FACULTY
OF MECHANICAL
ENGINEERING
CTU IN PRAGUE

Department of Aerospace Engineering

Systém vypouštění Cansatů z výkonného raketového modelu

System of releasing CanSats from high-power rocket

Master Thesis

Prague, 2022

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Study program: N3958 - Aeronautics and Astronautics
Field of Study: 3906T008 - Aerospace Technology
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Master's thesis title in English:

System of releasing CanSats from high-power rocket

Master's thesis title in Czech:

Systém vypouštění Cansatů z výkonného raketového modelu

Guidelines:

Bibliography / sources:

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Date of master's thesis assignment: **29.04.2022** Deadline for master's thesis submission: **08.06.2022**

Assignment valid until: ______________

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Acknowledgment

I would like to thank my thesis supervisor Ing. Jaromír Kučera for his guidance and his advice during the making of this thesis.

My family for endless support during my studies.

And finally Jan Spratek and the Czech Rocket Society.

Anotační list

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Název DP:	Systém vypouštění CanSatů z výkonného raketového modelu
Anglický název:	System of releasing CanSats from high-power rocket
Rok:	2022
Studijní program:	N3958 - Letectví a kosmonautika
Obor studia:	3906T008 - Letadlová a kosmická technika
Ústav:	Ústav letadlové techniky
Vedoucí DP:	Ing. Jaromír Kučera
Bibliografické údaje:	počet stran 66
	počet obrázků 47
	počet tabulek 3
	počet příloh 0
Klíčová slova:	Vypouštěcí systém, CanSat, výkonný raketový model
Keywords:	Release system, CanSat, high-power rocket

Anotace

Cílem této práce je návrh vypouštěcího systému na soutěžní satelity *CanSat* pro výkonnou modelovou raketu *Sherpa* stavěnou studentským spolkem *Czech Rocket Society*. Konceptuální řešení byly zpracovány po provedení rešerše používaných systémů v zahraničí. Jeden z konceptů byl rozpracován do detailního návrhu a poté vyroben. Systém byl nakonec použit pro národní finále soutěže CanSat.

Abstract

The goal of this thesis is to design a release system for *CanSat* competition and integrate it into high-power rocket *Sherpa* made by the student association *Czech Rocket Society*. After the research on release systems used abroad, several conceptual designs were created. Out of these one was continued to detailed design and was manufactured. Finally the release system was used in the national CanSat finale.

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Introduction

CanSats are small satellites which are designed and built by high school students with the intention of competing in CanSat Finale. After evaluation of each teams technical documentation, CanSats are then raised to height of about one kilometer and released to descent on their own parachute. On the way down, they gather scientific data and transmit it to ground station. Where possible, CanSats are lifted into the air by model rockets, usually provided by student rocketry teams.

Currently in the national round in Czechia, CanSats are released from ultralight planes or drones. Newly founded student rocketry association *Czech Rocket Society* hopes to change this by building a model rocket specifically to launch CanSats.

The objective of this thesis is to design a *hold and release* system tailored for the rocket built by the students association. Similarly to adult rocketry, low weight and reliability of a system is very important. Because the rocket was being designed parallel to the creation of this thesis, an imaginary box with specific dimensions was defined into which the system had to be designed.

Theoretical background

The CanSat competition is a project with the support of *European Space Agency* and its goal is to teach secondary school students how to solve engineering problems and to work in teams towards common goal. Teams usually consisting of three students design the structure of CanSat, recovery systems but also electronics for data logging and transmitting. Some subsystems are required by the rules, but there are extra points for additional data collected.

2.1. CanSat specifications

Since the national rounds of each competition are outsourced to local organizer, the requirements in each country might differ slightly in details. But since the hope for teams from national round is to advance to international round, the ruling specified there was used. In the following list rules relevant to the design of hold and release system for CanSats are summarized. [1]

- All the components of the CanSat must fit inside a cylinder with a diameter of *66 mm* and height *115 mm*.
  - Antennas for radio or GPS are allowed to be placed on the outside of this cylinder, however only on the flat face. In the rocket payload there is a designated space with the same diameter as CanSat and with length of *45 mm*. The parachute and external antennas must fit inside this space.
- Antennas and other components for data logging cannot reach past the defined cylinder up to the point of release from launch vehicle.
- The weight of CanSats *must* be *300-350 g*. Lighter CanSats must be equipped with ballast to reach the lower weight limit.
- CanSats cannot be equipped with pyrotechnical devices.

- CanSat must be able to withstand acceleration of up to *20 G*.

It is not necessary for CanSats to have an external shell for shielding. However it is often used to protect the inside wiring and prevent any entanglement with the internal structure of the launch vehicle. Few examples of structural solutions for CanSats are shown in figure 2.1 below.

Fig. 2.1: *Examples of CanSats with parachutes ready for integration [2]*

Because the teams have a free will in creating the insides of their CanSat and are not required to fill in the given space, it is necessary to quickly select a conceptual design and discuss it with teams. This will ensure that they have enough time to design with the release system in mind.

2.2. Inspiration from Space sector

First research focused on adult rocketry and how the professionals do it. Hold and release systems for big rockets share similar requirements. Specifically the system usually only needs to work once and reliably, be resistant to vibrations and have as little moving parts as possible.

2.2.1. Explosive devices

Criteria specified above are easily achieved by explosive devices. They are very simple and reliable and have been in use since the beginning of rocketry. These systems come in many shapes and sizes and are tailored for each specific use. The two parts can be held together directly by nuts and bolts or by retaining clamps. Explosive bolts or frangible nuts then remove the connection and separation springs push both segments apart.

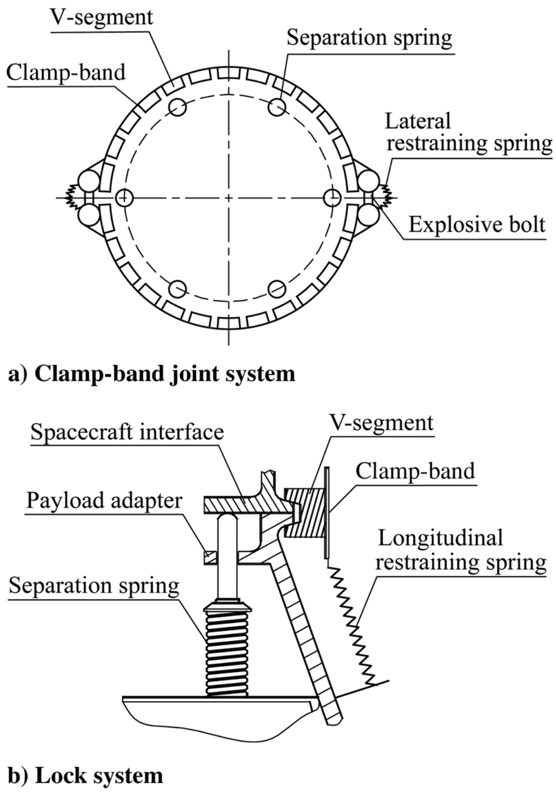


Fig. 2.2: Concept of release mechanism using an explosive bolt and a clamp-band [3]

Apollo 13

Linear shaped charges can also be used to separate cables and connections as seen on figure 2.3. Here charges are used to cut tension cables which hold the command module and service module of Apollo spacecraft together. After cutting the cables, they act as a spring and push the spacecraft apart. Additional thrusting from reaction control system is then used to put as much distance as possible between the two modules in preparation for reentry. Prior to this, different set of charges is used to cut electrical connections to fully separate them.

