

# Xatcobeo: Small Mechanisms for CubeSat Satellites – Antenna and Solar Array Deployment

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## Abstract

The Xatcobeo project, which includes the mechanisms dealt with here, is principally a university project to design and construct a CubeSat 1U-type satellite. This work describes the design and operational features of the system for antenna storage and deployment, and the design and simulations of the solar array deployment system. It explains the various problems faced and solutions adopted, with a view to providing valid data for any other applications that could find them useful, be they of a similar nature or not.

## Introduction

Xatcobeo is an educational joint project between University of Vigo and INTA (Spain National Institute for Aerospace Technology), which has been selected to be launched on the maiden flight of Vega. The space segment of the Xatcobeo project is mainly formed by a mechanical structure that complies with the CubeSat 1U standard. Into this structure, five subsystems are going to be implemented: a power subsystem, an on board computer, a Telecommand Tracking and Control system for communications, a solar Panel Deployment Mechanism (PDM), a software reconfigurable radio, and a sensor for measuring the total amount of ionizing radiation in the space.

### Mechanisms

Two different deployment mechanisms are included in the satellite:

- An antenna (four monopoles) deployment
- A solar array deployment.

### **Antenna Retention and Deployment Mechanism for a CubeSat 1U Picosatellite**

The CubeSat concept makes small-scale satellite launches viable on a low budget. Dimensions are limited to a 100 x 100 x 100 mm cube and mass to 1 kg, which means all built-in components must weigh and measure as little as possible. These limitations have been borne in mind from the outset when designing the mechanism offering storage capacity and deployment for antennas. The mechanism must fit a casing measuring 82.6 x 98 mm on the front and with a thickness of 6.5 mm. To fully explain the design needs and solutions chosen, the main problems and solutions are given below.

### Problems

The problems can be divided into a series of more or less independent sections:

- General configuration.

The design must leave clear as much of the face where it is installed as possible, insulate the antenna connection from the metal of the satellite, and respect the geometry for the antenna position, which will come out at an angle of 45 degrees to the adjacent edge.

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- **Materials selection.**  
The material must withstand the various types of radiation present in the working environment and avoid potential risks from electrostatic discharges produced by an atmosphere with a high ion density. In addition, it must withstand the temperature changes occurring when its orbit passes in and out of sunlight, which range from 243 to 293K, and the maximum temperature during launch of 353K.
- **Dimension and mass limits.**  
The mechanism must be as light as possible so that other elements can be included on the satellite. The aim is for everything to be under 20 g. Furthermore, it must not protrude more than 6.5 mm from the outer face of the shielding.
- **Mechanical strength.**  
The mechanism must guarantee its structural integrity and the retention of the antennas under the effects of knocks and vibrations.

#### Adopted solutions

All the solutions proposed for each of the above problems are briefly outlined below:

- The mechanism would be built in to a single piece that would act as a support for all the others, which we will call the sub-chassis from here on.
- The sub-chassis would be made of a polymeric material to insulate the antenna electrically; this would later be covered by a layer of dissipative paint.
- The sub-chassis was designed in a continuous ring shape with a C profile, so that the interior space was available for other elements such as solar panels, cameras and so on.
- The chosen polymer was polyamide as this brings together the many features needed for sub-chassis operation such as acceptable resistance to radiation and ultraviolet radiation and great dimensional stability against exterior temperature changes.
- To solve the weight problem, in addition to the material chosen for the sub-chassis, it was decided that the attachment elements should be high strength material in order to reduce size. Finally, titanium Gr5 (Ti6Al4V) M2 nuts and bolts were chosen.
- A surrounding sheet of polyvinyl acetate was chosen for the retention system, a tough and dissipative polymer to avoid static interaction with the antenna.
- This sheet shares its attachment to the sub-chassis with one of the antenna and acts as a retainer for the antenna whilst they need to be folded, as it envelops them on their outer part and keeps them within the continuous C-shaped profile described above.
- The triggering system chosen was a 0.125-W electrical resistance with a ceramic body instead of a Nichrome wire.

### **Antenna Deployment Mechanism Introduction**

One of the advantages and capabilities of a satellite is the ability to collect data in an environment that is difficult for people to access. However, it must be able to communicate that data to areas where humans do have access, i.e., it must have an antenna to send and receive data. These antennas cannot be sent into space already deployed, as this would take up too much room on costly space flights. This is where the deployment mechanism comes into play as it allows them to be folded during the journey and deployed once the satellite is in orbit. The deployment mechanism is, therefore, one that is designed to integrate antenna storage before deployment plus the deployment system and its corresponding burner circuit, all with the smallest size and weight possible.

To achieve such integration, a modular design was proposed that would allow all the mechanisms to be fitted to a single piece, thus saving weight and space, and keeping things simple. The base for this modular attachment system was called the sub-chassis, as the satellite itself was regarded as the prime chassis. The antenna, the retention mechanism and the burner circuit are attached to it and it also acts as

a profile guide for the antenna whilst they are folded. The deployment mechanism operation is analyzed below and the features of the elements that make it up are described.

### Sub-chassis

As explained, the sub-chassis is the piece upon which all the necessary elements are attached for deployment mechanism operation.

#### General requirements and design process

Antenna design basic requirements:

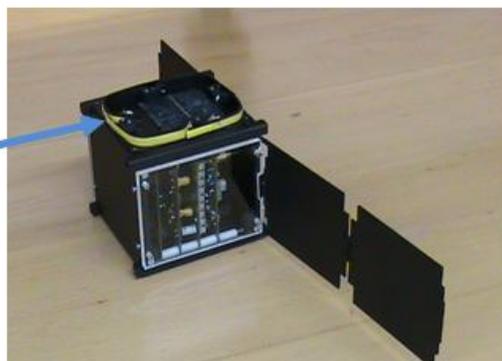
- Each antenna must be located in the center of the edge of the +X face of the CubeSat.
- The exit angle must be  $45^\circ$  ( $\pi/4$  rad) with respect to the adjacent edge of each antenna.

