DRAGON - 8U Nanosatellite Orbital Deployer

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Abstract

The Space Research Centre of the Polish Academy of Sciences (SRC PAS) together with Astronika company have developed an Orbital Deployer called DRAGON for ejection of the Polish scientific nanosatellite BRITE-PL Heweliusz (Fig. 1). The device has three unique mechanisms including an adopted and scaled lock and release mechanism from the ESA Rosetta mission MUPUS instrument. This paper discusses major design restrictions of the deployer, unique design features, and lessons learned from development through testing.

Introduction

BRITE Constellation is a group of scientific nanosatellites whose purpose is to study oscillations in the light intensity of the most luminous stars (brighter than magnitude +3.5) in our galaxy. The observations will have a precision at least 10 times better than achievable using ground-based observations. The BRITE (BRight Target Explorer) mission formed by Austria, Canada and Poland will send to space a constellation of six nanosatelites, two from each country. BRITE-PL satellite is based on the Generic Nanosatellite Bus (GNB) from the Canadian SFL/UTIAS (Space Flight Laboratory / University of Toronto, Institute for Aerospace Studies). The spacecraft are to use the SFL XPOD (Experimental Push Out Deployer) as a separation system.

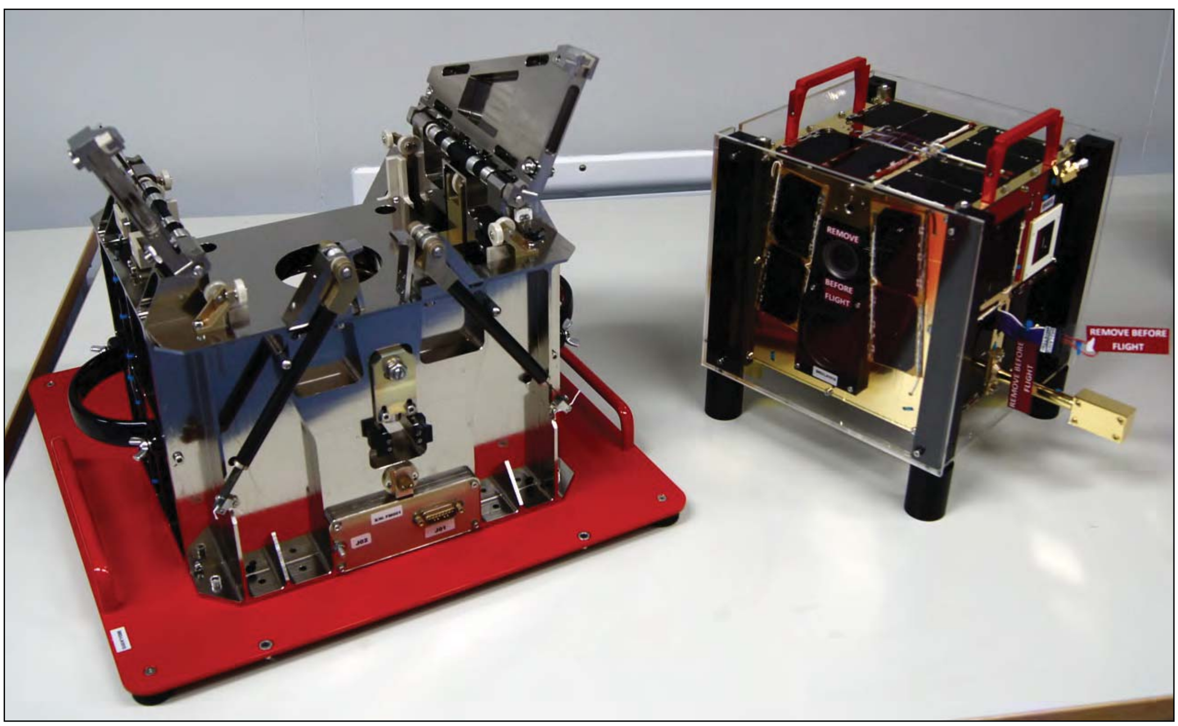

Figure 1. DRAGON Orbital Deployer and BRITE-PL Heweliusz Spacecraft (in a safety box)

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Proceedings of the 42nd Aerospace Mechanisms Symposium, NASA Goddard Space Flight Center, May 14-16, 2014

The first scientific satellite, BRITE-PL Lem, is a modified version of the original SFL design. The second one, BRITE-PL Heweliusz, has the significant changes – it carries additional technological experiments implemented by SRC PAS. Lem satellite was launched into orbit on November, 2013 as a secondary payload, using the XPOD, on a Dnepr vehicle from the Yasny Cosmodrome. Heweliusz will be launched from China by a Long March 4B rocket. In regards to its launch, a decision was made not to use XPOD and to develop a Polish-made separation device. The lack of a compatible device on the market prompted SRC to propose its own design.

Overview of Nanosatellite Deployers

To speed up and simplify placing nanosatellites in orbit in a cost effective way, a few standards and rules of building nanosatellites was established. The smallest standard unit of nanosatellite, so called 1U CubeSat, is a spacecraft that is a 10-centimeter cube with a mass of 1 kilogram. Each larger standard nanosatellite is a multiple of one unit. The first CubeSats were launched in 2000, with many more having been launched since then on a myriad of different launch vehicles. To facilitate the launch of nanosatellites as a secondary payload, several orbital deployers have been developed.