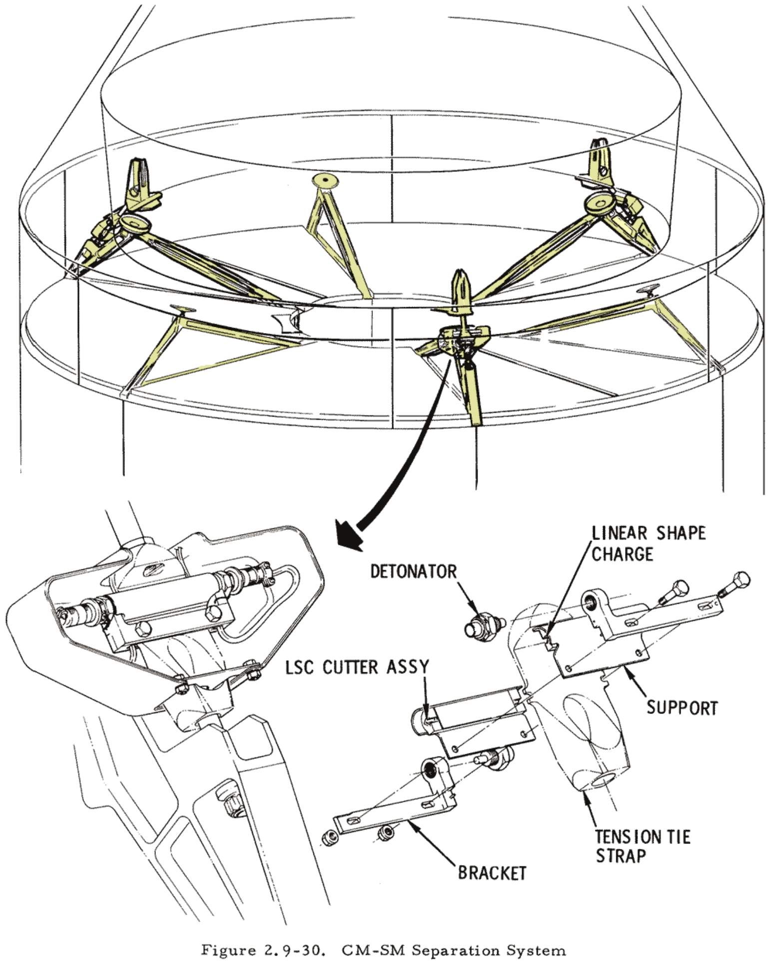


Fig. 2.3: *Tension cable separation mechanism on Apollo 13 [4]*

Ariane 5

Usually there are a few different types of separation systems suitable for each launch vehicle. This ensures wide range of payload masses that can be lifted by each vehicle. Additionally lower shock acceleration of some designs can be beneficial for the spacecraft as it might eliminate strengthening of structure and thus reduce the mass of spacecraft. Separation design shown in figure 2.4 is one of the simpler ones, as it uses four bolts and frangible nuts to securely hold the spacecraft.

The bolt shown in green is preloaded using special washer and upon releasing is captured in bolt catcher above it. Separation springs then separate the spacecraft using four rods. This simpler design is lighter and easier to manufacture, however introduces higher shocks into the spacecraft.

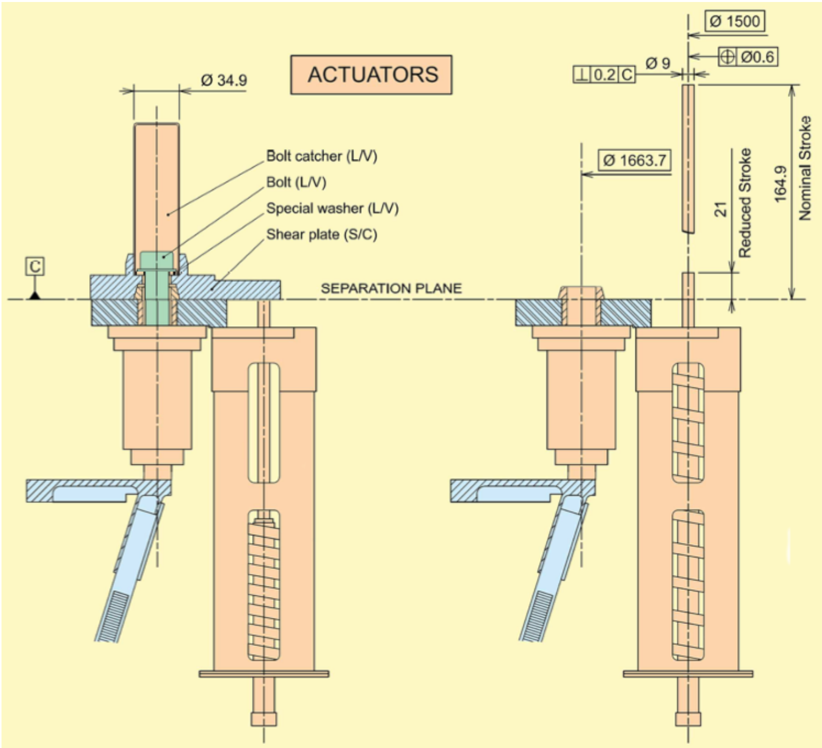


Fig. 2.4: *Separation system from PAS 1663 payload adaptor of the Ariane 5 [5]*

2.2.2. Motorized release systems

Slightly more complicated are motorized release systems. These use a motor to move a locking pin or a clamp and again separation springs are used to push the spacecraft apart.

Ring design

The design can be very similar to the one using explosives as shown in figure 2.5. Here the hold down clamp is on the inner side of the retaining ring. When engaged the retaining ring is pushing the leaf into the groove locking the two parts together. To release this locking mechanism, a motor with a moving screw contracts the inner ring disengaging the leaf and freeing the spacecraft and separating springs push it away.