A plaque with solar panels to power CubeSat was also expected to be installed on the +X face, so the part used to hold the antenna had to leave as much space as possible for the installation of these panels. Being the largest part in the system meant weight had to be kept down to a minimum to give as much margin as possible to other elements.

In order to save mass, system design began as a set of independent parts, four for antenna attachment and another four as guides to give the folded antenna curvature and keep them within the available envelope. However, the large number of attachment elements needed for this set-up made it unviable. The approach was changed and a continuous profile was designed for attaching the antenna and guiding them in their folded path. The profile moved as far out from the shielding as possible so that the greatest number of solar panels could be installed in the free interior space. The piece to which the antenna was attached was called the sub-chassis.



**Figure 1. Sub-chassis**



**Figure 2. Mechanism built into the Project Xatcobeo prototype**

#### Materials selection

The antenna had to be insulated from the metal of the satellite in order to avoid short circuits when touching the shielding faces. There were two options:

- Make the sub-chassis from metal and include a dielectric piece at the antenna contact areas to insulate them from the rest of the metallic parts.
- Make the sub-chassis entirely from polymeric material.

The first option was seen to have complications with the metal-dielectric interface fitting and there was a risk of contact between the antenna and any other part of the metal sub-chassis, so the sub-chassis made entirely of polymeric material was therefore chosen as safer in terms of antenna insulation.

The material has to fulfill a long list of requirements:

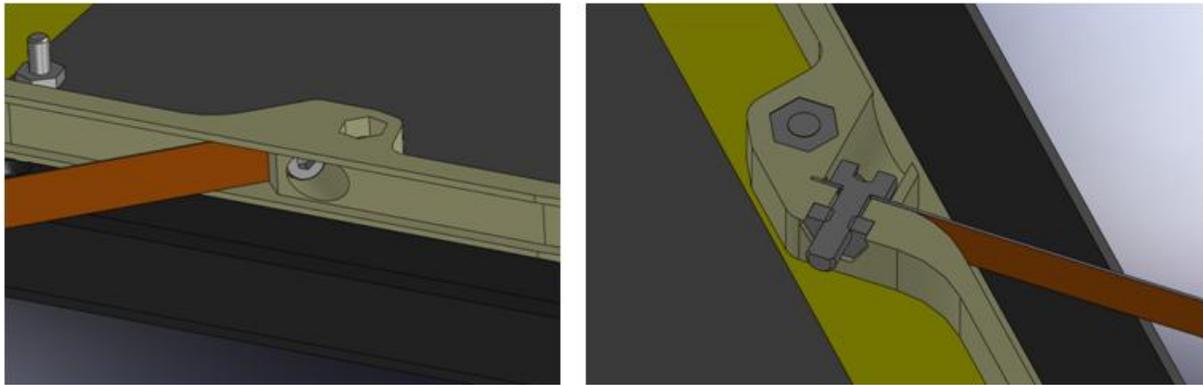
- It had to work correctly at temperatures ranging from 243K, reached when passing through the Earth's shadow, to 353K, reached during launch.
- It needed dimensional stability so that dilations and contractions did not cause tension at the mechanical interfaces of the attachments. At the same time, if the material over-contracted at minimum temperature, this could squeeze the antenna and prevent them from full or partial deployment.
- It needed acceptable resistance to radiation and ultraviolet radiation, both of which are present in the satellite's working environment. According to research in the literature, the e-beam radiation effect on the polyamide would be to increase its elastic limit and decrease its elongation, neither of which poses a problem for proper operation. As for UV radiation, the metallic-based paint cover used to dissipate static charges would notably increase resistance to this type of radiation.
- It had to be extremely light. The final sub-chassis weight is 5 or 6 grams and the attachment elements another 5 grams, which, when added to the weight of the antenna, the electrical resistance, the thermoplastic envelope sheet, the switch and storage thread, meant the whole mechanism weighs in at less than 12 grams.
- Over-fragility had to be avoided to prevent vibration problems during launch.
- It had to be as dissipative as possible so as not to become electrostatically charged when passing through orbital areas with high ion densities and so avoid the risk of experiencing electrostatic discharge that could affect the sub-chassis itself or other elements of the mechanism. To improve dissipation, the sub-chassis would be covered by zinc- or silver-based dissipative paint, except in areas of antenna contact. In this way, dissipation is increased in ionized environments and there is also increased resistance to ultraviolet radiation and, to a lesser extent, to nuclear radiation.
- Last, but not least in importance, it had to be simple, and if possible, cheap to make.

It was finally decided to make the sub-chassis from polyamide (PA6, PA66) using a selective laser sintering process to obtain parts designed by CAD without losing the initial properties of the polyamide produced. This material was able to acceptably fulfill the above requirements.

### **Antenna Attachment**

As described, the antenna had to be located in the center of each shielding edge and have a deployment angle of 45° to this edge. It was thus decided to design a hole in the sub-chassis going through the whole piece, from the outside of its profile to the opposing side. This drill hole is located in the central area of the edge and as close as possible to the sub-chassis attachment to the shielding as this gave the whole assembly more rigidity. Figure 3 shows the location of the entry hole for the antenna attachment bolt from the outside of the profile to facilitate assembly. Figure 4 is a cut away showing the antenna attachment and the area in which it is located. It can be seen how the antenna attachment is adjacent to the sub-chassis attachment to the shielding (yellow piece), as this is the most rigid area of the whole assembly.

