STUDENTS' SPACE ASSOCIATION

THE FACULTY OF POWER AND AERONAUTICAL ENGINEERING
WARSAW UNIVERSITY OF TECHNOLOGY

PW-SAT2

PRELIMINARY REQUIREMENTS REVIEW

Mechanics of the satellite
Deployment Team

Phase A of the PW-Sat2 project

1.1 EN

pw-sat.pl

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Abstract

This document is a part of summary of the phase A student satellite project PW Sat2. It contains a description of previous work on the mechanics of the satellite PW-Sat2 - the main structure and mechanisms for opening of the solar panels and the deorbitation sail

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Attention Phase A documentation may be outdated in many points. Please do not depend on Phase B or Phase A documents only. Current documentation is available on the project website pw-sat.pl

This document is also available in Polish.

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1 INTRODUCTION

This document is a description of previous work on the mechanics of the PW-Sat2 satellite - the main structure and mechanisms for opening solar panels and deorbitation sail. It describes requirements of elements, their design solutions, possible risks with their mitigation plan and basic tests on subsystems. At the end of each section a list of the work that remained to be performed for each of the subsystems to the end of phase B of the project can be found.

2 DEPLOYABLE SAIL IN PW-SAT2

2.1 INTRODUCTION

Deorbitation sail is the main payload on-board PW-Sat2. Its aim is to achieve accelerated deorbitation of the satellite, to remove it from orbit just after completion of the mission. It plays a role of the "parachute" - generates additional aerodynamic drag, which gradually slows the satellite and leads to a faster descent. Deorbitation system is an innovative mechanism which correct functioning can result in the creation of light, reliable, consuming little energy system, that will effectively assist the process of deorbitation of broken satellites (or those who have already performed its mission) on low Earth orbits.

2.2 SAIL INFLUENCES ON DEORBITATION

The main purpose of the sail is to increase the sail surface in a plane perpendicular to the velocity vector of the satellite. This will significantly increase the aerodynamic drag generated by the satellite. PW- Sat2 will perform its mission on low earth orbit (near-circular, with a height of up to 700 km), where the influence of the atmospheric drag on deceleration is significant. Estimated orbit life-time is more than two years, calculations has been based on similar CubeSat missions. Detailed calculation of the impact of the sail on deorbitation time has not been conducted yet. It is required to perform analysis in the Satellite Tool Kit (STK). After studying similar missions, gathering the necessary information and based on preliminary analysis performed for the mission of the PW- Sat2, sail with an area of 4m2 should shorten the satellite life on orbit several times. This would remove the satellite from its orbit in the range of a few to several weeks. Achieving such result would mean a great success of PW-Sat2 and result in flight-tested technology, which allows removing small satellites from low earth orbit.

2.3 ASSUMPTIONS AND SYSTEM REQUIREMENTS

The efficiency of the system, and so the time by which it will reduce life of the satellite on orbit, depends on the sail area, satellite's size and its weight as well as orbital parameters. For the fastest deorbitation the sail with the largest possible area must be used. Because we used a CubeSat standard, the opening mechanism and the material of the sail must be located inside the structure of the satellite with the maximum dimensions of the tray 8 x 8 x 8 cm and weight less than 0.7 kg.

After the phase 0 summary and mass budget estimation, we received initial dimensional and reliability assumptions for the deorbitation system:

ACCEPTABLE PARAMETERS

system dimensions	80 x 80 x 80 mm
system mass	0,7 kg
reliability	min 99%
sail area	2 m^2

Table 2-1 Acceptable parameters of the deorbitation sail

Preliminary assumptions must be fulfilled to make it possible to install the sail inside the structure of the satellite. During the development of the concept of deorbitation mechanism we will work to optimize the mass and volume. The main purpose is to reduce the weight and the dimensions of the system to a lowest value, while maintaining a predetermined level of reliability and sail area.

OPTIMAL PARAMETERS

system dimensions	80 x 80 x 50 mm
system mass	0,4 kg
reliability	min 99%
sail area	4 m^2

Table 2-2 Optimal parameters of the deorbitation sail

2.4 OPERATION OF DEORBITATION SYSTEM

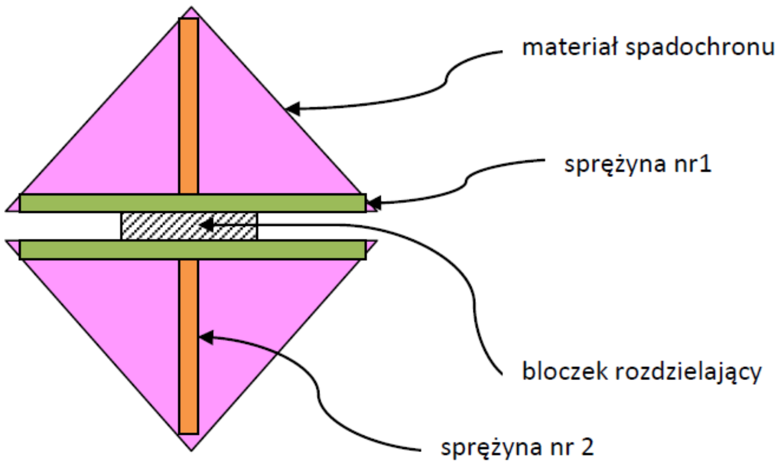
Deorbitation system was being developed and improved from the beginning of the PW-Sat2 project. It still changes in order to achieve the best possible parameters. Earlier projects provided different ways to increase the surface of the satellite by deployable or inflatable structures. Work began on isolating the most promising concept (opening using smart materials or flat springs), creating CAD models of several solutions and making the actual models of two best. It was decided to develop the concept with flat springs of the appropriate section (shape used in metal rulers).

The springs are very reliable and their shape stiffens the structure after deployment.

We considered two ideas of sail deployment (in both cases the prototype sail is a square with a side of about 1.3 m with springs placed in the pockets of the material on the diagonals):

• all springs "up" [Figure 2 1]

• folding sail around the cylinder [Figure 2 2]



1.