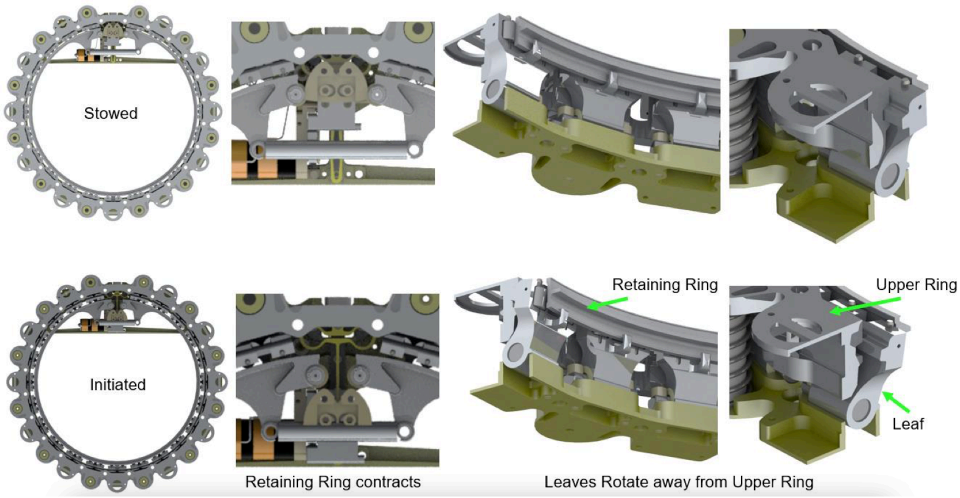


Fig. 2.5: Rocket Lab's hold and release clamp [6]

Cubesat release system

For smaller payloads such as cubesats motorized systems can be used as well. For these designs the advantage are the standardized dimensions of the spacecraft removing the necessity for specialized connector to be implemented into the design of spacecraft. As seen on figure 2.6 the container is box shaped to accommodate standardized dimensions of cubesats with spring loaded lid. When the satellite is ready to be released, DC motor releases the latch circled in figure below. That allows the lid to open and ejection springs pull on ejection plate on which the cubesat is sitting. This ejection plate is mounted on linear rail that allows for smoother release.

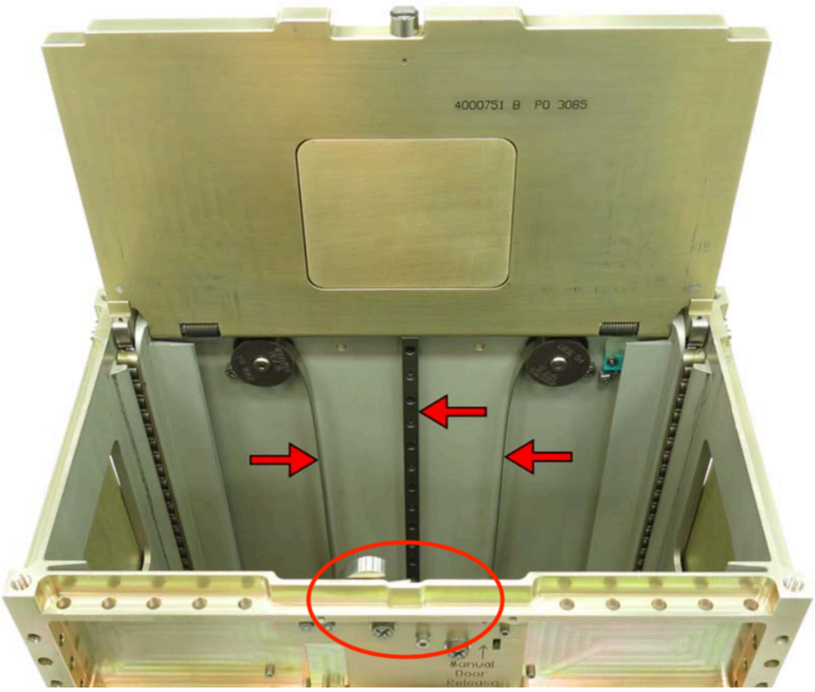


Fig. 2.6: Rocket Lab's Cubesat cannister release system [7]

2.2.3. Nichrome wire release system

Probably as light as it can be, these systems use resistor nichrome wire that heats up and cuts through polymer line, releasing the payload.

Bolt constraining system

This system was used as a demonstrator for non-explosive hold and release system for payloads. It was developed for cubesat mission *STEP Cube Lab* which carried several demonstrators and its purpose was to flight certify each system. As seen on figure 2.7 the system uses a segmented nut to hold down a constraint bolt in place. This segmented nut is hinged on connecting plate to not interfere with the released bolt. This separation is helped by set of springs to release the bolt. The two segments of the nut are held together by nylon cable wound around the nut in small V-shaped grooves. Nichrome wire is woven through the nylon cable alternating above and below it to ensure good contact surface.

Once heated up, the nichrome wire melts and cuts through the nylon cable, releasing the tension holding the segmented nut together. First set of separation springs splits the nut and second set of springs pushes the payload away.

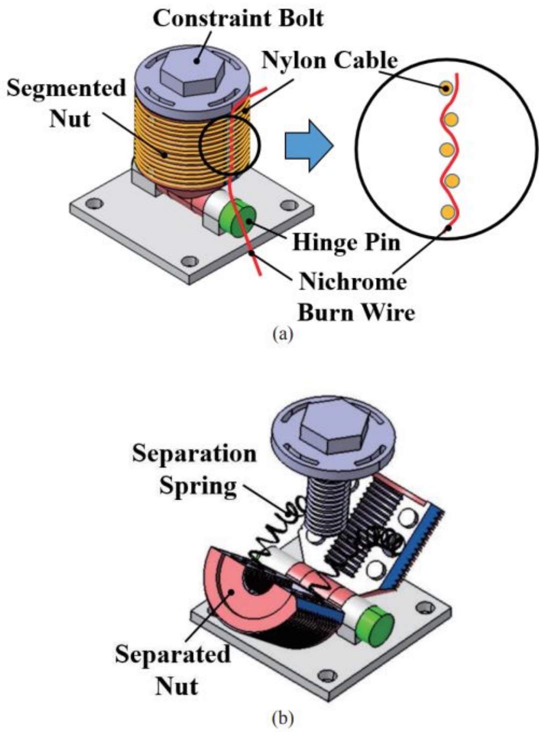


Fig. 2.7: Bolt release system using nylon line and nichrome wire [8]

Vectran cable lock mechanism

For this system the parts to be separated are not held together by a bolt and a nut, but by a preloaded vectran cable. It works similarly to the Apollo tension cable separation system of the *CM* and *SM*. Payload is connected on one end of the cable and then tied to the spacecraft making sure the cable runs through the loop of nichrome wire shown in figure 2.8. This is possible in the stowed position, where the springs are compressed and when released facilitate a good connection between the vectran cable and nichrome wire.

To release the nichrome wire is heated up using electricity and this melts the vectran line separating the payload. The goal of this system was to design a simple enough solution that can be replicated by any cubesat user and be inexpensive and reliable.

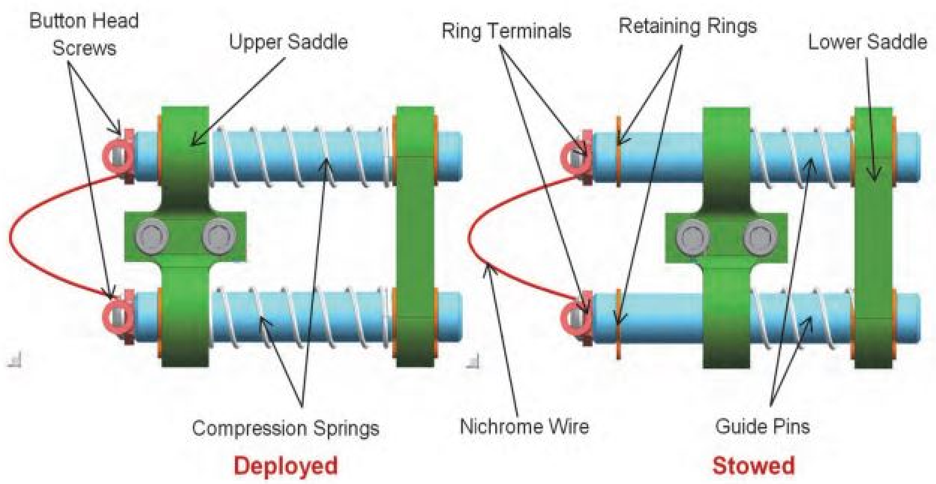


Fig. 2.8: *Vectran cable melting mechanism [9]*

2.3. Systems in use

As mentioned in the introduction, in many countries the CanSats are launched on real rockets and here are listed the major ones.

