite as a carrier. Two platforms were developed, namely UniSat and Tu-Pod, which are totally operative satellites themselves and that act like a mothership, carrying a

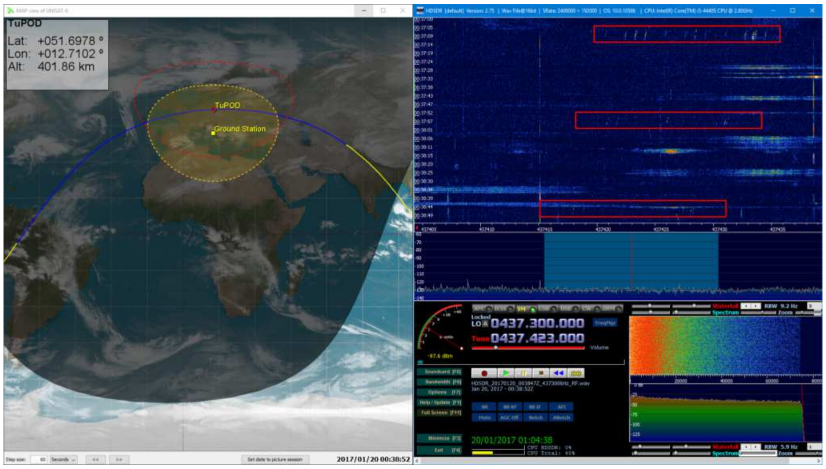

Figure 8: Tu-Pod beacon as received in the GAUSS ground station in Roma

number of micro-satellites inside and releasing them in orbit at an adequate time.

The UniSat platform is able to release in orbit two different standards of micro-satellites, CubeSats and PocketQubes. UniSat's first flight mission with this scope was in 2013, when it was the first time that a satellite released other satellites in space. As an operative, standalone platform, UniSat can perform other tasks such as test of new technologies and devices or remote sensing services.

The Tu-Pod is a satellite that allows to adapt the TubeSat standard to the dimensions of a regular Cubesat deployer, thus access to space to these kind of micro-satellites.

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