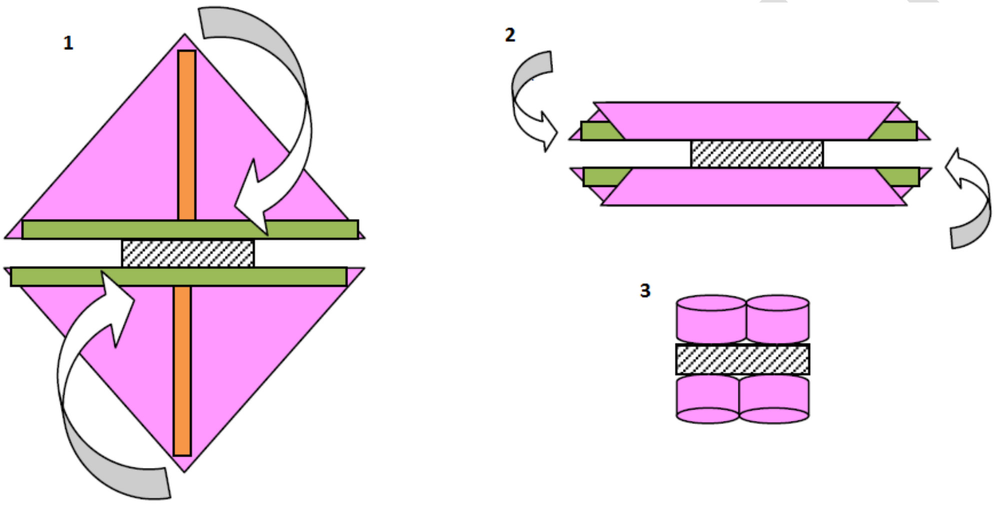


Figure 2-1 All springs "up"

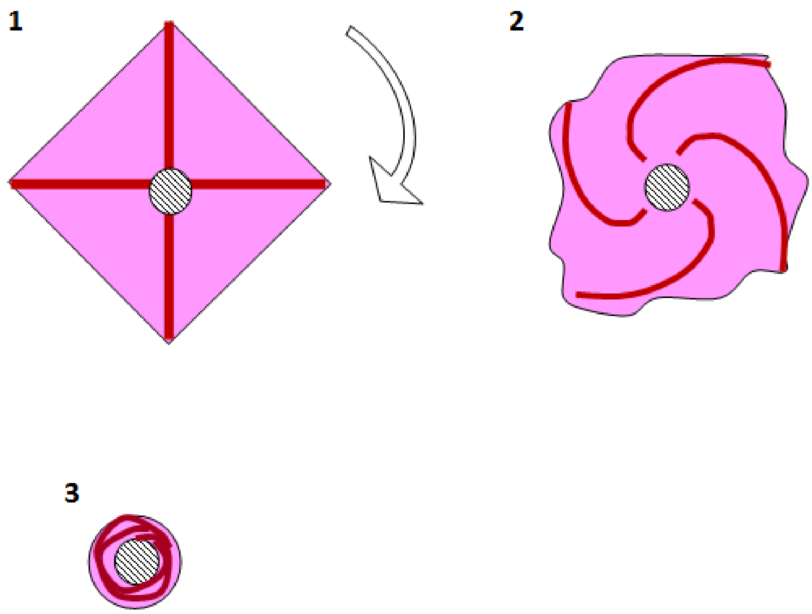


Figure 2-2 Folding sail around the cylinder

After phase "0" we selected a spring system as shown in Figure 2-2.

Material of the sail is attached to the two flat springs formed on the cross-sectional shape of two letters "c":

Springs are placed in the pockets of material extending from the centre of the mechanism to the corners of the material. As a result, the spring can be moved relative to each other during the opening of the sail, while remaining perpendicular to the surface of the material:

Springs are wrapped around the cylinder located in the axis of the satellite

Currently we are trying to optimize the cross-sectional shape of springs and make simulation of springs deployment with the Abaqus software. These analyses are time consuming and prone to large errors due to the complicated move of springs and the impact of the sail material on the process. For this reason it was decided to include empirical optimization including thickness of springs and material for the surface of the sail. This research will rely on building of more models using various materials and testing of deployment mechanism.

The method of releasing wounded springs is not well investigated. It requires a lot of tests and several options are being considered for mounting and releasing of the holding string. At the moment outweighs the following concept: after rolling, sail is wrapped by first string (Dyneema or another with a rougher surface) and bounded. One of its ends creates a node, which can be untied by pulling of the other end of the string. This second end of the string is free.

The shaft with wounded springs is attached to the tray using a conical spring. Conical spring was chosen because of the possibility to minimize the height of the compressed spring to 1-2 turns (it will reduce the size of the whole system). Its task is to push out the sail at a distance of 20 cm from the main structure of the satellite. To prevent the welding effect in vacuum, spring's coils will be covered with a layer of solid lubricant.

2.5 METHOD OF STARTING OF THE MECHANISM

Burnout Dyneema springs will release conical spring. During ejection of the sail from the container, spring attached to the underside of the container will be tightened and the string, which held the springs flat, will untie. After the untying of the node, the major part of the mechanism will be released. Flat springs will begin to unfold, spreading the material and creating a flat surface.

2.6 MOMENT OF START

Moment of start of the operation of deorbitation system is defined by the profile of the satellite mission. In the case of PW-Sat2 mission, deployment of the sail is going to take a place after tests of other subsystems (SunSensor). At the appropriate time satellite will receive a request, after which the sail will be deployed. It is planned to record the sail deployment and send images to the ground for ascertain whether the mechanism deployed properly. For this reason, the sail system cannot interfere with the permanent communication with the satellite.

In case of the loss of communication before sending of the request for deploying the sail, on-board computer will start the countdown sequence to automatic start. If within 30 days from the start communication with the satellite will not be reached and automatic deployment will not be delayed by a command from the ground station, the sail will be automatically deployed. The mechanism is independent from the on-board computer and also from the power supply.

Dyneema strings are connected in parallel to the battery and to the solar cells and have its own clock counting down the time that has elapsed from the launch of the satellite. This makes it possible to open the sail even without contact with the ground station, on-board computer failure, battery failure and still complete the main mission of the satellite.

2.7 POSSIBLE PROBLEMS

There will be several tools to verify system operation, a small camera (CAM 2) located on a deployed solar panel and telemetry data from NORAD system. CAM 2 will be activated before sending of the command to open the sail for recording of the biggest slice of sail surface. The telemetry with photographs documenting deployment of the sail will be used to evaluate whether the sail was developed properly. If data from camera will not be available, deployment of the sail will be confirmed using telemetry data. The faster decrease of the orbital period and other parameters will make sure that the structure has been spread. However, TLE data does not allow assessing information about the full effectiveness of the system - it will not be possible to verify whether the sail deployed correctly or only partially.

MECHANISM WAS NOT OPENED

In this case the sail will not open and will not affect on the deorbitation. This can occur as a result of: "welding" the metal during spring ejection, no burnout of Dyneema strings, or the automatically start (after 30 days of loss of communication) system failure.

Protection against these problems must be provided at the design stage, by selecting the appropriate coverings for spring, providing enough energy for burn strings and designing a reliable algorithm to burnout them automatically.

INCOMPLETE DEPLOYMENT

Observation of incomplete deployment should be possible by analysis of images from CAM2. This should determine what kind of problem occurred during deployment process. The result of this issue will be a slower deorbitation process. The sail can also open asymmetrically, which will cause unwanted aerodynamic torque rotating the satellite.

To prevent such accident, a detailed procedure for folding of the sail and installing it in container should be described and abided. Also it is required to design a repeatable test procedure for the mechanism and to perform the necessary number of attempts to achieve a satisfactory level of system reliability.