2.3.1. The Dutch Amateur Association for Rocket Research

This association called *NAVRO* is consisting of amateur hobbyists with interest in model rocketry. They design and construct small model rockets that are around *40 cm* tall to high power rockets measured in meters. Also to supply the right amount of thrust for the rockets they develop their own solid fuel rocket motors.

To accommodate the CanSats a tube with a diameter of around *150 mm* is used as the inner shell and a different tube of a larger diameter is used as a hatch. These tubes are slid into one another with holes cut into them to allow CanSats to be released. The outer tube can rotate outside of the inner shell opening and closing the hatch in the process. To push the CanSats out of the rocket body a piece of cloth is attached on one side of the hole on the inner tube and similarly on the outside tube, but on the other side. When CanSats are pushed in, the cloth wraps around them and the outer shell closes the hatch.

When the time comes to release the CanSats, the outer shell rotates and stretches the cloth inside seen in figure 2.9, which in turn pushes the CanSats outside of the rocket. This is a simple way of holding onto the CanSats and at the same time it gives sideways momentum to CanSats during the release.

Fig. 2.9: *NAVRO CanSat release system [10]*

2.3.2. Delft Aerospace Rocket Engineering

Delft Aerospace Rocket Engineering is a group of students with ambitions in rocket science. They design and build rockets with the intention to learn and also compete. The team consists of around 180 students from different faculties of the Delft University of Technology covering many projects, not just the CanSats. The idea for secondary school students to build CanSats originated here in 2007 and DARE has been the main supplier of rockets to the competition in Netherlands. In 2014 ESERO took over the newly styled CanSat competition, however DARE is still the main supplier of rockets and continues to improve on the design.

The rocket shown in figure 2.10 is the seventh iteration. It can hold four CanSats and its design focuses on ease of use, cheap price and fast turn around after landing. Its diameter is around *150 mm* and the payload area is covered by two aluminium panels. These panels are ejected at the desired altitude and CanSats are released by the rocket swinging under drogue parachute.

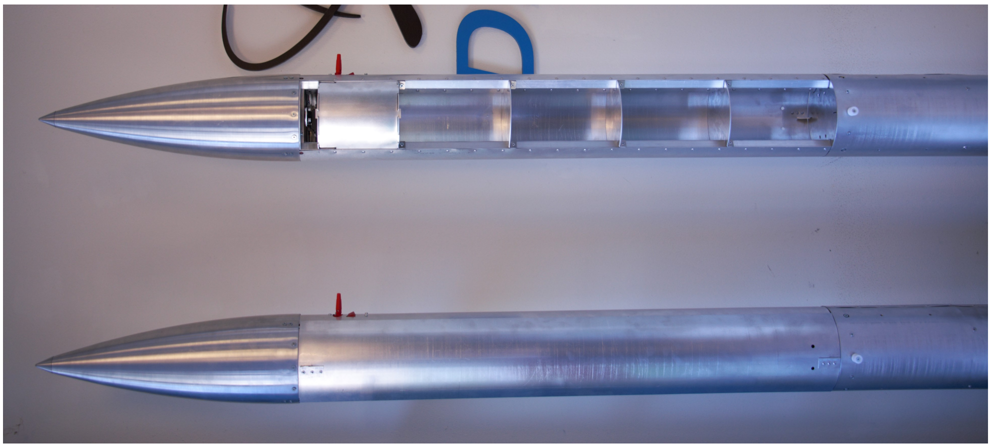


Fig. 2.10: *DARE CanSat release system [11]*

2.3.3. Pyrotechnic charges

In model rocketry explosive means of separating rocket parts are used as well. Although explosive bolts or frangible nuts are not used due to smaller size, pistons are used to eject recovery systems usually stowed under the nosecone. In smaller models using commercially available solid rocket motors. This ejection is done by an ejection charge glued to the top side of motor and separated from it by slowly burning fuel grain. This ensures parachute ejection few seconds after burnout.

However for high-power rocket models this is usually not practical, since the rocket flies longer without thrust, the body of a rocket is much larger and it usually requires two parachutes. Smaller one is used for stabilizing the rocket for most of its journey back to ground and second large one to slowly descent to touchdown. Completely separate system of ejection using avionics is then used to deploy parachutes. This usually consists of cylindrical enclosure with pyrotechnic device and piston under the drogue chute. The nosecone is press fitted inside the tube of the rocket and is pushing against the parachute to ensure its securely inside the rocket. However to further secure the fit, shear pins shown in figure 2.11 can be used.

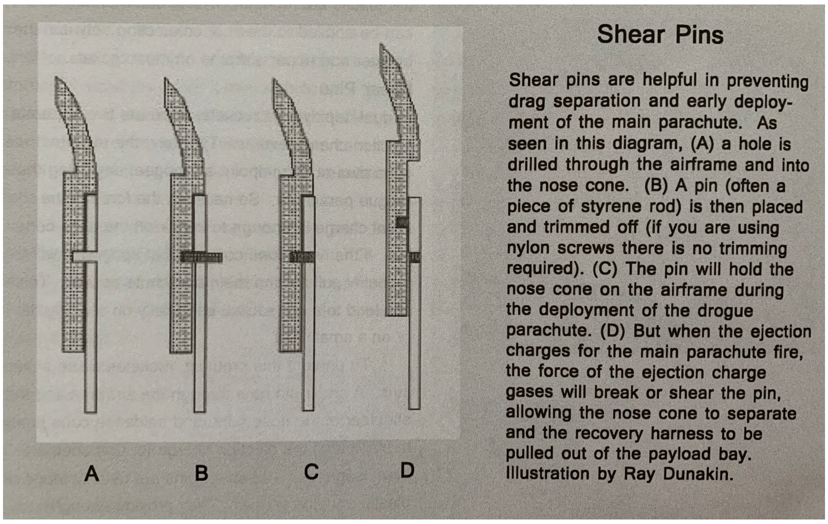


Fig. 2.11: *Piston ejection system utilizing shear pins [12]*

2.4. Summary

In the space sector explosive devices such as frangible nuts or explosive bolts are used as a way to separate rocket stages. These systems have a great hold down force and are very rigid, however they introduce shocks to the system and the debris left by the device needs to be dealt with to protect the rocket. Because of the unwanted shock, motorized systems using clamp bands can be utilized for payload release. These clamps hold the interface locked until needed and upon releasing few separating springs push the parts away from each other. Nowadays with Cubesats being used regularly, standardized release systems are used too. Utilizing the cube shape of the satellite they are shaped as a box with spring loaded pusher plate at the bottom and a hatch with locking mechanism operated by DC motor.