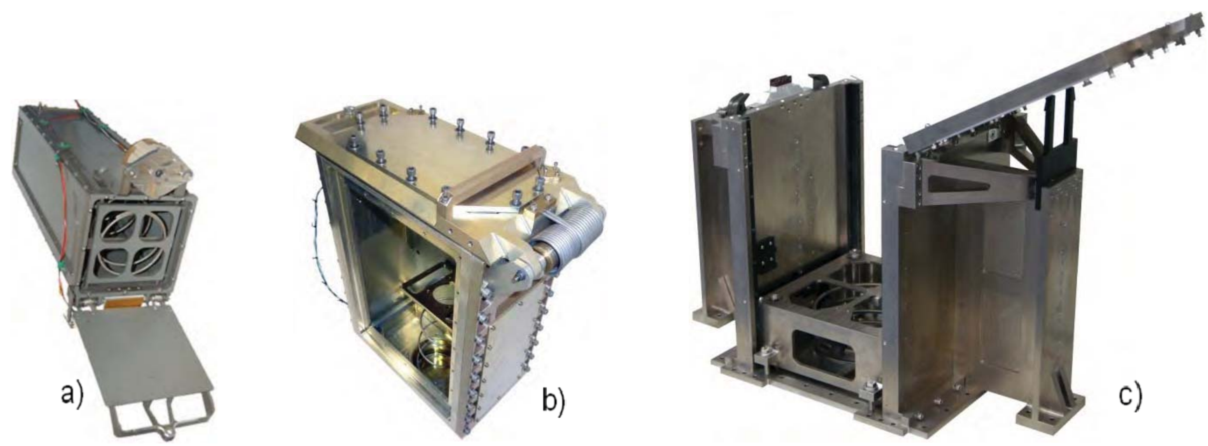

Figure 2. Popular nanosatellite deployers: a) CalPoly 3U P-POD; b) NASA WWF 6U Deployer (with one wall removed); c) SFL 8U GNB X-POD

Being first, California Polytechnic State University developed the Poly Picosatellite Orbital Deployer (P-POD), which became a virtual industry standard. Shown in Fig. 2a, the P-POD accommodates three CubeSats in a linear configuration of individual satellites but also combinations of satellites occupying the same volume, including a single 3U (triple-unit) CubeSat. By using the entire dispenser, a 3U CubeSat can have a maximum length of approximately 34 cm and mass of 4.5 kg. A similar but larger deployer is the NASA Wallops Flight Facility (WWF) 6U Deployer, which is able of carrying a 10x23x35-cm cuboid payload with a maximum mass of 12 kg (Fig. 2b). Both are characterized by a closed structure that does not allow for the projection of any part of the satellite outside the container and block electrical noise. A little different ejector is designed by SFL. Shown in Figure 2c, XPOD has a partially open structure, which allows the ejection of satellites with sticking out elements beyond the outline of the deployer. XPOD is designed to carry a GNB-type satellite platform that has the shape of a cube with dimensions of 20x20x20 cm, an equivalent of 8U and mass of around 7 kg. Common features of these three deployers include satellite sliding along guide rails during ejection pushed by a pusher plate that is driven by a linear spring. Other features are a single satellite clamp plate with a hinge on one side and a lock and release system on the other side. During launch, the spacecraft structure is maintained in tension by locking pins located in corresponding sockets on the top and bottom of the spacecraft.

Design Requirements

The DRAGON project was subject to a very tight schedule. Satellite requirements included size, ejected mass, ball-pin interfaces, and protruding elements like UHF antennas and a magnetometer. The Launcher requirements included spacecraft deployment speed less than 1.5 m/s; electrical signal for releasing to be 0.6 A for 10 sec at 28 ±4 V; telemetry signals indicate door opening and spacecraft escape; up to 12 g of overload level; and a shock of 1000 g. Since original plans assumed the usage of XPOD, the launch provider supplied an interface bracket mounted to the main spacecraft adapter, which followed XPOD-like footprint guidelines. This resulted in constraints such as the mounting hole arrangement, limited overall deployer dimensions, and lower dry mass, which was almost 10 kg in the case of the XPOD.

Mechanical Design

DRAGON deployer design includes three main mechanisms: a pushing platform, doors with latches, and the hold down & release mechanism (HDRM). The deployer structure is made of a nickel-plated 7075 aluminum. It consists of four walls connected at the bottom by a thinner panel. Two opposing side walls provide hinge support and the front wall provides mounting for the HDRM. The general view of the deployer is shown in Figure 3.