LOSS OF COMMUNICATION AFTER DEPLOYMENT

This problem can occur as a result of a sudden satellite spin up due to the release of energy accumulated in the folded springs, or damage to antennas during deployment of the sail.

Antenna damage can occur when the sail will deploy asymmetrically, or will fall in large vibrations caused by the movement of the springs. The probability of this must be demonstrated in tests and corrected by appropriate balance and symmetrical folding of the sail.

2.8 TESTS

The mechanism tests must be repeated many times to be reliable.

Testing procedure will be developed after the final realization of the deorbiting system and adapted to its requirements. The test stand should be designed with a view to carrying out multiple tests over a few to several dozen days. The best testing room would be *clean room*, where the influence of dust particles on the mechanism would be eliminated. Currently the test stand for imitating the microgravity conditions is being created. The deorbitation system will be suspended above the ground. The influence of gravity will be eliminated by the surface as smooth as possible, over which the tapes deploying the sail will slide. The block of material with the size and weight similar to the real satellite will imitate the influence of weight and inertia of the satellite on how the sail will be deploying. If the mechanism will overcome friction between the material and the surface, we can be sure that it will deploy also in the microgravity environment, where it will not be this kind of friction.

An important thing are the vibrational tests on a shaker, which by causing vibrations of different frequencies can damage the sail parts or shift some of its elements to each other. The influence of these vibrations is taken into account in the design process. The vibrational tests will make us sure, that the system is designed properly.

2.9 LEVELS OF SUCCESS AND FURTHER WORK

Level	Realization	Description
1	$t_{SAIL}<1/4\ t_{STD}$	Time after which the satellite has been deorbited with deployed sail t_{SAIL} is 4 times shorter than expected lifetime of the satellite on this orbit without the sail t_{STD}

2	$t_{SAIL}<1/2\ t_{STD}$	Time after which the satellite has been deorbited with deployed sail t_{SAIL} is 2 times shorter than expected lifetime of the satellite on this orbit without the sail t_{STD}
3	$t_{SAIL}<t_{STD}$	Time after which the satellite has been deorbited with deployed sail t_{SAIL} is shorter than expected lifetime of the satellite on this orbit without the sail t_{STD}

Table 2-3 Levels of success for the deorbiting sail

2.10 NEXT STEPS (TO THE END OF PHASE B):

1. flat springs shape optimization
2. more precise sail model and its tests
3. different concepts of the arbour clamping springs (3D printing)
   a) new material of flat springs (beryllium bronze)
   b) different materials of sail surface (films, MLI)
   c) the ejectional cone spring – different parameters
4. design of the sail container inside the satellite structure
5. design of the system stiffening cone spring after deploying
6. tests of optimal model in simulated microgravity conditions

3 SOLAR ARRAYS DEPLOYING MECHANISM

3.1 RELIABILITY

Due to the nature of space missions the subsystems on the orbit launched device must have reliability at least 98%. That is why designed mechanism should have simple construction and consist of components that individually have a high reliability.

3.2 PRINCIPLE OF MECHANISM OPERATION

One of the most reliable parts in the mechanism is a spring. Thus the project of solar panels deploying system was based on using helical torsion springs with properly matched torque. The mechanism was designed in a way to make modifications easily, for example to change the solar panels opening angle. In this case sufficient will be to redesign the part locking the panels position (by changing the surface abutted on glued hinge part) and change the parameters of torsion springs combination.

MECHANISM OPERATION:

1. while satellite launching into orbit and in the initial phase of the mission the solar panels are closed (adjacent to the walls) – Dyneema wire is attached to the free ends of the panels and immobilizes them [Figure 3-1]
2. torsion springs placed in the panel's hinge are subjected to pressure (the angle between the free ends of the springs is 0°)
3. satellite receives a signal to open the panels – electric pulse is send to the resistors touching the Dyneema wire
4. resistors heat up and the wire is burned
5. torsion springs are opening the panels
6. specially shaped hinge part locks the panels in position of 90°
7. residual torque causes a continuous spring pressing and prevents the closing of the panels

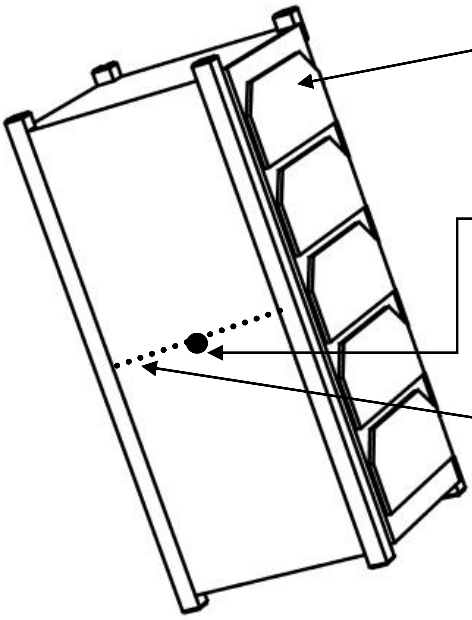


Figure 3-1 Mechanism holding the panels in the closed position

In the designed mechanism we select a spring to the calculated case, in which the input data are start and end moment and operating angle of spring torsion.

Due to designing a device working in zero gravity, we have to choose the spring with a small starting moment (it should be at least 4 times bigger than estimated moment of friction).

The estimated moment of friction between spring coils is not more than 0,1 Nm (use of coils clearance reduces the moment of friction), starting moment was estimated at about 5 Nm, ending moment (pressing the locking part) at about 1 Nm (ending moment should be 4 times greater than the moment of friction and take into account possible difference between real and calculated angle of torsion as large as 15%).