For smaller applications such as antenna or solar panel opening system a polymer line with the combination of resistor wire can be used. The parts are attached to each other either directly by the polymer line, or through a two part frangible nut as shown in figure 2.7. A resistor wire such as nichrome wire is then placed on the polymer and heated up by electricity. This melts it and the tension in the cable is released. Set of separation springs can then be used to further separate the payload.

In CanSat competition held in the Netherlands two teams supplied rockets over the years. The *CanSat launcher v6 (fig. 2.9)* built by amateur rocketry club *NAVRO* consists of two tubes that fit into each other and the outer sleeve can rotate around using a stepper motor. The sides of the CanSat sized holes cut into the side of the tubes are connected by cloth. This cloth holds the CanSats inside and when the outside tube is rotated it pushes it out of the rocket. The second team is a student association *DARE* which supplied rockets since the beginning of the competition. Their most refined seventh iteration seen in figure 2.10 is built to be as simple as possible and as reliable as possible. Utilizing aluminium body with two panels covering the payload area. To release the CanSats these panels are jettisoned and upon swinging on drogue parachute, the CanSats are released.

Design

This chapter includes the conceptual designs considered for the system, their comparison and choosing of the final concept which is then continued in the detailed design. This final design's manufacturing process is also included in this chapter.

To better understand where each part is located a layout of the rocket is shown in figure 3.1. The rocket itself is *2.5 m* long and weighs about *13 kg* when fully loaded.

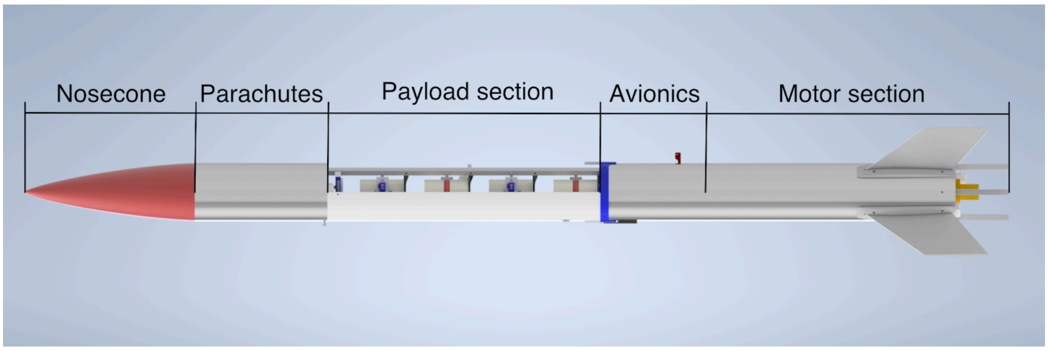


Fig. 3.1: *On the left side is the nosecone under which the parachutes are located. Under the parachute bulkhead is the locking system for panels and the payload bay. The panels are connected by hinges to the blue collar between payload an avionics. Payload section connects structurally to the motor section and between these sections avionics is located*

3.1. Restricting factors

Since the release system is designed in the same timeline as the rest of the rocket, some restricting factors and mechanical connections had to be decided in the beginning of the project. These are defined mainly by the diameter of the rocket, which was chosen to be *150 mm* and the inside structure of the rocket. As seen on figure 3.2 the inside structure consists of four aluminium U-beams with the dimensions of *15x15x2 mm* and they create the main bearing structure of the rocket. The acceleration load from CanSats is transferred mainly through a platform that is bolted to the U-beams and on which the CanSats sit.

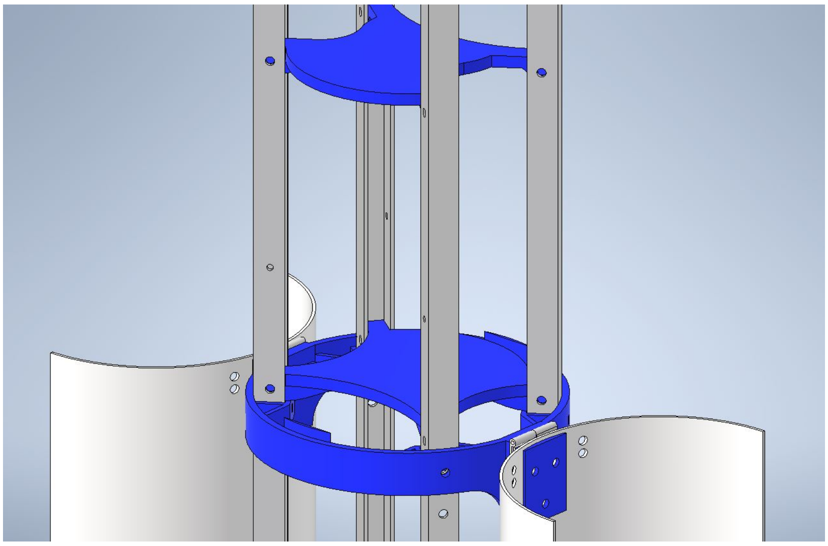


Fig. 3.2: Internal structure of the Sherpa rocket with 3D printed platforms and PVC panels

The aerodynamic shell is a PVC tube cut in half and bolted to two hinges. Around these the panels can rotate freely upon release by the spring mechanism shown in figure 3.3. When closed the panels are held together by polymer line which also holds the separation springs loaded. A resistor wire is then used to melt the nylon and to release the springs and panels.

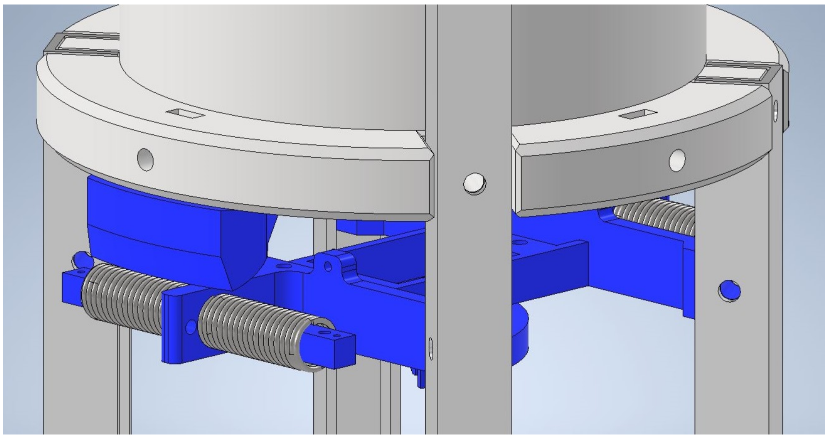


Fig. 3.3: Locking mechanism for panels with separation springs and a parachute bulkhead at the top of the payload bay

Above the CanSat there is a *45 mm* tall cylindrical space devoted to accommodating parachute and optional antennas. This cylinder has the same diameter as the CanSats and is defined by rolled aluminium sheet.

The main requirements for the release system are following:

- Low weight

- Reliability
- Low cost
- Manufacturing capabilities
- Minimal requirements for teams to consider in design

Space used by the release system was not restricted and only required that the CanSats rest safely on the load bearing platform. As for the mechanical connection to the rocket it was decided that straight connection by bolts or one-sided rivets to the U-beams was the best option.

3.2. Conceptual designs

Based on the research done in previous chapter many draft designs were considered including those shown in figure 3.4.