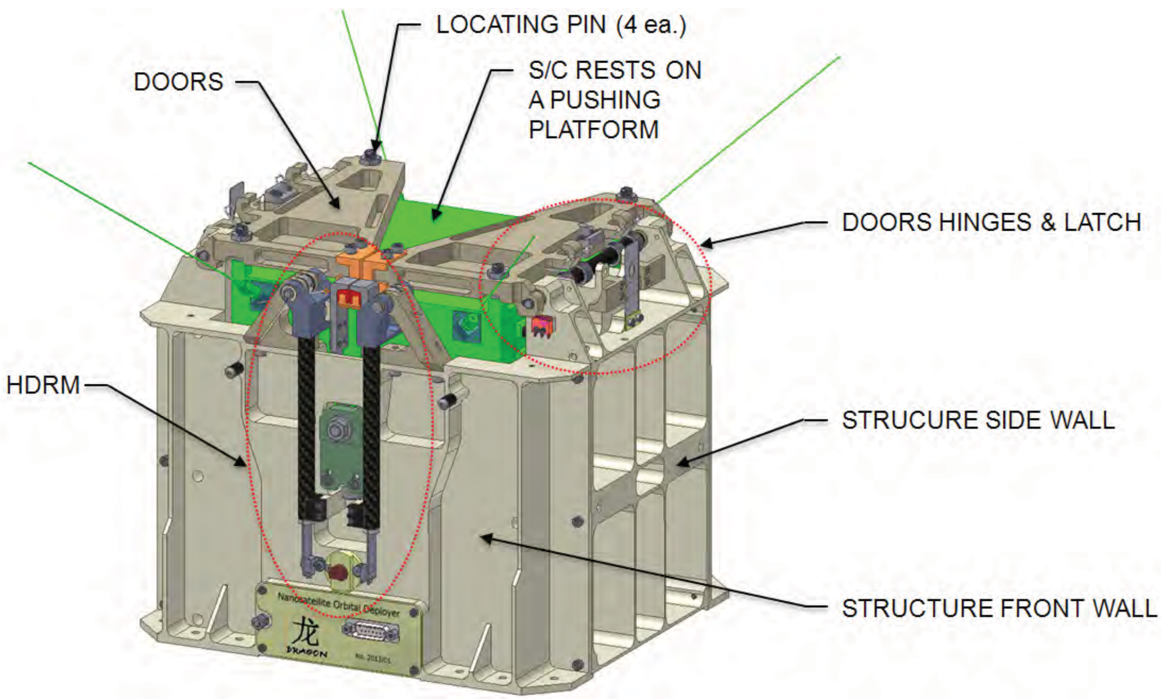

Figure 3. DRAGON CAD model (in stowed position)

<u>Pushing Platform</u>
Although BRITE-PL Heweliusz has a structure suitable for sliding along guide rails, it was decided not to apply this solution. In order to protect the spacecraft better during deployment, a sliding motion along rails was replaced by a rolling motion. This is accomplished using a pushing platform shown in Figure 4a. The platform consists of an aluminum base to which are mounted two sets of wheels located opposite to each other. Wheels roll in a groove in the structure's side panels (Fig. 4b). In the stowed position, four conical elements are touching the sockets in the base panel of the structure, thus transferring all loads. The spacecraft is located on the platform base in the appropriate slots, and safety brackets prevent it from sliding off. The energy needed to eject the satellite is stored in a conical spring located between the

platform base and the bottom plate of the structure. A conical spring was used instead of a simpler linear spring to decrease its length in the stowed position, which resulted in a reduction of height of the ejector as well as its mass. Initial force of the spring is 83 N. The pushing platform end positions are shown in Figure 4c.

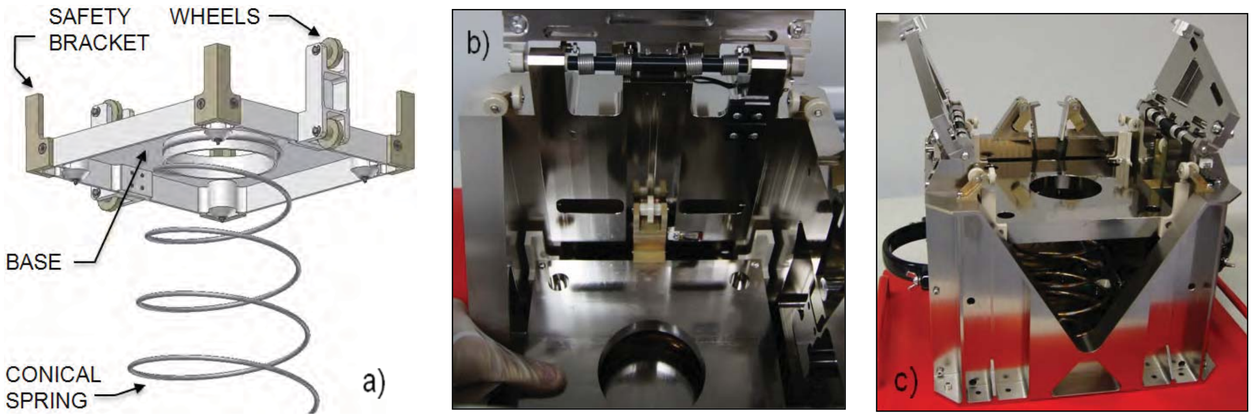

Figure 4. Pushing platform: a) main components;
b) view of the initial position; c) view in the deployed position

<u>Doors with Latches</u>
From the top, the spacecraft is secured by locating pins fastened in a pair of symmetrical doors containing their own latches. The doors are equipped with locking brackets on one side and are driven by hinges, attached on the opposite side.