With regards to the approach used for attachment, a hole was made at the base of the antenna, through which the attachment bolt was introduced. This bolt served as the axle for the washer, the antenna itself, and the conducting wire in contact with the antenna. The conducting wire transmits signals both from the antenna to the satellite and vice versa. On the other side of the attachment bolt is a nut, also M2, which is inserted into the sub-chassis and whose function is to keep the whole assembly of antenna, connection cable and washer together, as once the bolt is tightened the assembly will be kept fixed by the tension between the nut and the sub-chassis it is embedded in.



**Figure 3. Drill hole and antenna attachment. Figure 4. Method and location of attachment.**

### **Antenna Retention**

The retention mechanism keeps the antenna folded from the time the satellite is finally assembled and ready for launch to the moment when the antenna controller indicates they must deploy. It needs to be able to cope with vibrations produced on rocket launch and the temperature changes from assembly to deployment, i.e., dilatations produced by heat variation must not put the system's retention capability at risk nor, obviously, cause damage to the material that would lead to structural breakage or weakening, which would harm the project's aims.

Each antenna, or monopole, is located in the center of the edge of the shielding for the +X face of the CubeSat, coming out at a 45° angle. Each one is 170-mm long, whereas the continuous profile of the sub-chassis is 325 mm in perimeter. This means that no antenna goes right around the profile or any of the others completely. This led to a problem, as it involved 4 retention points, one for each antenna. This meant, furthermore, guiding 4 nylon threads towards the area where the burner element is located, or four burner elements and four burner circuits. The latter was rejected as four circuits and burners would increase overall weight too much, so a way was sought to deploy the four antennas using a single circuit and burner element.

The idea to take a thread from the end of each antenna towards the burning area did not seem the most ideal because of the amount of thread needed to cover the distance and the risk of threads getting crossed. Furthermore, pivots had to be introduced to redirect the threads to an area where the burner element would not interrupt the solar panel positions. That is, the most suitable configuration was sought to ensure that the retention thread was as short as possible and that a single thread was enough to hold all the antennas at the same time, thus requiring only one burning point. This removed the need to place additional burning points and so kept weight down.

Thus the final retention system consisted of an enveloping sheet of thermoplastic material, fixed at a single point to the sub-chassis, which was 425-mm long and so allowed four antennas to be enclosed, once they had been folded, and keep them retained against the continuous profile of the sub-chassis. A perforation was made at the same point on all the antenna for the retention thread to pass through from the outside to the inside of the profile, where the burning element was located.

#### Attachment system

For the sheet to function properly, it needed to be joined to the sub-chassis. When enclosing the folded antenna, the traction tangential to the sub-chassis profile applied to the enveloping sheet would be turned into pressure on the antenna and so achieve a force at every point along them and keep them folded. The

sheet is attached to the sub-chassis at one of the antenna attachments, which avoids the addition of a new nut and bolt and so keeps weight down.

#### Operation and explanation of the retention method

The retention system is based on the enclosing sheet's ability to generate pressure on the folded antenna. Given that the sheet shares an attachment with one antenna, it will come out over this and then go a complete turn, around the profile until all the antennas are covered. A traction force is applied to the sheet tangent to the line of the profile, which turns into pressure on the antenna and keeps them pressed in against the sub-chassis profile. Once the sheet has enough force for it alone to keep the antenna folded, it can be tied by the retention thread, which will keep it closed until triggered. This thread is joined to the enveloping sheet using a double knot, one on the internal side of the sheet and one on its external side, to prevent it coming loose after deployment has taken place.

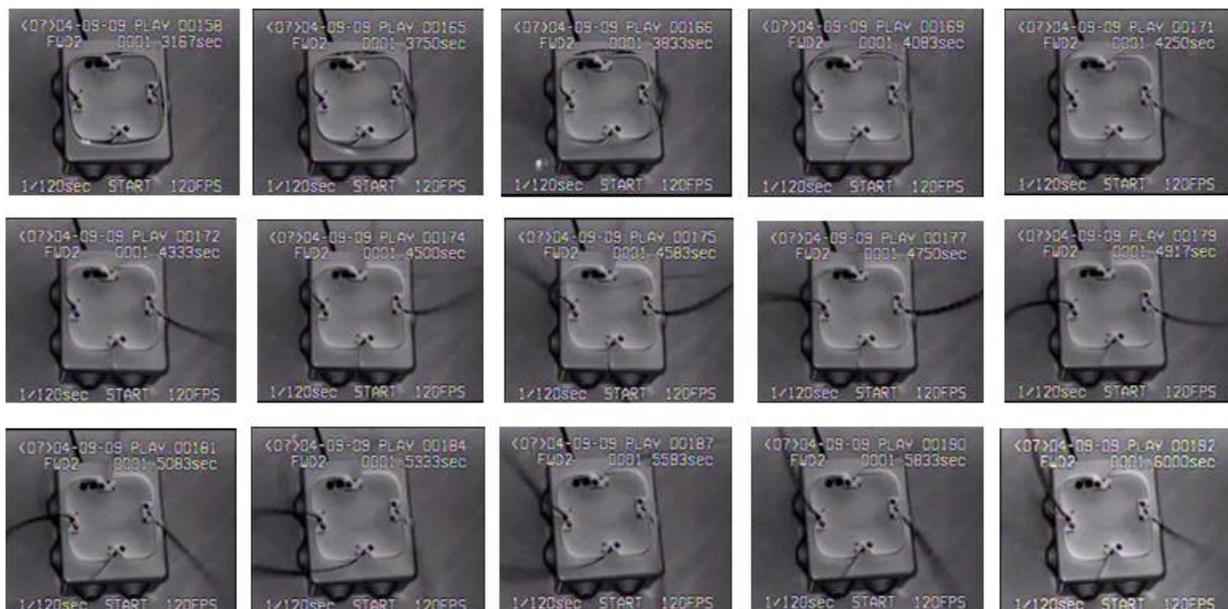
#### Materials selection criteria

The enveloping sheet needed a material that was flexible but also resistant to traction and that, furthermore, had good dissipation properties for electrostatic energy to avoid build ups that could discharge onto any of the antenna and have unwanted effects. A sheet of polyvinyl acetate was chosen.