3.3 CALCULATION OF OPENING SPRINGS

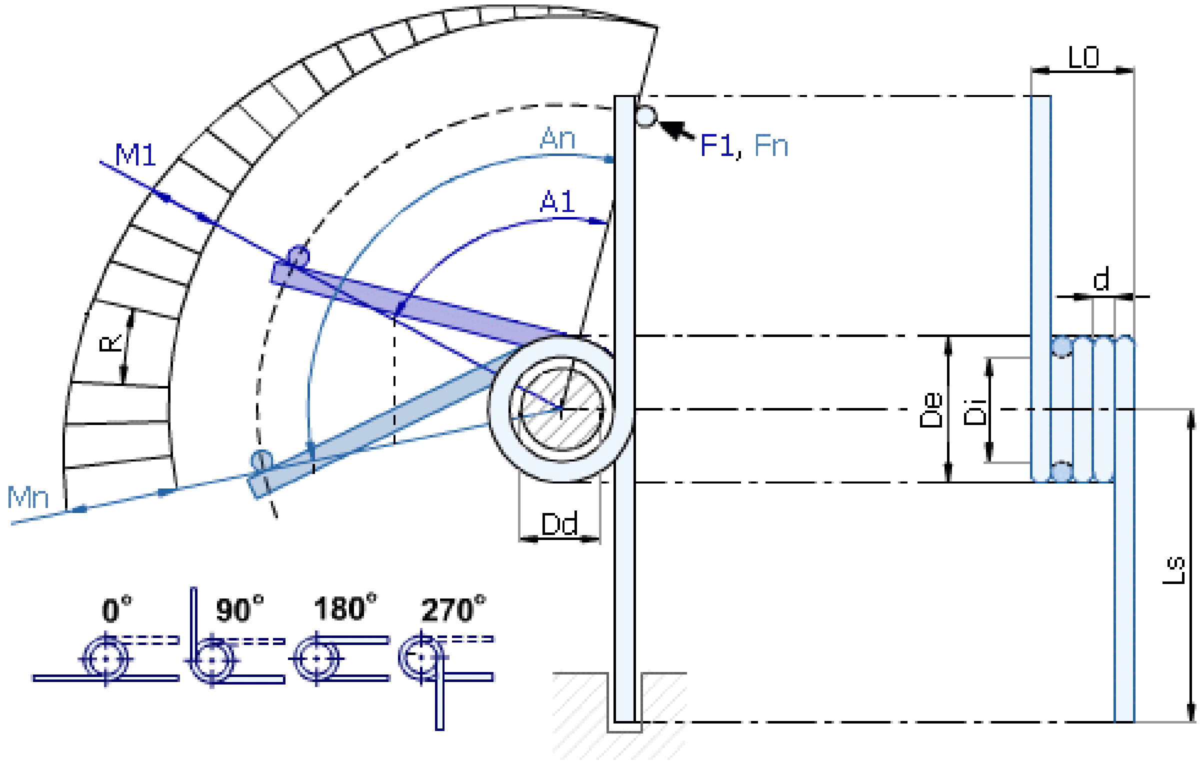


Figure 3-2 Torsion spring parameters

Denotation according to [Figure 3-2]:

D_d = 2 mm (diameter of shaft mounting the spring)

M_n = 5 Nm

M_1 = 1 Nm

ϕ_r = 90° (operating torsion angle = panels opening angle)

ϕ – total torsion angle

D – average spring diameter (from core to core)

d – wire diameter

c = D/d – spring index

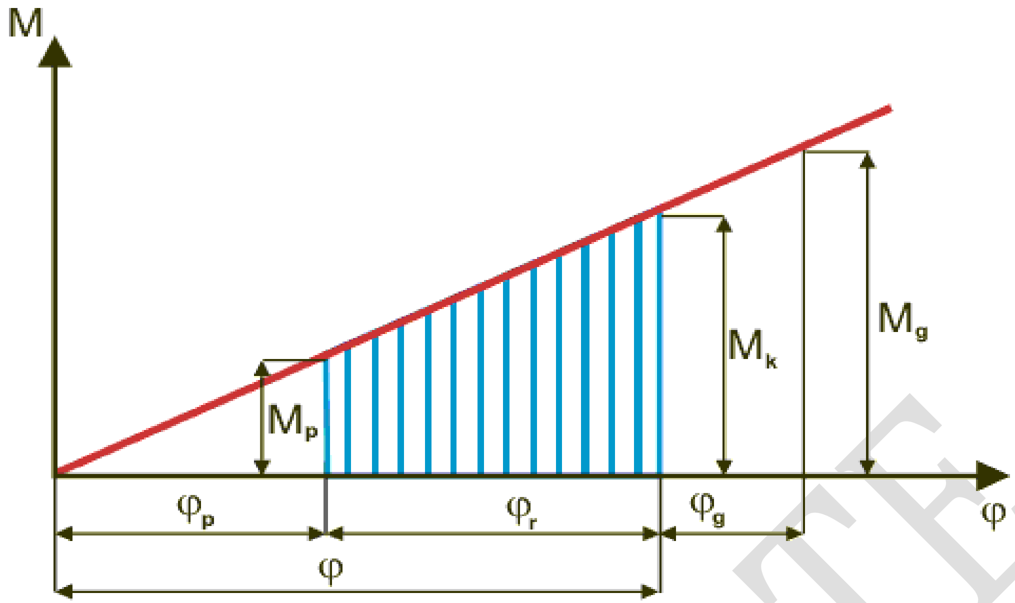


Figure 3-3 Helical torsion spring characteristics

Torsion spring characteristic is linear, therefore:

$$\varphi = \varphi_r \frac{M_n}{M_n - M_1} = 90° \frac{5}{4} = 112{,}5°$$

Making an assumption of constant c = 7,5 from where Wahl's correction factor (K):

$$K = \frac{4c - 1}{4c - 4} = 1{,}12$$

Taking into account the spring working condition the spring material is selected (carbon steel A, by PN-71/M-80057) and the value of the allowable stress is found $k_g \approx 1200$ MPa.

Calculated wire diameter:

$$d' = \sqrt[3]{\frac{32 M_n K}{\pi k_g}} = 0{,}36mm$$

The nearest normalizes diameter d = 0,4mm.

Average spring diameter:

$$D = cd = 3{,}12mm$$

Minimum spring diameter D_{min} = D-d/2 = 2,92mm so the clearance between the shaft and spring = 0,92mm.

Number of active spring coils n = 3,5, total number of coils z ≈ 6,19.

Checking whether loaded spring diameter is not reduced in an unacceptable manner. Approximately reduced diameter is:

$$D_1 = \frac{D}{1 + \frac{\varphi}{360z}} = 2{,}99mm$$

Coils clearance:

$$\delta = d\left(0{,}2 + \frac{\varphi}{360z}\right) = 0{,}1mm$$

Checking the spring for buckling:

$$\varphi' = 123{,}1\sqrt[4]{z} = 200{,}2°$$

$$\varphi = 112{,}5° \leq \varphi'$$

The spring will not buckle.

3.4 BREAKING SPRING SELECTION

Breaking spring is selected for the calculation case, where the input data are: operating angle of torsion spring, initial moment and normalized diameter.

The final moment of breaking spring should be smaller than the final moment of opening spring, thus also the wire diameter of breaking spring have to be smaller than diameter of the first spring wire, which is 0,4 mm. Next normalized diameter is 0,32 mm, therefore this will be the breaking spring diameter.

For the operating torsion angle we assume 60°, less than operating torsion angle of first spring, which is 90° .

Calculations were carried out in analogy to the calculations of the main opening spring.