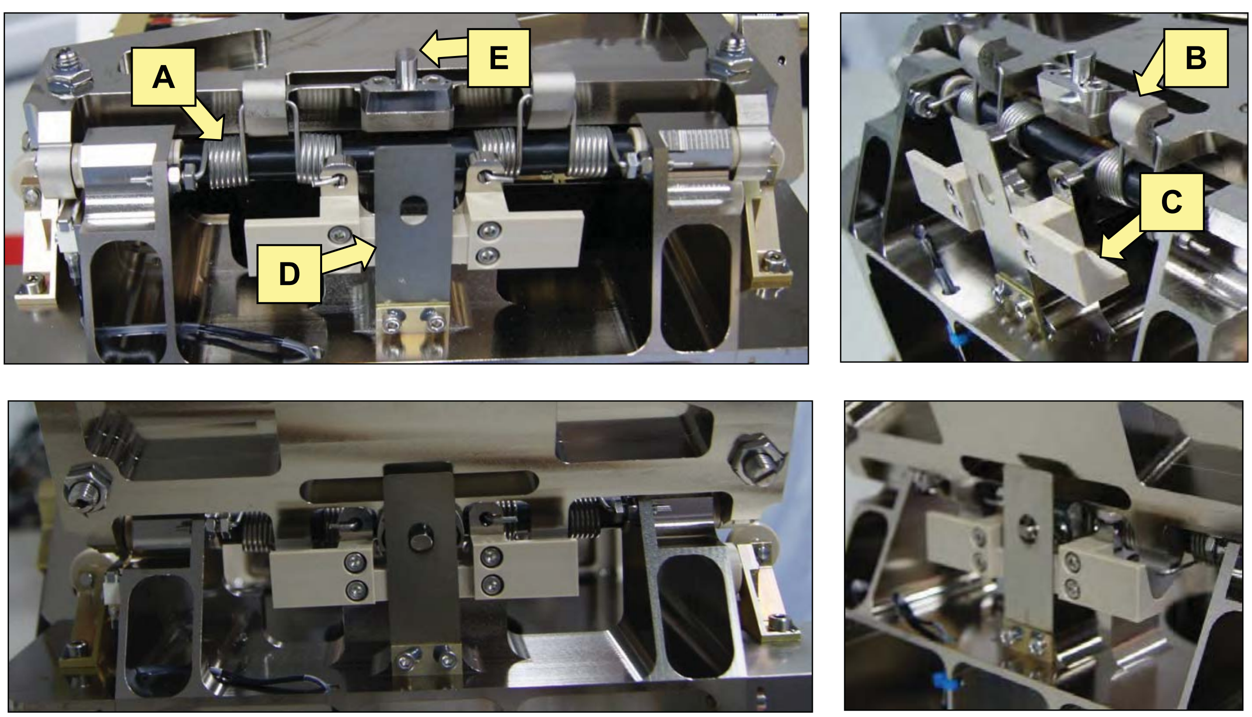

Figure 5. DRAGON door hinge and latch in the initial (top) and locked position (bottom)

Figure 5 shows one of two pivotally mounted doors which opens rapidly due to the torque from two double torsion springs (A). To slow down the opening of the door, friction was used to act between a specially profiled bracket (B) to which a hinge spring hook was attached and a plastic wedge (C) attached to the structure side wall. The wedge element is also used as a soft stop component. To prevent violent door bouncing and subsequent satellite damage, the latching system is used. The latch works with the leaf spring (D) which, when pressed by the moving door deflects until the latch pin (E) slips into the hole in the leaf spring. Thus the door is caught, preventing the rebound and stays wide open at an angle of 110 deg. A microswitch is used to verify and confirm door opening.

Hold Down & Release Mechanism (HDRM)

To hold the door during take-off, a very reliable HDRM was used, which is released by the Dyneema cord melting system. This type of lock and release mechanism has been tested during the ESA Rosetta mission preparation of the MUPUS instrument. In DRAGON, the mechanism, shown in Figure 6, has been scaled to meet higher loads.

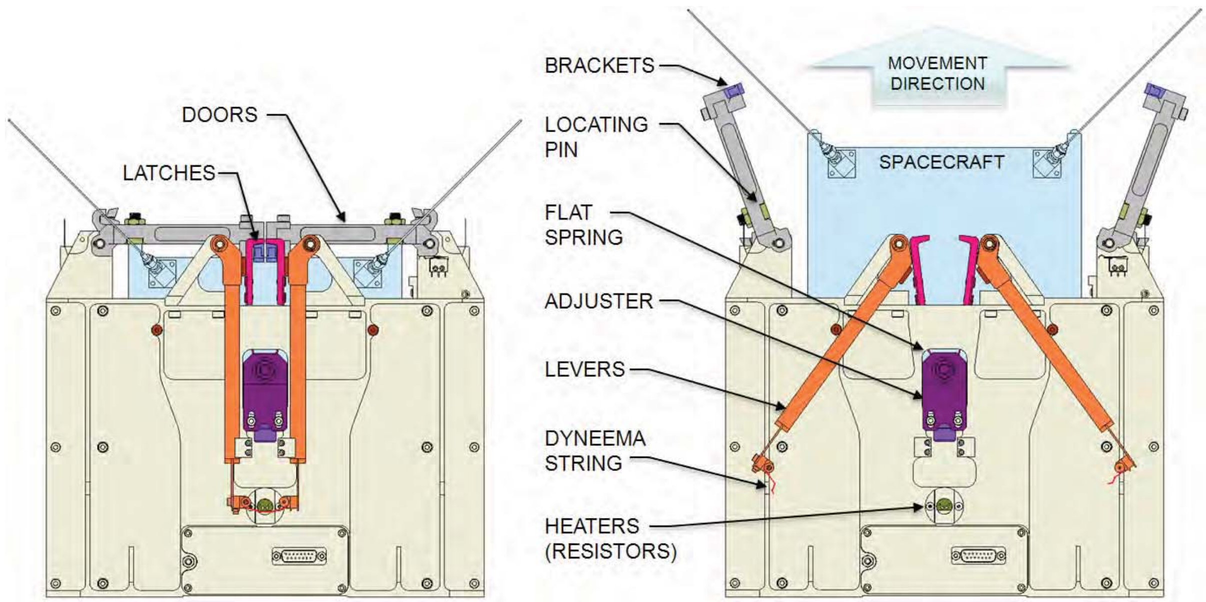

Figure 6. DRAGON Hold Down & Release Mechanism principle of operation shown in stowed (left) and released (right) position