### **Deployment mechanism and burner circuit**

#### Deployment

Antenna deployment was produced by releasing the pressure they were under by burning the nylon thread keeping the enclosing sheet up against them. Once released, the recovery of the elastic force retained in them would place them in the correct position for sending and receiving data. If the antennas are not rigid enough they will take more time to stabilize the oscillation produced during deployment. It could even be the case that insufficient rigidity would leave them in an incomplete curved position due to the rotation of the orbiting satellite of roughly 1 rpm (0.00265 rad/s), which would greatly decrease their properties. To solve this problem, a steel was sought that enabled work in the cold without becoming too hard and that could absorb large amounts of energy without suffering plastic deformation, that is, with a large elastic limit, which led to a steel alloy with chrome and nickel being chosen.

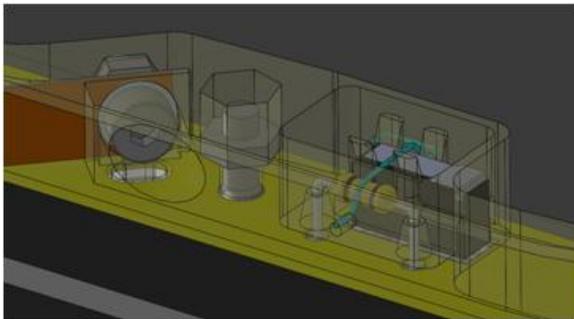


**Figure 5. High speed recording of antenna deployment**

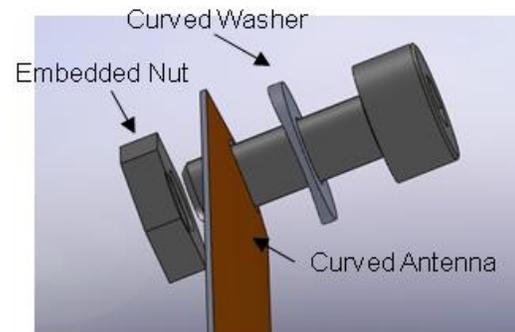
However, tests carried out on a 5-mm-wide flat metal band, showed that this configuration was not totally valid: it responded well to folding but was too limp during deployment and, once deployed, took too long to stabilize and lost position when even slightly acted upon.

We found the solution to this problem by giving the metal strip a curvature, in such a way that it was slightly arched in a plane perpendicular to the direction of the antenna. This modification reduced deployment stabilization time by 55% and notably improved resistance to losing its position through external activity.

However, it was observed that when tightening the bolt on the convex part against a flat plane (the sub-chassis), the antenna was deformed and its angle out from the shielding edge was no longer  $45^\circ$  but approximately  $60^\circ$ . To solve this problem it was decided to change the flat surface of the sub-chassis for one with the same curvature as the concave part of the antenna and use a washer with a flat side (in contact with the bolt) and a curved one (in contact with the antenna) in order to avoid deformation and so maintain the outward angle of  $45^\circ$ .



**Figure 6. Antenna attachment area**

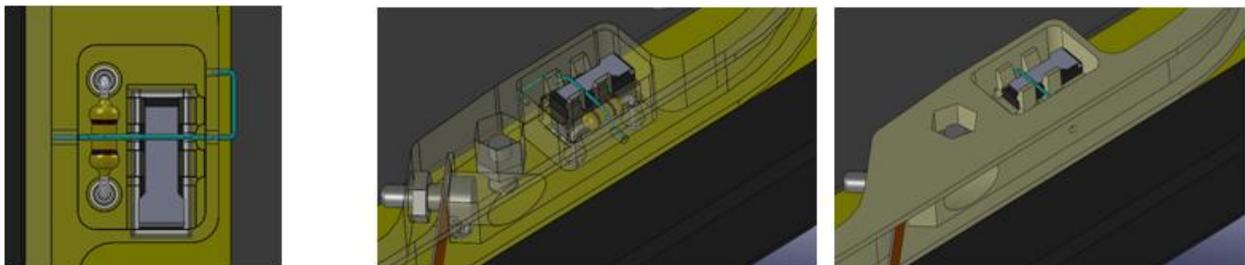


**Figure 7. Antenna attachment elements**

#### Burner circuit

The burner circuit is the set of elements that break the thread keeping the antenna folded at the moment of deployment. It is made up of a ceramic resistance and a power circuit to the battery and includes a switch to check deployment, which is triggered by the storage thread. Both the electrical resistance and the deployment switch are housed in a receptacle specially located to get them nearer to the area where the antennas are tied with the retention thread. This minimizes thread length and so prevents possible knots or unwanted tangles.

A 9- $\Omega$ , 0.125-W ceramic bodied resistance is used. One idea was to use Nichrome wire but this had the problem of heating its whole volume, which could damage the polymeric sub-chassis, whereas the ceramic electrical resistance focuses the heat source much more, which, moreover, favors retention thread burning.