CALCULATED BREAKING SPRING PARAMETERS

Dla różnych wartości średnicy drutu:

φr	φ	M_1	Mn	d'	D	D_{min}	l
60°	70°	0,5	3,44	0,32	2,4	2,24	0,24
60°	85°	0,5	1,64	0,25	1,9	1,75	-0,25
60°	65°	0,5	6,73	0,4	3	2,8	0,8

Dla różnych wartości momentu początkowego:

φr	φ	M_1	Mn	d'	D	D_{min}	l
60°	70°	0,5	3,44	0,32	2,4	2,24	0,24
60°	85°	1	1,64	0,32	2,4	2,24	0,24
60°	143°	2	6,73	0,32	2,4	2,24	0,24

Dla różnych wartości roboczego kąta skręcenia:

φr	φ	M_1	Mn	d'	D	D_{min}	l
60°	70°	0,5	3,44	0,32	2,4	2,24	0,24
80°	94°	0,5	1,64	0,32	2,4	2,24	0,24
50°	58°	0,5	6,73	0,32	2,4	2,24	0,24

Table 3-1 Calculated breaking spring parameters

3.6 HINGE PARTS DESIGN

In order to save the satellite side surface, the hinge structure is located inside the satellite's rail. To maintain the panels stiffness there is designed a connection of panels with the main structure by using two identical hinges.

Hinges built into the rails will need to make cut-outs in the rails.

The condition of contact rails with P-POD for at least 75% of the rails surface results in restrictions of the cut-outs length in the rail:

$$w = \frac{0,25L}{2} = 27,1mm$$

where:

L – rail length=217mm

w – maximum width of a single cut-out

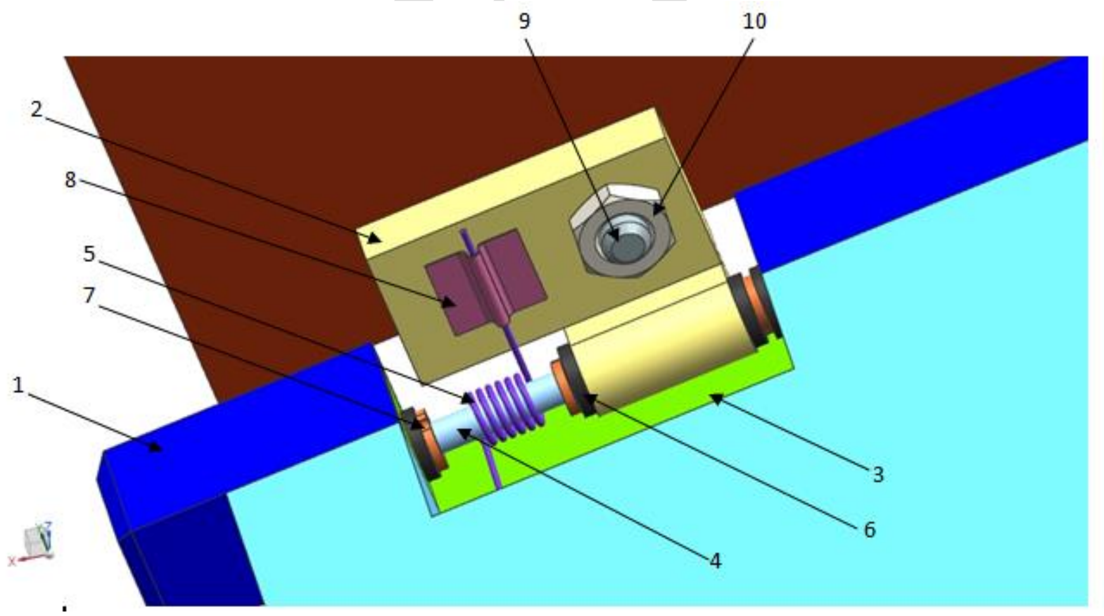


Figure 3-4 Hinge visualization

Part number on Figure 3.1	Part name	Quantity	standard/document/comments
1	left/right rail	2	CubeSat Design Specification
2	hinge part 1 (locking)	4	
3	hinge part 2 (pasted)	4	
4	shaft φ2mm	4	
5	helical torsion springs system (opening + breaking)	4	PN-71/M-80075
6	teflon sleeve	16	
7	Seger clamping ring	12	ring under shafts without grooves
8	spring mounting plate	8	pasted plate
9	enlarged head screw M3x8	4	DIN 921
10	Hexagon low nut M3	4	DIN439

Table 3-2 List of hinge elements

3.7 MECHANISM PARTS

RAIL

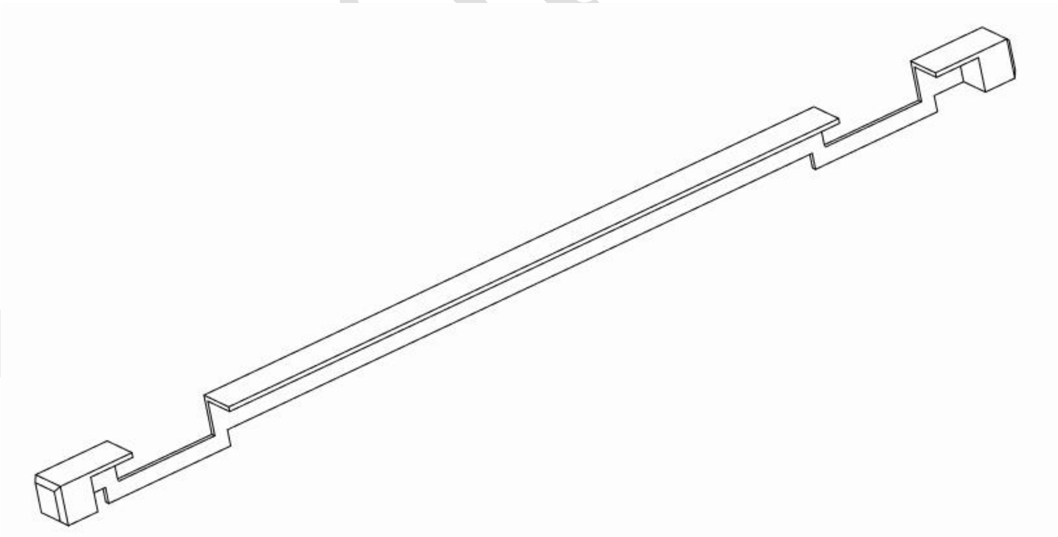


Figure 3-5 Rail

Rail is made in the form of angle bar with full ends. These ends are required in accordance with the CubeSat standard, they are used for ejecting the satellites from the P-POD. The angle bar can definitely reduce the weight of the item.

In the rail there are two cut-outs with a length of 23 mm and depth of 8,5 mm which allows to mount the hinge of opening panels mechanism.

In order to facilitate the assembly and avoid problems with fitting the parts, there is a „frame" milled around the cut-outs – the rail is not divided with this treatment.

The rail is wholly milled – material: aluminium 7075.