When stowed, the doors are held by latches mounted to the tensioned elastic flat spring and adjusted by tightening an M10 screw that changes the position of an adjusting element with respect to a structural wall. Latches are held in place by the levers constructed of carbon fiber tubes (to decrease its mass and inertia). At the ends of the levers, flat springs are provided with attachments for the Dyneema string. The use of these flat springs guarantees the mechanism not to loosen during Dyneema creep. Therefore, it is possible to use a string with a small diameter (0.5 mm) that is easy to melt with little power. Melting of the Dyneema string releases the levers rotated by torsion springs, which allow the latches to slip from the door brackets and thus letting the doors open. The clamp ratio between shear pins and Dyneema string for this mechanism is 200:1.

Test and Qualification

The Dragon deployer passed a full series of tests, beginning with functional and ending with environmental. Functional tests have been carried out on the existing test bench located at SRC, to actively simulate the lack of gravity and were recorded by high-speed camera. A system, shown in Figure 7, uses a spring that generates constant torque and is able to compensate the impact of gravity acting on the suspended object. The system relies on feedback from a force sensor that is turned on by the PID controller that sends a signal to a DC motor, which adjusts the tension of the spring tape by appropriate rotation. During the test, a spacecraft mass model mock-up was used. The mock-up suspended on a rope was ejected from the deployer located below the test stand. Motion of the satellite during ejection is quite a fast phenomenon. Therefore, setting parameters of the PID controller play an important role in simulating zero gravity.

Three tests were conducted with different settings of control parameters. In an ideal case, the satellite ejection speed is increased in accordance with the characteristics of the force generated by the conical spring. The satellite separates from a pushing platform after the pushing action stops. From that moment, the spacecraft should move at the same final speed. Tests results shown in Figure 8 are presented in the form of plots of time vs. speed and speed vs. displacement. They were obtained from the analysis of high-speed camera images.

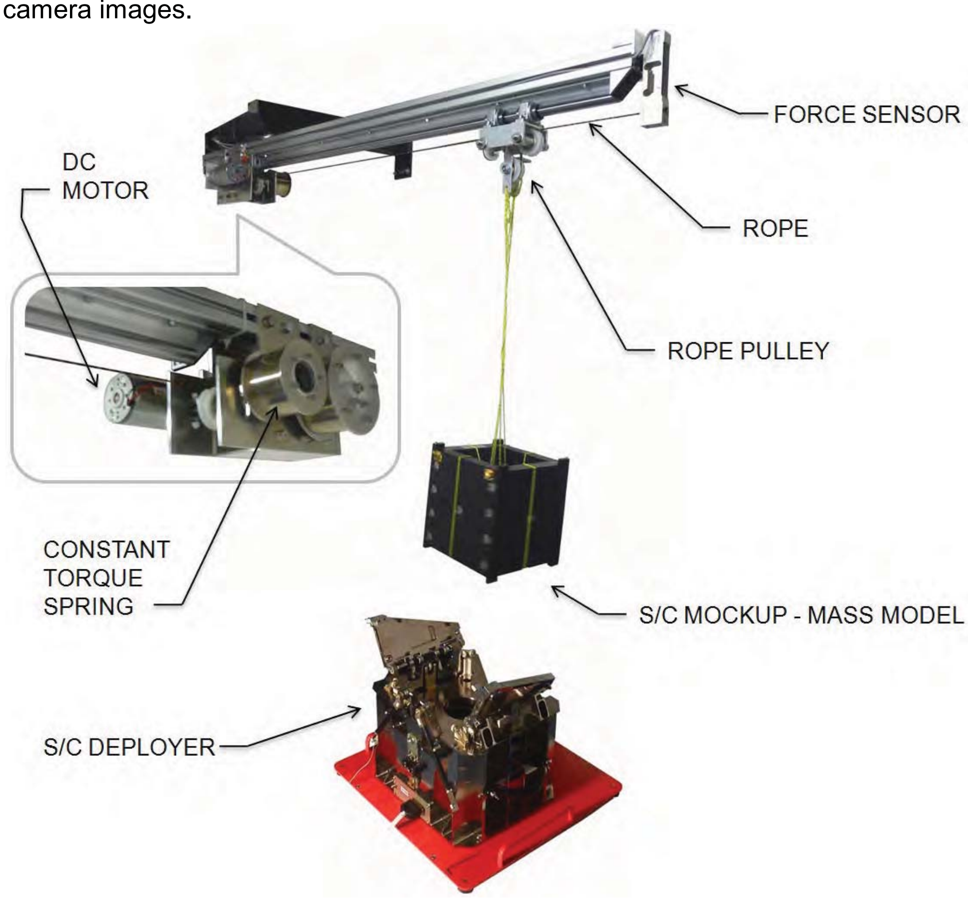

Figure 7. Functional test stand to actively simulate the lack of gravity

Triangular marks on the plots indicate the time when a pushing platform reached its end position and thus the point at which the satellite begins free flight. Square marks indicate both time and location when the satellite passes remaining protruding elements of the deployer and is considered to be outside of it.