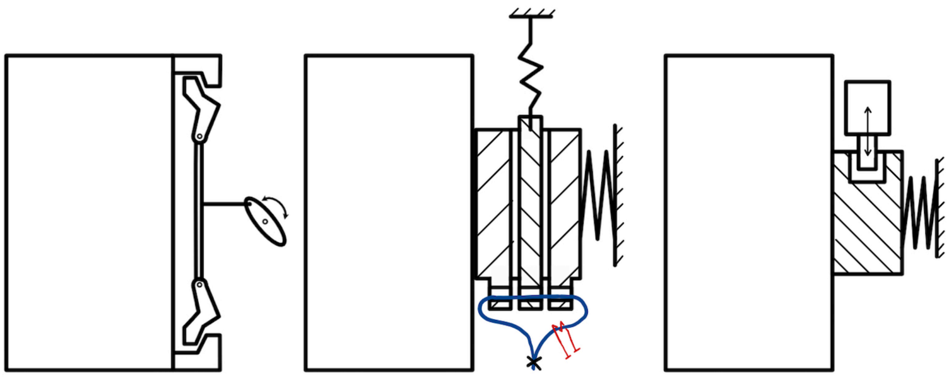


Fig. 3.4: Conceptual designs of the lock mechanism considered. The leftmost uses a servomotor, the middle one uses a set of spring and a polymer line and the last one uses a solenoid as a lock

Varying in complexity and in locking mechanisms used, they can be mainly categorized into three groups. With the use of pyrotechnic device, motorized and using a polymer line. These three categories of concept designs are further examined in the following sections.

3.2.1. Piston ejection system

As touched upon in section 2.3.3 pyrotechnic devices such as explosive bolts and frangible nuts are not suitable for model rockets. However the expanding gases from explosions can be used to eject parachutes and move pistons. Such a system utilizing a moving piston is shown in figure 3.5

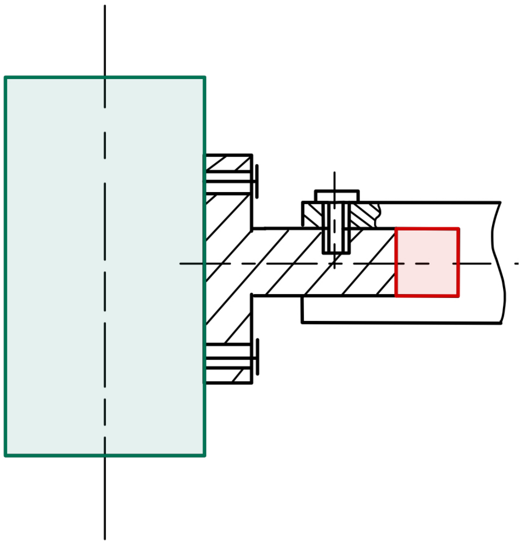


Fig. 3.5: *Draft design of hold and release system utilizing pyrotechnic charges*

On the left side of the figure shown in green is the CanSat with hold down clamp attached to it. Next to it is the piston inserted into the main body. This piston is used to transfer momentum from explosion to the CanSat and also protect it from hot gases. To load this system a pyrotechnic charge is inserted into the main body of mechanism. Piston is then slid into it closing the charge inside the small chamber shown in red. Lastly the hold down clamps with CanSat attached are pressed against the piston and shear pins are inserted to hold it in place.

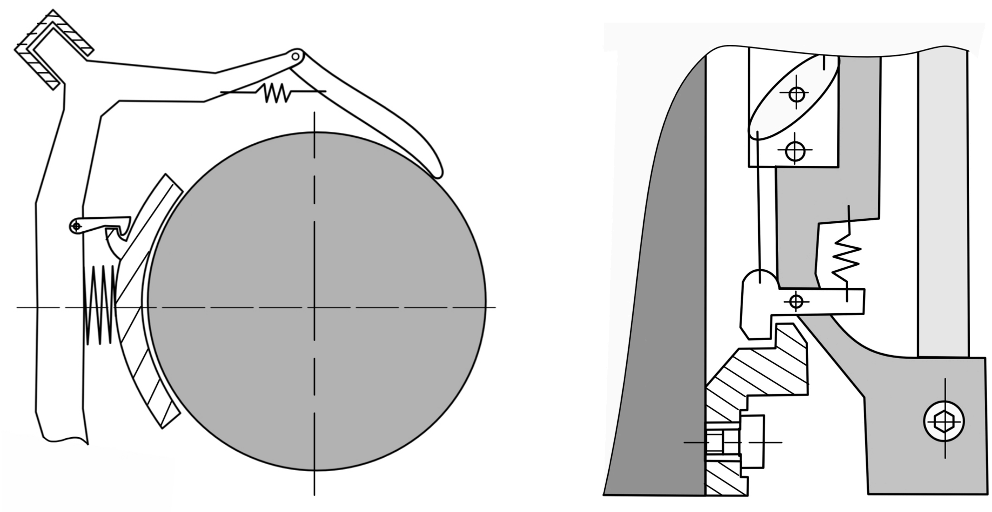
When the charge explodes, it creates a pressure pushing against the piston and when large enough pressure builds, it shears the pins and ejects the CanSat.

This system is very simple and uses few parts, therefore it is easy to manufacture and put into use. Depending on strength of the pyrotechnic charge most parts could be 3D printed, which is a cheap and relatively accurate manufacturing method. Pyrotechnic charges are also very reliable and commonly used rocket igniters could be utilized here. They rely on resistor wire that heats up when current is ran through it igniting the explosive.

The disadvantage is that when dealing with explosive devices a raised caution is required. The charge would not be too powerful, but it still could cause major burn injuries or injury to eyes. Considering there would be one charge for each CanSat, totalling four charges, that would increase the risk of accident significantly. Also each charge can be used only once and all parts would have to be checked for damage and potentially replaced.

3.2.2. Servomotor

As a second option a motorized mechanism was considered using RC hobby rated servomotor and springs as actuators. Examples of considered designs can be seen on figure 3.6.



(a) Servomotor concept with spring loaded arm

(b) Servomotor concept with the CanSat shown in dark grey with attachable clamps

Fig. 3.6: *Servomotor concept designs*

All of the draft designs considered utilized a separation spring held in compressed position by locking clamps. These clamps are connected by a push rod to the servomotor allowing it to actuate them. A set of springs is connected to these clamps to ensure secure locking of the mechanism even during high vibrations. To securely hold the CanSat inside payload bay a few different approaches were considered.

One design shown on the left side of figure 3.6 lacks a mechanical connection to the CanSat itself and instead uses a set of arms and springs to hold it in place. A larger spring, used to push the CanSat out, is connected to a pusher plate equipped with locking clamps. The lack of mechanical connection makes it easier for the teams, as they do not need to consider it into their design. However the hold down force is limited by the springs on clamp down arms which during release work against the release itself.