HINGE PARTS 2 AND 3

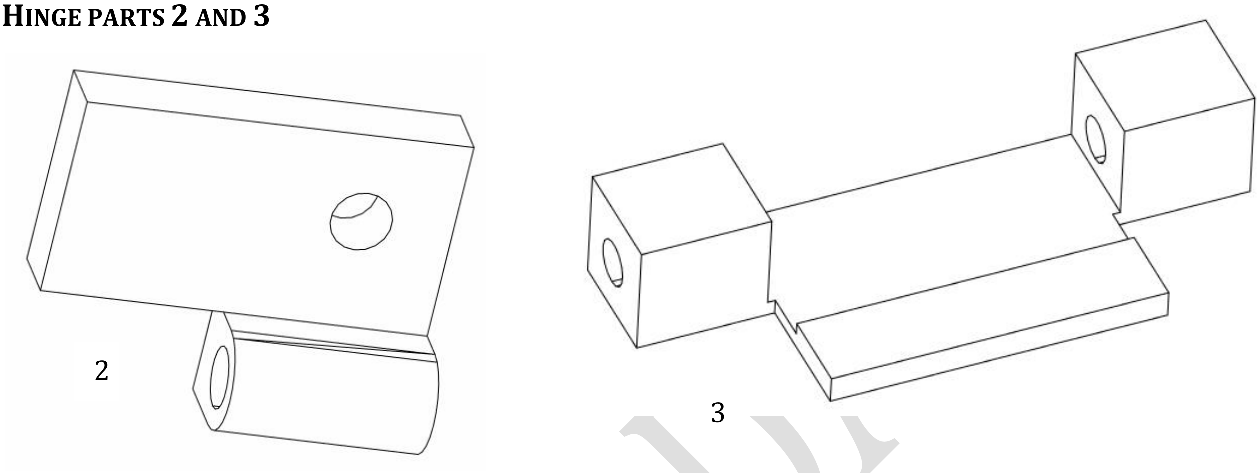


Figure 3-6 Hinge parts 2 and 3

Both components are designed to form a hinge and mechanism locking the panels in proper position.

Part nr 3 has a through hole φ3mm to mount other hinge components. Once assembled, the element is pasted to the rail's angle bar.

Part nr 2 material – stainless steel type 304

Part nr 3 material - aluminium 7075

In the Fig. 3.4 the mechanism parts are presented in closed and opened (locked at 90°) positions. Suitable surface fitting of both elements effectively locks the mechanism in fixed position. In addition, the shape of contact surfaces can be easily changed to lock the panels in a different position (e.g. 30°, which may be necessary for a specific satellite mission).

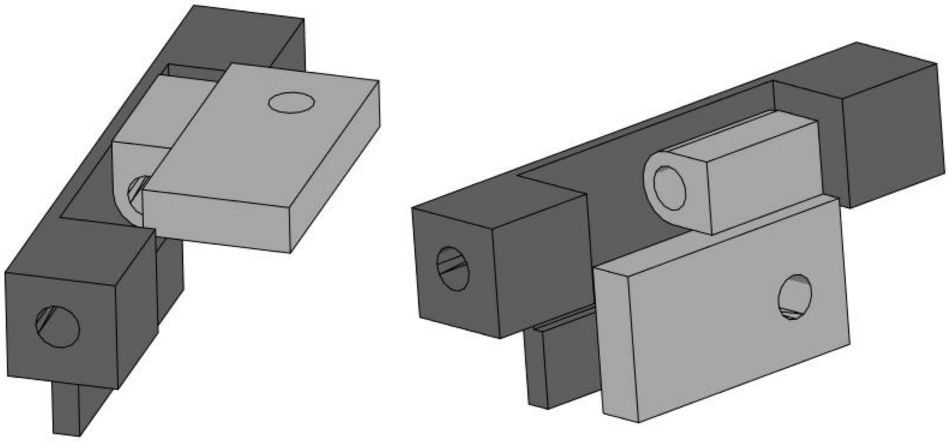


Figure 3-7 Closed and opened mechanism visualization

SHAFT

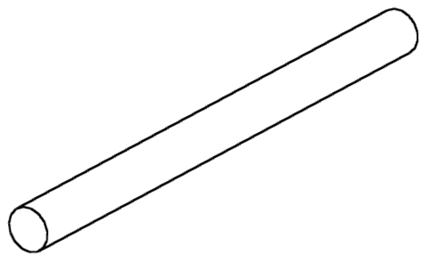


Figure 3-8 Hinge shaft

The shaft performs the functions of an arbour which the hinge elements rotate around and on which the torsion spring is mounted. The elements are mounted on the shaft by normalized Seger clamping rings (the rings do not require grooves).

Shaft dimensions: φ2mm, length 28mm.

Material: stainless steel 304.

HELICAL TORSION SPRING

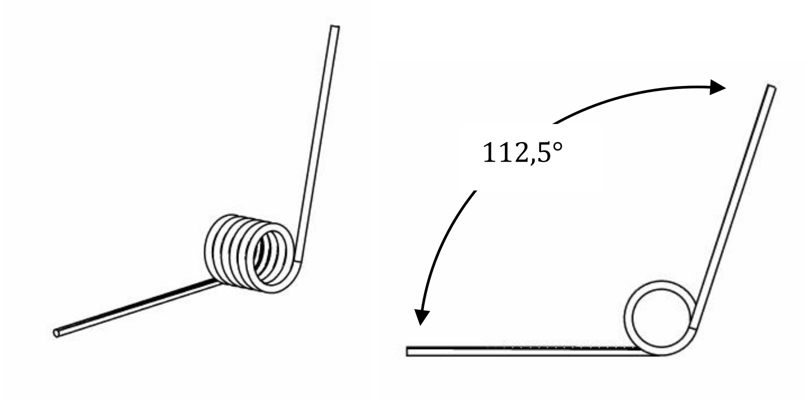


Figure 3-9 Torsion spring

The spring causes opening of the panels. Its free ends are attached to the satellite using stuck bent plate (part nr 8). The spring is made of round wire of carbon steel type According to PN-71/M-90057.

TEFLON SLEEVE

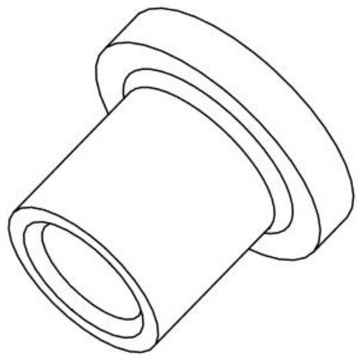


Figure 3-10 Teflon sleeve

The teflon sleeves are used to embed the shaft and part nr 2. Teflon properties provide good mating with metals and prevent seizing the elements during rotation.

Dimensions:

internal diameter: 2 mm
external diameter: 3mm
flange diameter: 4,5mm

The weight of all four hinges does not exceed 80g.

3.8 SOLAR PANELS' OPENING SYSTEM TESTS

As in the sail's case, the demanded reliability of the mechanism is to be gained through carrying out multiple tests. In the hinges' tests, the simulation of microgravity conditions appears to be more difficult (while the sail's deployment test can be simply carried out on a flat surface). Testing the hinges consists of multiple opening of the mechanism on its working plane, perpendicular to the gravitational force's plane (satellite suspended vertically on rails). The research on possible occurrence of satellite's oscillations after the opening of the solar panels is essential, as well as is carrying out tests on an oscillation exciter to check if the elements of the mechanism are not getting damaged or moved from their positions or if the panels do not accidentally open due to oscillations.