**Figure 8, Figure 9 and Figure 10. Receptacle where the Burner circuit is housed.**

Dozens of tests were carried out on the burner circuit in the presence of air and at room temperature, and the result was always the same: the resistance burned the 0.25-mm nylon thread in roughly 2 seconds. Tests were also carried out in a climate chamber to simulate the temperature variations experienced in orbit, and the mechanism has shown the same efficacy as at room temperature, having worked at both the minimum and the maximum temperature.

### **Panel Deployment Mechanism (PDM)**

CubeSat missions run into the problem of obtaining more power but having little space allowable to locate solar cells. So starts the look for more power, and to achieve that, more solar panels are needed, and thus small deployment systems. The design of a solar panel deployment mechanism for Xatcobeo is mainly based upon the following goals:

- To ensure a packed maximum envelope of 6.5 mm from the structure in stowed configuration.
- To allow an easy integration in the structure of Xatcobeo. It is intended to pack with the lateral shear panel of Xatcobeo to integrate it as a single unit.
- To minimize mass of deployable parts.

The toughest requirement for solar array deployment in Xatcobeo mission is the necessity to fit all the system in an envelope of 6.5 mm from lateral plate of satellite to avoid interference with the satellite deployer. With this limitation it is possible to fit:

- One lateral aluminum shear panel, one board fixed to that panel holding solar cells, and one movable panel with cells in both faces over a 1.6-mm board.
- One lateral aluminum shear panel, one board fixed to that panel holding solar cells, and two movable panels with cells in both faces over 0.8-mm boards.

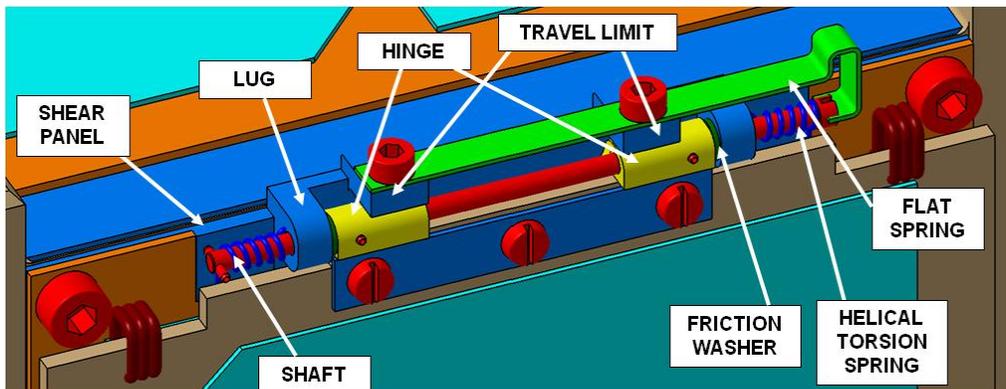
Both options have been used in Xatcobeo PDM design.

### **Solar Array Deployment for Xatcobeo**

PDM is a mechanism consisting of two sets of deployable solar panels. In the first one, only one panel is deployed (PDM1) and the second is a double unfolding (PDM2).

Both share the first deployment system, and in the double an extra mechanism is added to allow the unfolding of an extra panel. Due to mass restrictions (to allow higher life span to this satellite mission is necessary to give extra protection against radiation environment and increase the lateral shielding plates) the double deployment system is only used to validate the mechanism concept and instead of boards with solar arrays, two aluminum frames are used.

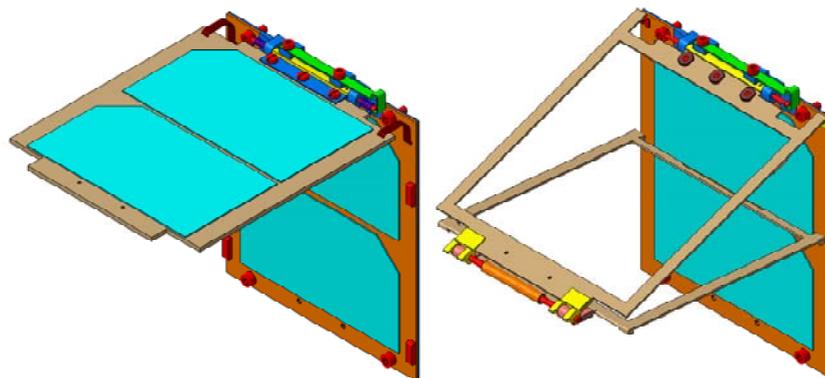
The primary mechanism (Figure 11 and Figure 12), involves a two-spring system in one axis with a travel limit. The deployable board is fixed to an aluminum hinge by three bolts. This hinge is mounted in the lateral shear plate of structure of Xatcobeo by a system composed by two lugs and shaft. The lugs are mechanized in an enlarged area of that aluminum shear panel. At both ends of the shaft, two steel springs are located. Those springs are the actuators of the rotation movement. There are two mechanical limits (physically stops the opening rotation); first one fixed to the shear plate ensuring the correct maximum angle during deployment (90°), second one is a steel flat spring which fixes the panel in the final position reducing vibration problems (the rotating shaft has a slot on its end, during the rotation the folded part of the spring slips over the shaft till it matches with the slot and the movement stops).



**Figure 11. First mechanism detail**

In the double deployment (Figure 12) case, two frames (for mass reduction requirements) are deployed successively. The first mechanism is the same described above, and an extra mechanism is added with a harder envelope limitation. The mechanism that unfolds the extra panel consists of two aluminum hinges, each one glued to one side frame. All the parts are assembled by a shaft with two steel rotation springs, and blocked in both sides.