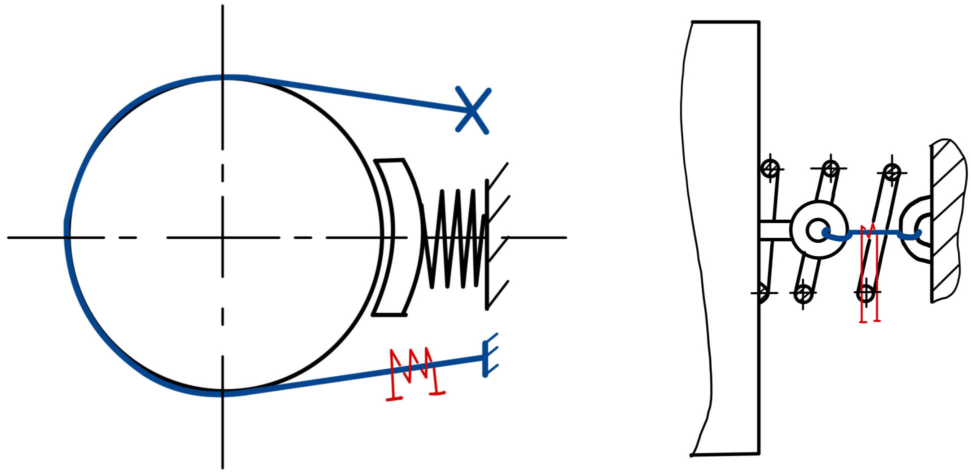
Second concept in figure 3.6 is designed with mechanical connection in mind. This can be achieved by bolting predefined hold down clamps to the CanSat which then lock into swivel arms connected to servomotor. Pair of springs located at the top and bottom can be used to eject the CanSat as the location is stiffened due to the use of mechanical connection. This allows for larger forces to be transferred and it secures the CanSats in place, however it requires the teams to add it into their design.

Both of these draft designs offer greater control over the release sequence and how the CanSat is held in place. The actuation of servomotor can be very precise and the release mechanism could be designed to minimize the number of servos used. Utilizing commonly used servomotors in RC hobby would also keep the price down. RC planes use small, light, durable and relatively strong servos, which would be suitable.

Although relatively cheap, using servomotor makes the design much more complex. Small and precise parts need to be manufactured to guarantee smooth movement. This hinders reliability as well, which generally lowers with more parts that can fail. To control these motors, specific electronics are also required adding to complexity and price, either by improving flight computer or adding separate board.

3.2.3. Nylon line

In the last category are concept designs based on nichrome burn wire and fishing line derived from designs in section 2.2.3. Similarly to designs with servomotor, the transfer of forces can be realized with or without direct mechanical connection to the CanSats as can be seen on figure 3.7.



(a) Nylon line is wrapped around the CanSat holding it in place, resistor wire is used to cut it and spring to eject the CanSat

(b) Two eye bolts are tied together by a nylon line which holds the spring compressed, resistor wire melts it releasing the CanSat

Fig. 3.7: *Nylon line concept designs*

Visible in the design on the left side is the simplicity possible with such system. Nylon line is wrapped around the CanSat and pulled inside the payload bay. This compresses the release spring and arms the system. Resistor wire is wrapped around the nylon line and when heated up by current from battery, it melts the line releasing the CanSat. However as with the servomotor design, this one does not hold the CanSat as securely. CanSats can also be of different designs, not completely filling the given maximum dimensions and that could cause trouble either when releasing or during launch.

To properly secure the CanSat inside the payload bay and prevent it from shifting a loop can be attached as an anchor point for the nylon line. To lessen the prescribed manner of connection, the teams themselves could decide how to connect their CanSat. They would be given height at which they would receive the nylon line and they could choose how to attach it to their design. An example of this solution is shown in figure 3.8.

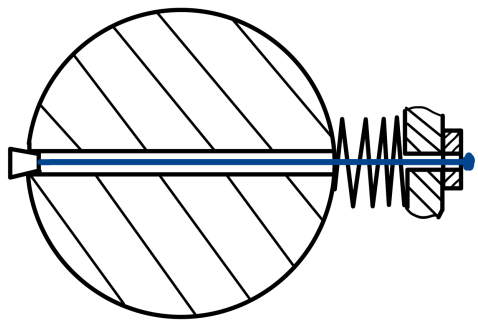


Fig. 3.8: Possible attachment method where the nylon line runs through the CanSat

Here the nylon line is routed to the CanSats side through the release spring to a hole running through the whole diameter of CanSat. When pulled through and tightened it compresses the spring and after tying it down the CanSat is now securely stowed and ready for launch. Similarly the line could be only looped inside the CanSat and then fed back to the rocket side, where it would be tied down.

These concepts are light and in principle very simple. They use only one spring to eject the CanSats and as with pyrotechnic devices require only sufficient current from battery to operate.

However they are only one time use and fast reset might be necessary. This could be problematic since properly connecting resistor wires to cables is problematic and so is tying down a polymer string. Encountering sharp corners while in high vibration scenario might also cause the line to snap.

3.2.4. Concept comparison

The first metric considered is the weight of the whole system as it determines what height can the rocket reach. Out of the concepts mentioned before, the motorized design is the heaviest. This is due to the complexity of the whole system including the motors themselves and wiring. The weights of the remaining two would be very similar and therefore are considered equal.

With increasing complexity the reliability usually decreases and so the motorized concept is also considered as the least reliable due to its high count of small parts. By far the simplest is the gunpowder charge system as it only requires an igniter and supply of current. Somewhere in between is the nylon line ejection system as it uses resistor wire to create heat similarly to igniter, but has the added complexity of connecting the wires and securely tying down the nylon line. It is important to note here, that all the systems could be designed reliably, this comparison is more about the effort needed to make each system reliable.

Another important aspect was how much the release system would affect the teams design. Although it was possible to influence the rules to some extent, it was desirable to keep the teams need to adjust to a minimum. Again the motorized system requires the most attention from competitors as it needs a solid mechanical connection. Both the nylon line and the ejection charge concepts can do without it and influence the teams designs less.

The concept using nylon line and resistor wire was chosen to be the one developed in detail as it offers the best combination of reliability, cost and weight. Motorized release system turned out to be too complicated and difficult to manufacture. Ejection charge offers many of the same benefits as nylon line, however includes a certain amount of danger coupled with handling of explosives.

3.3. Detailed design

In this section the steps necessary to develop the chosen concept into a working system are written down. The starting point of the design is shown in figure 3.9 below. It consists of a main body made from aluminium sheet, compression spring and a 3D printed mechanical interface for the CanSat. The main body is bent into *U-shape* when viewed from the side and houses all necessary components. To connect it to the rocket, two aluminium rectangles are riveted to the body and bent in desired angle. The compression spring sits in the middle and is held in place by metal sheet and is also riveted to the main body.

On the top side of figure 3.9 is the mechanical interface which houses the spring and provides surface area to transfer the ejection force to the CanSat. A hole is built into the design for the nylon line to guide through to the CanSat side of the system. Another hole running perpendicular to the spring action is used to compress the spring and hold it in place by split pin. This makes connecting the CanSats easier and lowers the risk of accidental release.