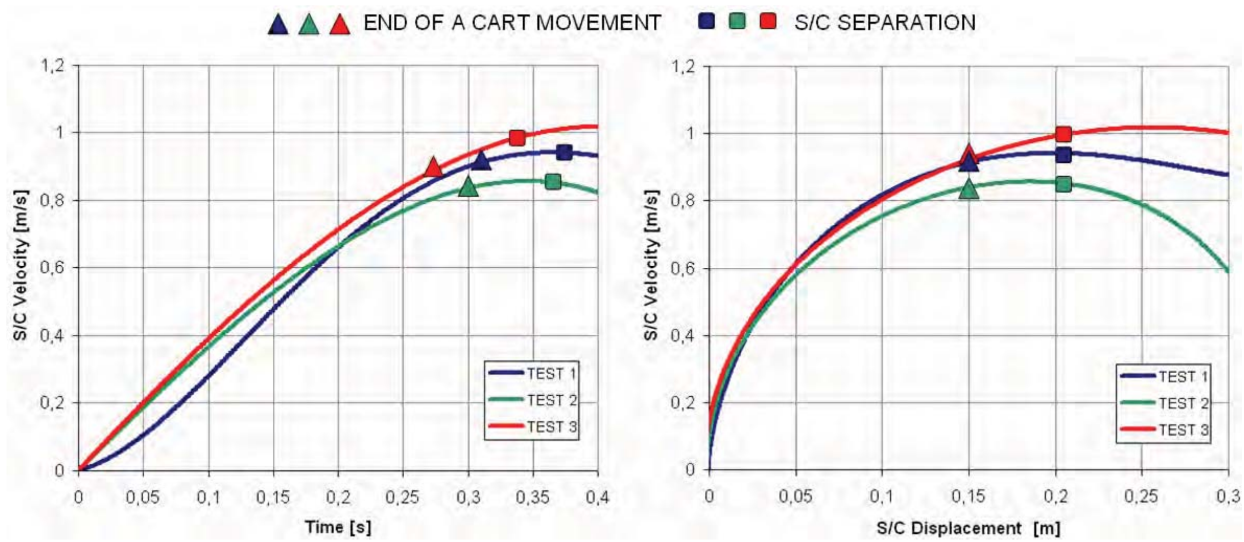

Figure 8. Satellite ejection speed graphs

Results from test 1 and 3 best fit the theoretical movement conditions of the spacecraft in zero gravity. Test 2 is characterized by a sudden drop in speed of the satellite after separation which indicates that the mass was not supported adequately. From the time of the doors' release, the pushing platform supporting the satellite moves 150 mm in about 0.3 sec to reach an end speed slightly less than 1 m/s. The speed limit was set at 1.5 m/s and the expected value, which did not take into account motion resistance, was 1.2 m/s. The test demonstrated that assumptions have been met, and a video recorded with a high-speed camera showed that the ejection takes place very smoothly and doors open much faster than the spacecraft is ejected.

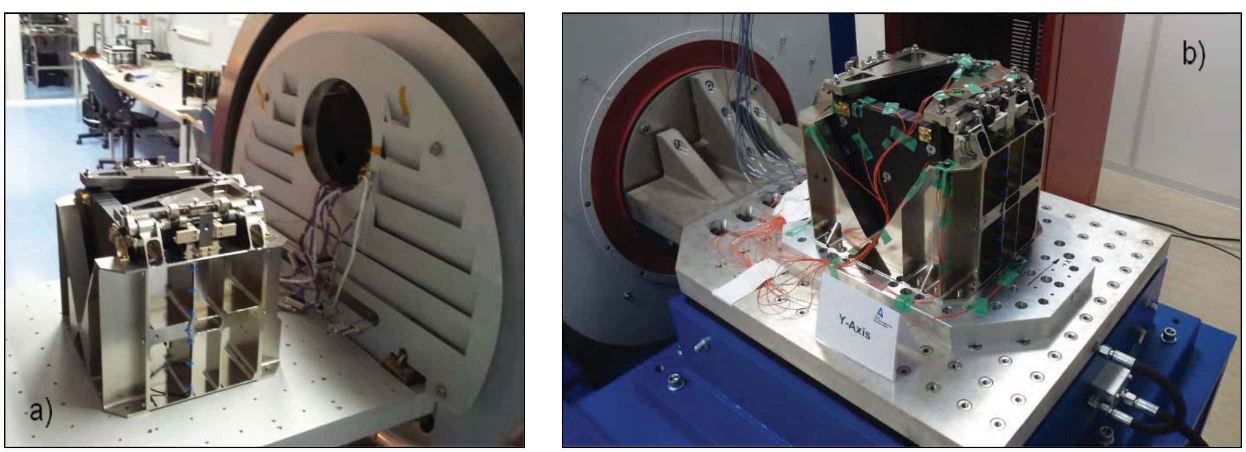

Figure 9. Deployer qualification tests: a) thermal-vacuum; b) vibration

The next functional test was performed in the thermal-vacuum chamber shown in Figure 9a. The time of Dyneema string melting and mass model ejection was less than 1 sec at -20°C and a 0.0004-Pa vacuum level. There was no destruction or change of resistance of the heating element. DRAGON passed all required vibration and shock tests. No change was observed in resonant frequencies after sine and random vibration. The resonant frequencies in the X and Y axes (the base plane axes) were 205 Hz and 278 Hz in Z axis (along which spacecraft ejection occurs). Light ringing could be seen coming from the deployer main spring.