Both deployable systems are fixed in stowed configuration by a nylon yarn. This nylon wire attaches the assembly formed by the movable panels, and the lateral shear panel of structure. So each PDM with its corresponding shear panel can be integrated in the Xatcobeo structure as an individual assembly. To start the movement of the mechanism there are two pyroelectric elements that cut the nylon yarn setting free the panel when commanded. Using two pyroelectric elements, a redundant configuration could be achieved. When the yarn is cut, all the rotation springs are free to start the deployment of the system.



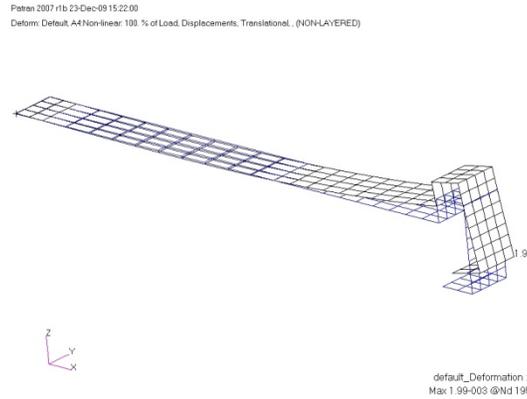
**Figure 12. PDM1/PDM2 design**

Two main requirements are issued for PDM: it shall deploy only once and shall send the result of the deployment action. To detect the deployment in the single system, power telemetries are used, and in the double a contact switch is designed.

Flat spring blocking system

One of the new advances in this design is the introduction of a flat spring to block the first deployment. It prevents micro vibrations induced movements in a space environment and serves at the same time as the helical springs as an additional blocking system. The blocking induced by this system consists in

fitting the tip of the flat spring into a 1-mm depth slot machined in rotating shaft head. The tip of the flat spring produces a friction force on the head of the shaft, acting as a damping for the rotating movement. The lateral force induced in the shaft is derived from a MSC/Nastran non linear static analysis of the flat spring using different thicknesses and materials. The values obtained are listed in Table 1. From the analysis, a vertical movement above the equilibrium position is observed when the tip of the spring is out of the slot, so this implies to make a thicker slot in shaft head. Other option to be taken into account is to manufacture the shaft head as a half cylinder instead of a slotted cylinder.



**Figure 13. Deformation of flat spring**

**Table 1. Lateral force for different spring thickness and materials**

Spring material	Thickness (mm)	Force (N)
Steel	0.3	1.813
Steel	0.4	7.29
Steel	0.5	13.57
Al	0.4	1.319
Al	0.5	3.525

Lubrication and materials selection

Being a one-shot mechanism avoids lubrication, with the only matter of use different materials in contact areas, and also a test campaign to minimize single failures. The damping of the rotation movement is achieved by: friction between metallic parts in the lug (Al) and shaft (steel) assembly; lateral contacts of plastic washers with principal hinge and lugs; and by friction between tip of flat spring and head of rotating shaft. The damping of the movement that requires friction goes against the requirement of reducing heat transfer amount between deployed parts and main body of the satellite. So the material of the friction washer will be one that allows friction but with low thermal conductivity. And in the lug – shaft area, the design tolerances will be adjusted to attain low contact area.

**Simulation**

A set of simulations have been run to dimension the springs and select the values for the springs that will be used in flight model. The kinematic and dynamic simulations have been developed using MSC/Adams program.

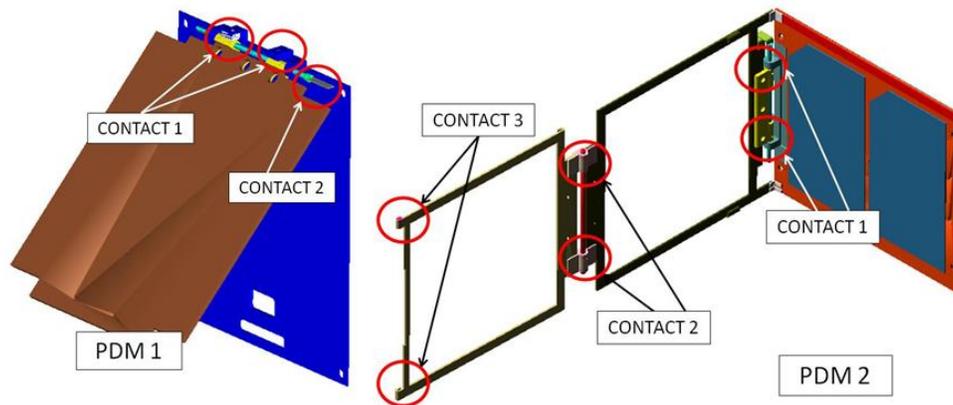
PDM 1 simulation

In the first simulation, the model is mounted with different sets of helical torsion springs and different flat springs looking for the lower impact force in the mechanical limits. Prior to the simulation, the model needs to be calibrated to define the characteristics of the movable parts and the contacts presented in it.

The mobile part consists of four solar cells, a FR4 board in which panels are fixed, the shaft, the hinge, the bolts that fix it to the board and the wiring of the solar arrays. The mass amount considered in the mobile parts is 40 grams.