3.9 POSSIBLE PROBLEMS AND THEIR CONSEQUENCES

NON-LOCKING OF THE MECHANISM IN THE RIGHT POSITION (90 DEGREES)

The non-locking of the mechanism in the demanded position may be caused by the damage of the opening spring or a change of the blocking surface in the mechanism (for example due to interrupting elements between the hinge's surfaces). It could result in oscillations of the panels or hitting the satellite's walls by them, in consequence causing the damage of the whole mechanism or even tearing off the panels. That would put in danger other components of the satellite (for example UHF/VHF antennas) and diminish the efficiency of the power supply system and cause problems in satellite's stabilization.

NON-OPENING OF BOTH / ONE SOLAR PANEL

This problem may occur if the line holding the panels in closed position is not burned or if any of the hinges gets blocked. To minimalize the risk of incorrect opening, a second resistor will be installed (redundancy in the line-burning system) and the opening springs will be covered with layer of special grease.

Total non-opening of the panels may cause problems in generating electricity from the solar panels. In that case placing the satellite's correct surface on the Sun will become pointless but the satellite, rotating in random way around all three axes, still will be collecting sufficient amount of electricity to support the power of the main systems.

The non-opening of one solar panel will cause diminishing of the collecting of energy from the panel's solar cells when turning them to the Sun and will result in difficulties in trimming the satellite. If such asymmetrical opening occurs, the satellite may start rotating due to only one solar panel open. That means that the solar panels' opening mechanism has only one degree of success – full opening. Every failure, minor or major (partial/total non-opening) will cause problems in other systems' functioning.

3.10 Further work

Next stages of the works (up to the end of the B-phase) are as follows:

1. Improvement of the opening-braking system and the system holding panels in their demanded position,
2. Integration of the hinges' real models:
    a. manufacturing of the opening- and breaking springs,
    b. manufacturing of the frame with cuts designed to house the hinges (3D print),
    c. manufacturing of the hinges' elements (3D print),
    d. assembly of the hinges' elements into a complete mechanism.
3. Tests of the hinges' models (speed of opening, breaking of the main spring, symmetry of the opening),
4. Possible modifications of the elements and their further tests,
5. Careful choice of the hinges' materials.

4 MAIN STRUCTURE

4.1 INTRODUCTION

The initial design of the satellite's structure was based on the structure of PW-Sat. A part of this satellite's solutions was adopted and re-designed for use in a 2U-class satellite.

The structure consists of three frames, joined together by screws, holding other subsystems.

The frame's rails have the cross-section shape of an angle-bar on the majority of their length, the remaining parts of them have the obligatory shape of a cuboid (due to the location of switching-on elements and separating springs which are located on the edges of the satellite). Frame no. 1 has cuts in its rails in order to place there the solar-panel-opening mechanism.

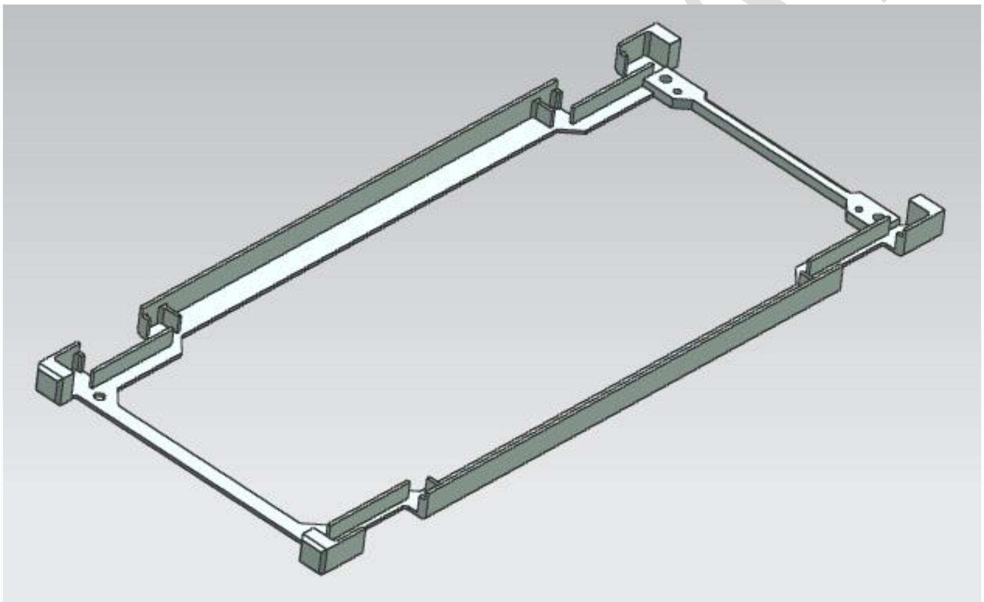


Figure 4-1 Frame no. 1; cuts for the opening mechanism are visible.

Frame no. 2 has the supporting structure for CAM1 camera, which is (together with its electronic circuit plate) placed inside the main satellite structure and fixed to it by screws and spacing sleeves.