Finally, a fit check was performed on a launch vehicle. DRAGON was attached to the bracket on the adapter ring between the rocket and the main satellite. A deployment signal was sent from the launch vehicle and the deployer opened safely. Telemetry with sensor confirmation of deployment was sent to the rocket computer.

Lessons Learned

There was not enough time to design a new suitable and reliable separation device or order it from an outside source. In the deployer, a scaled hold down & release mechanism from MUPUS instrument was used. This approach has been proven as reliable. A general lesson connected with this issue is to carefully analyze a scaled device that will be used in a new application. We dedicated a lot of attention to redesign with this new mechanism so it could withstand higher loads. What we did not notice originally was that the MUPUS mechanism levers were arranged in a position towards the operator, while in DRAGON that position was just opposite. The use of components to mount the Dyneema string in a way similar to that used in MUPUS made arming of the mechanism very difficult. So two new redesigned components had to be manufactured.

To cut costs and to speed up the deployer production, all rotating joints used commercially available PEEK flanged sleeve bearings and polished stainless steel (SS) shafts. This combination was also used for latches made from stainless steel pressed against PEEK lever blocks and sliding across PEEK door brackets. Tests showed that such a combination is sufficient for applications working in not too low nor too high temperatures.

Two utility issues have sprung up during the deployer testing with the Heweliusz spacecraft. Both concern satellite safety. DRAGON is not a tightly closed container but has a structure with many open spaces that could expose a spacecraft to danger. Also, deployer doors have open cutouts to save mass. This causes the possibility of damage in case of an unintended fall of some piece on spacecraft solar cells during locating pins set up. To avoid it, suitable ground-use covers were designed to protect the satellite. In Figure 10, the satellite integration procedure is shown on the left and the deployer with a safety cover on the right.

DRAGON, different from other separation ejectors, is equipped with a pushing platform. Satellite structure rails are not supported. This results in a possibility of hitting satellite parts, for example solar cells, during satellite insertion into the deployer. To prevent this, four wheel assemblies were added in every corner with a 1-mm gap between the spacecraft and every wheel. Figure 11 shows wheel assemblies that also help to provide a very stable low friction guiding during satellite deployment.

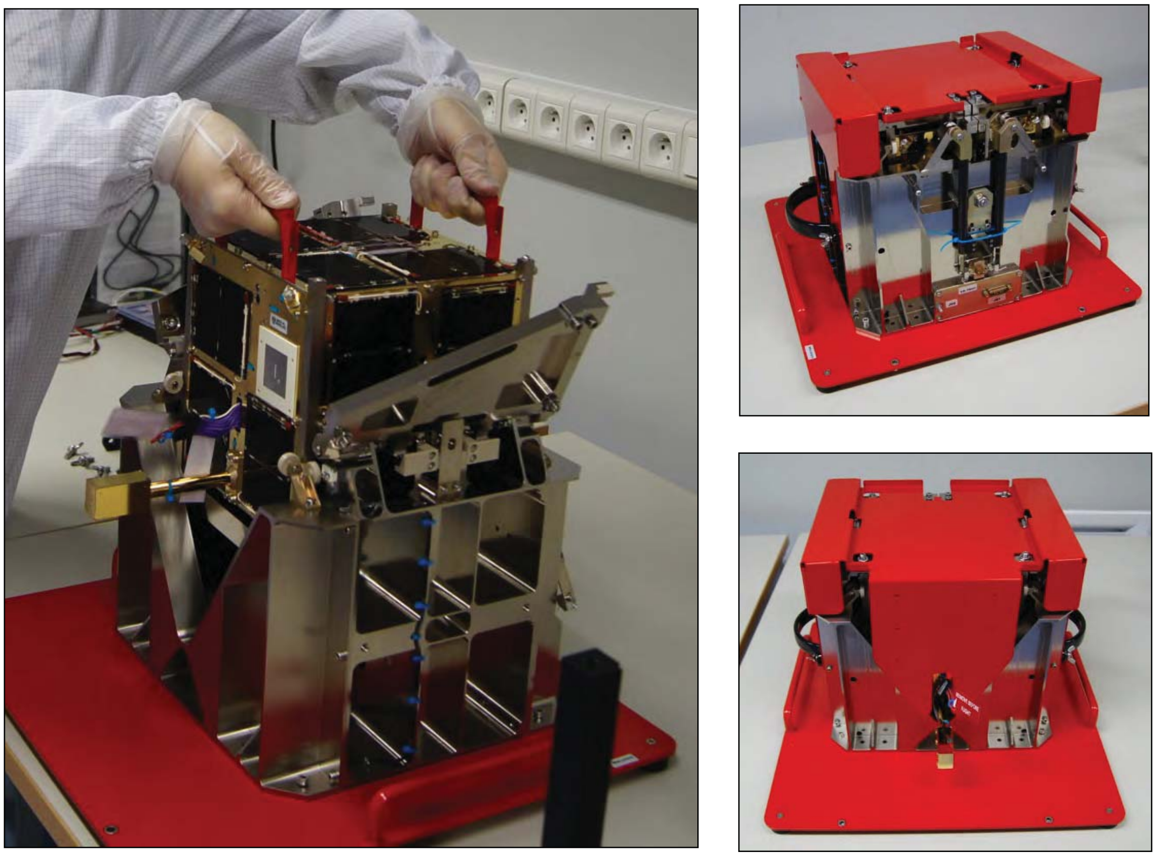

Figure 10. Spacecraft insertion procedure (left) and ground-use cover (right)