There are two contacts in the model (Figure 14):

- The first contact between the hinge and the two blocks in the lateral shear panel of the satellite is of impact kind. It's defined by:
  - Stiffness of the contact. The two blocking elements are the same so only one contact has been considered in the calculations to reduce computation time. So the stiffness of that part has been increased to simulate the stiffness of the other blocking element. The stiffness is the one obtained in a beam with flexion load. The value considered is 21185 N / mm
  - Penetration depth: 0.01 mm
- The second contact between the head of the shaft and the flat spring. The contact has first a friction phase and when the plate enters in the slotted area of the head of the shaft it has an impact phase. The characteristics are:
  - Impact phase:
    - Stiffness of the contact. The stiffness is the one obtained in the tip of the flat spring with flexion load. The value considered is 414 N / mm
    - Penetration depth: 0.5 mm
  - Friction phase. It's between the tip of flat spring (steel or aluminum) and the steel head of the shaft. It's defined as a Coulomb friction force.
    - Static friction coefficient: 0.6
    - Dynamic friction coefficient: 0.4



**Figure 14. PDM1 / PDM2 Simulation model**

The movement is obtained by a revolute joint between the mobile parts and the grounded parts (lateral shear panel of the satellite), located in the shaft axis, and free to rotate around shaft axis.

The parameters that will be used to look for the lower impact force with the analyses are the stiffness coefficient of the torsion spring (one or two acting in parallel) and the lateral force induced in the shaft by the flat spring. The stiffness coefficients of the torsion spring calculated for different wire thickness, spring diameter, number of loops, and number of spring is are listed in Table 2.

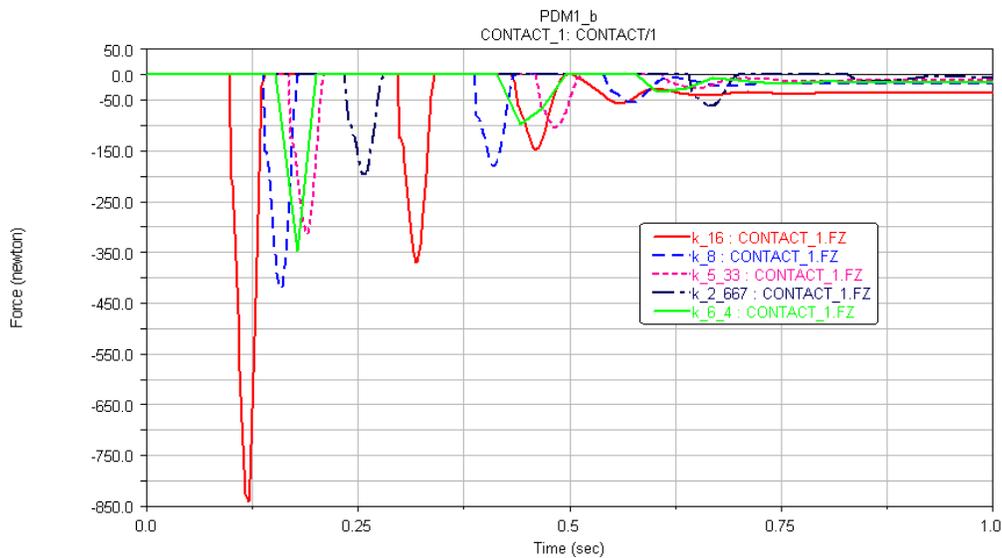
**Table 2. Stiffness coefficient for helical torsion spring**

Wire diameter (mm)	Spring diameter (mm)	Number of turns	Number of springs	Stiffness coefficient (N mm / rad)
0.4	2	5	2	16
0.4	2	5	1	8
0.4	2	10	2	8
0.5	3	10	1	6.51
0.4	2.5	5	1	6.4
0.4	2.5	10	2	6.4
0.4	3	5	1	5.333
0.4	3	10	2	5.333
0.4	2	10	1	4
0.4	2.5	10	1	3.2
0.4	3	10	1	2.667

In the first set of simulations a constant lateral force of 7.29 N is used with different spring stiffness values: 16, 8, 6.4, 5.33, 2.667 N-mm / rad. The results obtained are shown in Figure 15 and Table 2.

**Table 2. PDM1 simulation results obtained with spring stiffness variation**

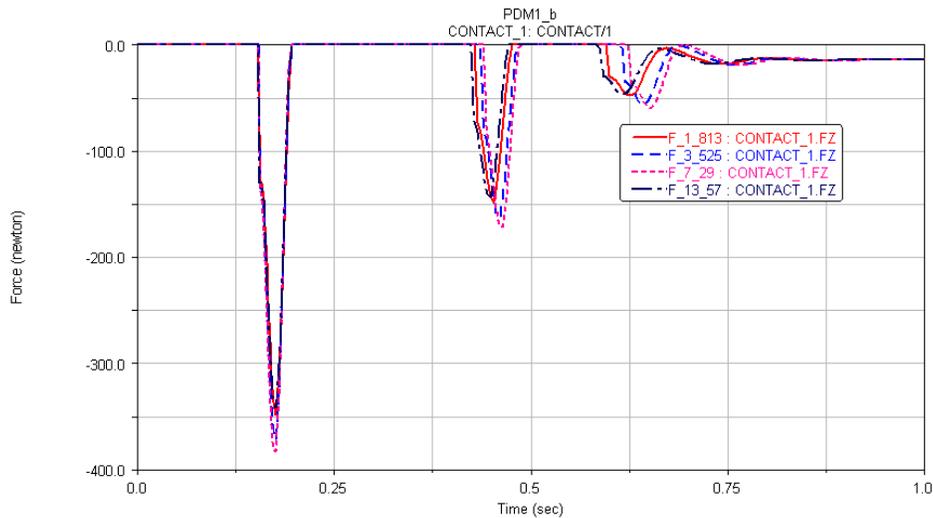
Spring stiffness	Force of first impact (N)	First impact time (s)	Number of measurable impacts	End time (s)
16	850	0.12	4	0.6
8	400	0.15	3	0.67
6.4	350	0.17	3	0.69
5.33	300	0.19	3	0.75
2.667	200	0.26	3	0.9



**Figure 15. Impact force for different spring stiffness**

The end time is taken to be when constant impact force is obtained. Observe that the movement is slower when reducing spring stiffness, and also the impact force decreases.