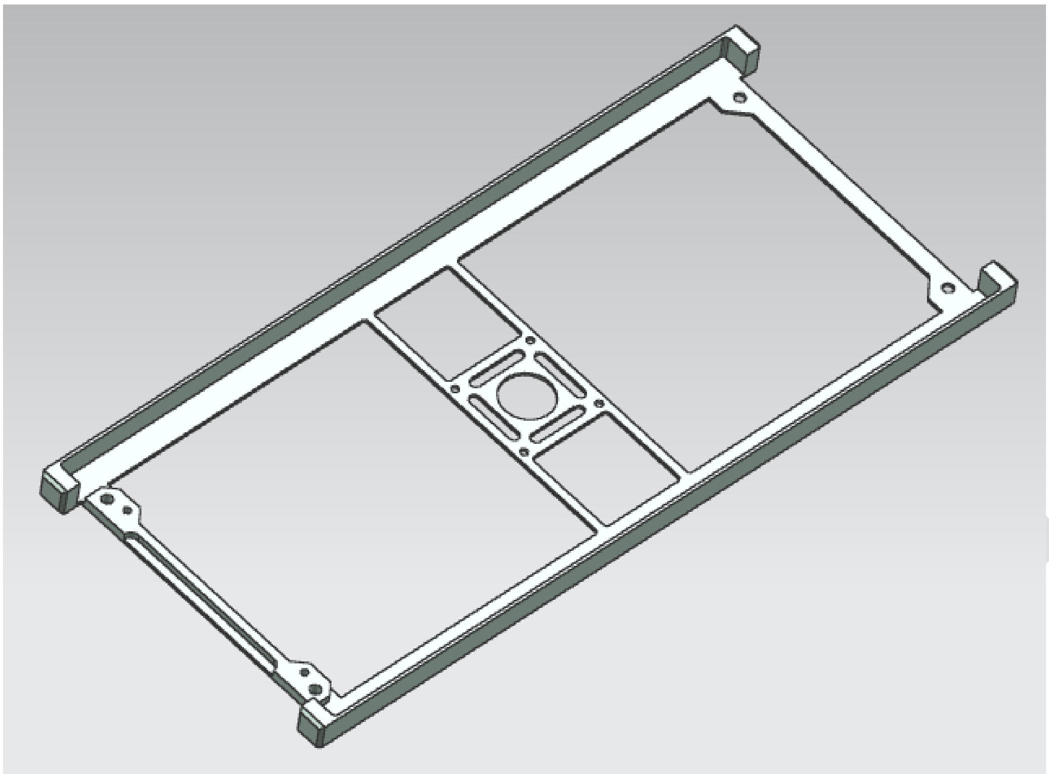


Figure 4-2 Frame no. 1; cuts for the opening mechanism are visible.

Frame no. 3 connects frames no. 1 and 2; it is the base for fixing the UHF/VHF antenna module and makes the whole satellite structure stiff. The element was designed to keep the both side frames in correct positions, which simplifies the satellite integration process.

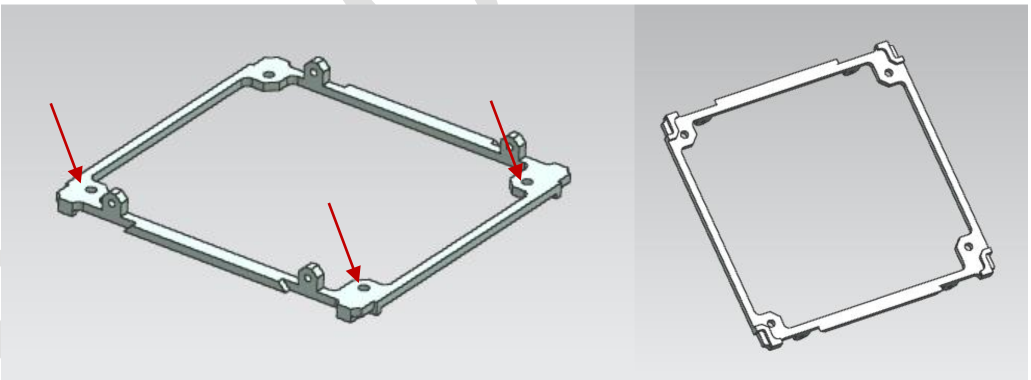


Figure 4-3 Frame no. 3; on the left the side on which the side frames are fixed, on the right – the side on which the communication module is attached.

On the other side of the main structure frames no. 1 and 2 are joined together by the deorbitation sail container [see Figure 4-4].

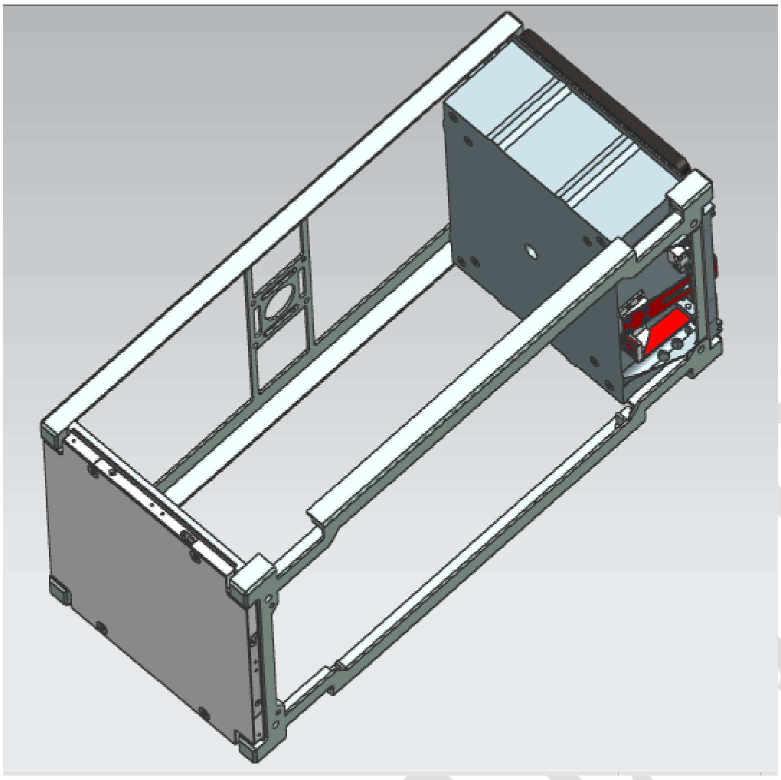


Figure 4-4 PW-Sat2 main structure: frames no. 1, 2 and 3, antenna module and sail container.

4.2 REQUIREMENTS

The forces acting on the satellite's structure on other orbit are minimal, so the structure is designed to sustain stresses occurring during the launch to the orbit and to integrate well all the systems inside the satellite. The main limits (mass, dimensions, shape of the side rails) come directly from the CubeSat standard under which PW-Sat2 is designed. The rest is the result of the planned specific mission (SunSensor testing, deployment of the deorbitation sail).

The designed weight of approximately 140 grams would be changed if another stiffing frame was added or the CAM1 camera supporting structure was re-designed. The rails of the structure, on which the satellite moves during the launch from the P-POD, have to be manufactured with exact precision (according to *CubeSat Design Specification*) and have to have proper elements to fix turning-on switches and separating springs.

Frame no. 3 has 4 holes (on which red arrows are pointed on Illustration 4-3) to fix the elements inside the structure of the satellite. In these holes threaded rods will be screwed on which electronic plates will be put (every plate will have proper holes). The plates will be separated from each other by plastic distance sleeves in order to maintain between them the correct space. The entire plate assembly will be then properly tightened to eliminate oscillations of the elements inside the satellite.

4.3 INTEGRATION AND CONFIGURATION

The creation of a new, separate team responsible for configuration and integration of the satellite is essential. The team's tasks will be for example: proper location of the subsystems inside the main structure in accordance with their specifications, connections between the subsystems and the electronic circuits and the design of electric ducts locations and securing these ducts from unplugging. During the configuration design process, many requirements, such as mass limit, consumption of energy, thermal resistance, hum generation by electronic circuit plates and their sensibility to static, must be kept in mind.

4.4 FURTHER WORKS

Next stages of the works (up to the end of the B-phase) are as follows:

1. Re-design of a part of the screw connections in the structure's frames,
2. Adding the element stiffing the structure in the middle part of the satellite,
3. Manufacturing of the prototypes of the structure (3D print),
4. Initial location of the subsystems inside the structure,
5. Computing the inertial momentum on every axis and the location of the centre of mass of the satellite.