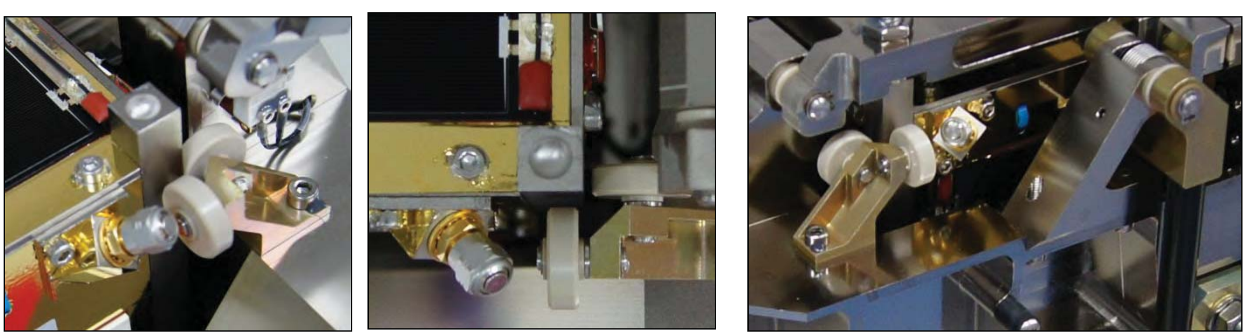

Figure 11. Wheels assemblies added for spacecraft safety during insertion

Conclusions

A nanosatellite orbital separation device was designed, manufactured, assembled and successfully tested. The overall dimensions of the deployer are 282x320x287 mm and its mass is 7.2 kg. It is able to deploy a small cuboid BRITE-PL Heweliusz spacecraft of dimensions 200x200x200 mm and mass of 7 kg.

Commercially available standard orbital deployers are usually developed with particular spacecraft in mind. DRAGON separation device was developed with a target to satisfy preexisting specific constraints. The mass ratio of DRAGON deployer to satellite is about 1. In the author's opinion, such a system should have a mass ratio less than 0.8, preferably 0.5, and that is possible to achieve with a closed-type deployer and structure optimization. Figure 12 show graphs where masses of aforementioned popular deployers and Dragon are plotted. In the deployer mass vs. payload mass graph (left) markers that represent standard American-made container-type ejectors are joined by a line (CalPoly P-POD 3U and NASA WWF 6U). If we take this line as a determinant of representative orbital deployers, it turns out that the ejector designed for 7 kg payload should have a mass of about 5 kg.

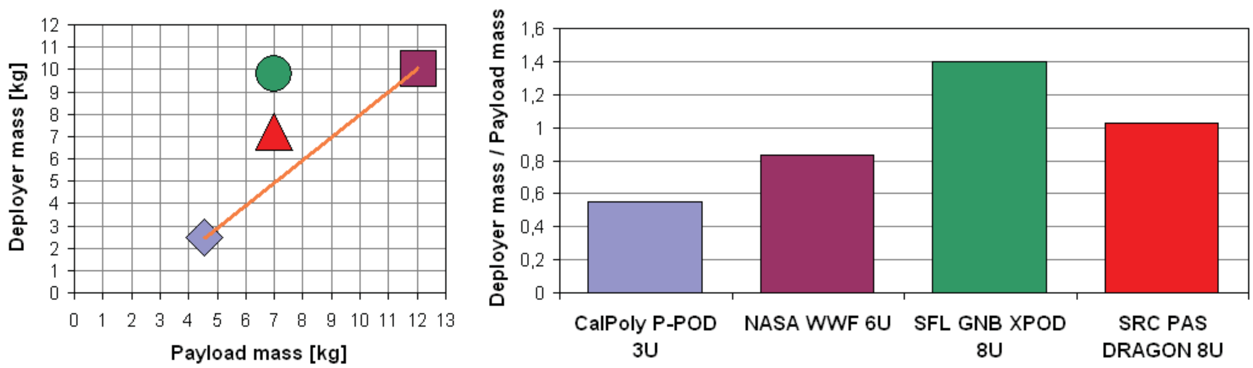

Figure 12. Deployers mass vs. payload mass that they are able to eject

General conclusion: it is very hard to design, manufacture, integrate and test a space device in two months. It is even more challenging during the holiday period which was the case of DRAGON development. But all this was possible with a well-motivated team that was using solutions already proven and previously tested during development of the space instruments in SRC PAS.

References

1. Dobrowolski M., Grygorczuk J. "Lock and release mechanism for the CHOMIK penetrator device and its tribological properties" *Proceedings of the 41st AMS*; NASA/CP-2012-217653 pp. 29-37
2. Grygorczuk, J., Banaszkiewicz, M., Seweryn, K., Spohn, T. "MUPUS Insertion device for the Rosetta mission" *Journal of Telecommunications and Information Technology* (1/2007), pp50-53.
3. Toorian A., Blundell E., Puig Suari J., Twiggs R. "Cubesats as responsive satellites" *Proceedings of the 3rd Responsive Space Conference 2005* AIAA-RS3 2005-3001
4. Thompson L. D. "Development of a NASA 6-U Satellite" *Proceedings of the 25th Annual AIAA/USU Conference on Small Satellites* SSC11-X-8