In the second set of simulations, the stiffness coefficient has been maintained in 6.4 N-mm / rad and the lateral force has changed with the values provided by the use of different spring material and thicknesses. The results obtained are presented in Table 3 and Figure 16.



**Figure 16. Impact force in for different lateral forces**

The lateral force has small influence in impact force. When lateral force is small, impact force can increase, and impact time of last rebounds also increases; but when it's bigger, the friction phase is more important and reduces impact force and impact time, and the flat spring enters in head slot before and helps to finish the movement.

**Table 3. PDM1 simulation results obtained with lateral force variation**

Lateral force (N)	First impact force (N)	Third impact force (N)	Third impact time (s)
13.57	340	44	0.61
7.29	380	60	0.66
3.525	365	53	0.64
1.813	350	46	0.625

#### PDM 2 simulation

In the double deployment mechanism, a similar simulation has been held. In this case only the springs have been considered in the optimization of the problem. There are two groups of mobile parts involved in the movement: one group consists of the first frame with its shaft, the principal hinge, and its secondary hinges, with a mass of 8 grams; and the second group is formed by the second frame, its hinges and the secondary shaft, with a mass of 6 grams.

There are three contacts in the mechanism (Figure 14):

- The first contact between the hinge and the two blocks in the lateral shear panel of the satellite is of impact kind. It's the same contact defined for PDM1.
- The second is between the hinges of the two mobile frames. It's also of impact kind and defined by:
  - Stiffness of the contact. The value considered is 1000 N / mm
  - Penetration depth: 0.1 mm

- Third contact between the curved ends of second frame and fixed board over lateral shear panel. It has two phases, one of impact and one of friction. The characteristics are:
  - Impact phase:
    - Stiffness of the contact. The value considered is 10000 N / mm
    - Penetration depth: 0.1 mm
  - Friction phase. It's between the tip of aluminum frame and the FR4 board. It's defined as a Coulomb friction force.
    - Static friction coefficient: 0.3
    - Dynamic friction coefficient: 0.1

Two revolute joints have been included in each rotation shaft to allow movement between mobile parts.

The parameters used during optimization process are the stiffness of principal (k1) and secondary (k2) springs. The results obtained are shown in Table 4.

**Table 4. PDM2 simulation results obtained with k1 and k2 spring stiffness variation**

k1	k2	Contact 1 Force (N)	Contact 2 Force (N)	End time (s)
16	8	180	670	0.4
8	4	110	340	0.45
6.4	3.2	110	---	0.5
3.2	2.667	102	220	0.55
2.667	2.667	62	---	0.75

As happens with PDM1, when stiffness is reduced the movement is slower and contact force decreases.

### Conclusions

#### Antenna deployment

When this work was begun, the Xatcobeo project management was counting on the possibility of introducing a commercial deployment system weighing more than 100 g. Over time, this cost in weight became unacceptable. So work was started on in-house development with the final aim of dramatically reducing the mass needed for the antenna deployment mechanism. It was decided to use polymeric materials and titanium instead of metals such as aluminum or steel, and the deployment and retention systems were unified around a single support component, which in turn would be the electrical insulation for the antenna. All these decisions had the same aim: reduce weight without compromising the reliability and stability of the mechanism or the assembled whole.

By selecting polyamide 6 as the structural material for the sub-chassis and covering it with zinc- or silver-based dissipative paint, the requirements for the behavior of materials in the working environment were fulfilled.

The choice of attachment elements made of titanium in M2 metric instead of steel in M3 reduced the final weight to just 20% of the initial weight. Furthermore, by making the sub-chassis from polyamide and not aluminum, its mass was reduced by 58.67%.

The final result of development is that the assembly made up of the sub-chassis, attachment elements (bolts, nuts and washers), electrical resistance, switch, heat-stable enclosing sheet and nylon retention thread had a total weight of 12 g.

The reliability shown in the tests; the great lightness of the assembly achieved using low density materials; the large internal space leaving room for solar panels, cameras or other installed devices in the mechanism's installation face; its robustness, which makes it easy to handle and simple to assemble; and its low cost and short manufacture time, thanks to the Selective Laser Sintering rapid prototyping process;

all this, and all that has been explained above means that we have, in conclusion, achieved an ideal mechanism for the storage and deployment of antenna not only for picosatellites such as the CubeSat 1U developed in the Xatcobeo project, but also for other types of picosatellites.

### PDM

Small satellites require small mechanisms. But from miniaturization appear new problems such as manufacturing difficulties; in PDM it was to build shafts with the required length, small diameter and the adequate tolerances, which will lead to make shorter broken shafts instead the of full length used now.

A deployment system with a mass of 45 grams using boards of a 1.6-mm thickness was completed, and also it's possible to reach a double deployment with 55 grams using 0.8-mm boards (that in our case is not applicable due to mass restrictions). It's achieved the desired goals of having a system in a 6.5-mm envelope protruding from the satellite and allowing easy integration in such tight dimensions.

A flat spring retention system has been designed to avoid in flight induced micro vibrations and act as an additional blocking system. The flat spring used should be the one that produces the greater lateral force to induce damping in the movement, but not too thick to provoke plastic deformation in the bended area. The selection of springs for PDM1 and PDM2 leads to look for springs with small stiffness: more wire turns, less wire diameter, higher spring diameter and to use only one spring.

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