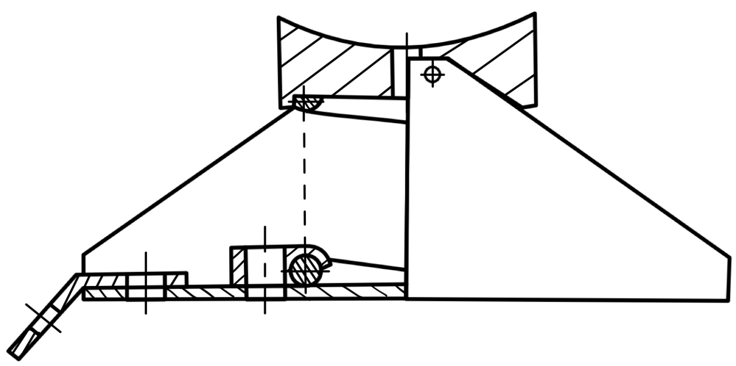


Fig. 3.9: *The selected concept continued to detailed design, bent aluminium sheet body houses a compression spring with 3D printed interface for the CanSat*

Throughout the process of designing and testing, some parts were iterated number of times, namely the adapter connecting the CanSats. Some parts were also added as they were required to make the system more reliable or make the preparation easier. Therefore each component has its own subsection where the iterations are described.

3.3.1. Ejection spring

The first component that needs to be properly sized is the compression spring since it determines the size of the whole system. To select the properties of the spring needed a simple model was used depicted in figure 3.10. But first the minimum requirements had to be established. The main one is the final speed of the CanSat when leaving the rocket as it must be enough to safely exit the payload area. This covers the absolute speed of the rocket moving through air as well as rotational speed.

However maximizing final speed is not optimal as it increases *G-forces* experienced by the CanSat. Since these forces are lateral and the construction of CanSats is mainly designed to withstand longitudinal forces, this acceleration should be kept as low as possible.

Another restricting factor is manipulation requirements. This limits the maximum strength of the spring, because it needs to be compressed by hand without major difficulties. This fact is made slightly worse by the inner construction of the rocket as it limits the space around the system. The spring also should have low enough length to diameter ratio as it is not supported during compression and it might deviate from center line.

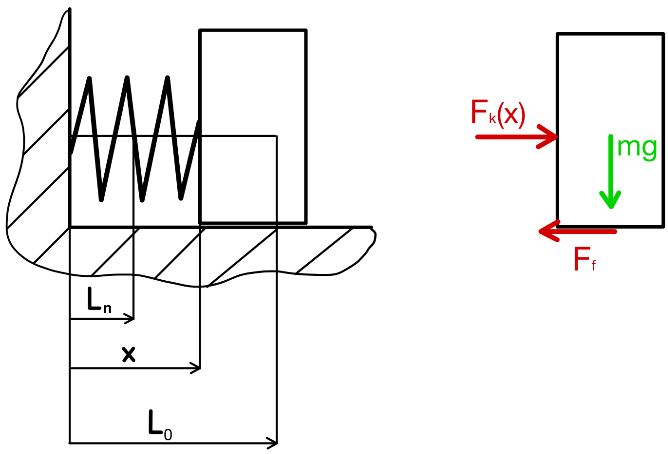


Fig. 3.10: *Model used to predict final speed of CanSat and maximum acceleration*

The forces acting on the CanSats shown in figure above are the force of gravity mg, the spring F_k which is dependent on the position and friction F_f. In the following equations all the forces used in model are itemized starting with the force from the spring which is calculated by multiplying the coefficient of stiffness of the spring with the distance the spring is compressed. The friction force used in the model is only dependant on the mass of the CanSat and the coefficient of friction which was chosen to be *0.4*. This assumes polymer to polymer contact for which the coefficient of friction ranges from *0.2* to *0.6*. [13]

$$F_k(x) = k \cdot (L0 - x) \tag{3.1}$$

$$F_f = m \cdot g \cdot \mu_c \tag{3.2}$$

$$F(x) = F_k(x) - F_f = k \cdot (L0 - x) - m \cdot g \cdot \mu_c \tag{3.3}$$

$$a(t) = \frac{dv}{dt} = \frac{F(x)}{m} \quad ; \quad v(t) = \frac{dx}{dt} = \int \frac{dv}{dt} \quad ; \quad x(t) = \int \frac{dx}{dt} \tag{3.4}$$

As can be seen from the equations above the moment arm of the friction force was neglected and only the translating force was considered. The following *Simulink* program was then created to simulate the model.

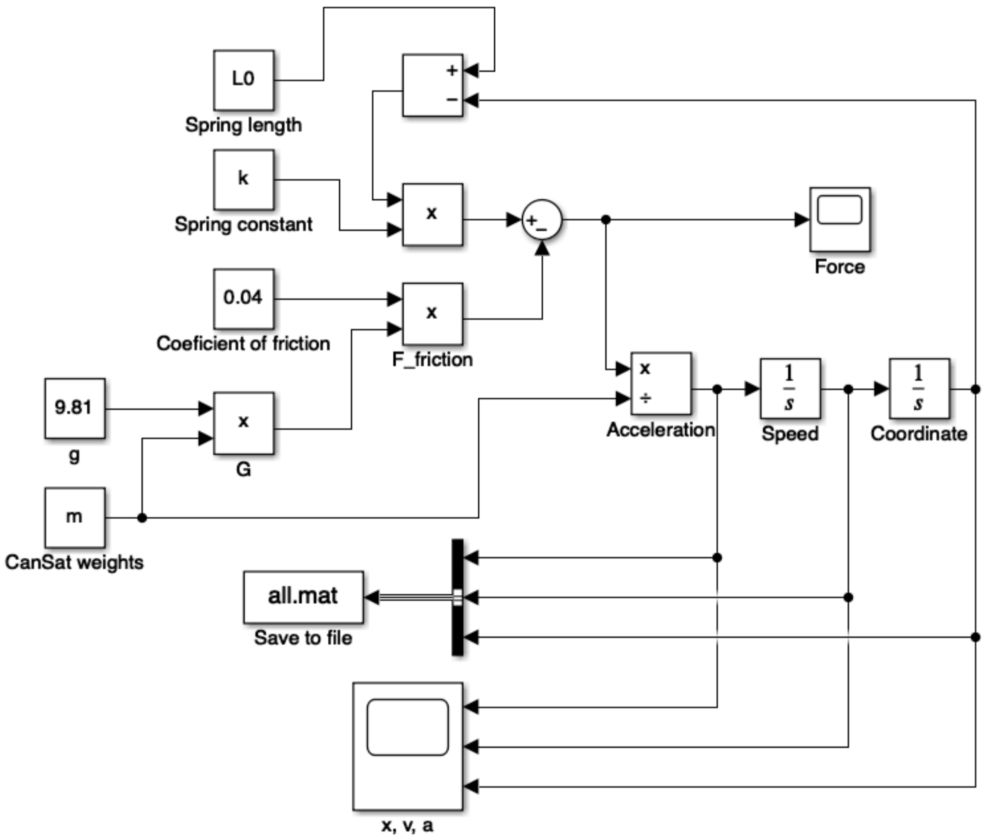


Fig. 3.11: *Simulink model with inputs in top left corner, integration blocks on the right side and outputs at the bottom*

The limiting parameters of the spring were set as follows.

- Maximum spring force $F_{max} = 60\ N$
- Maximum length of the compressed spring $Ln_{max} = 30\ mm$
- Diameter of the spring between $D_{min} = 15\ mm$ and $D_{max} = 30\ mm$

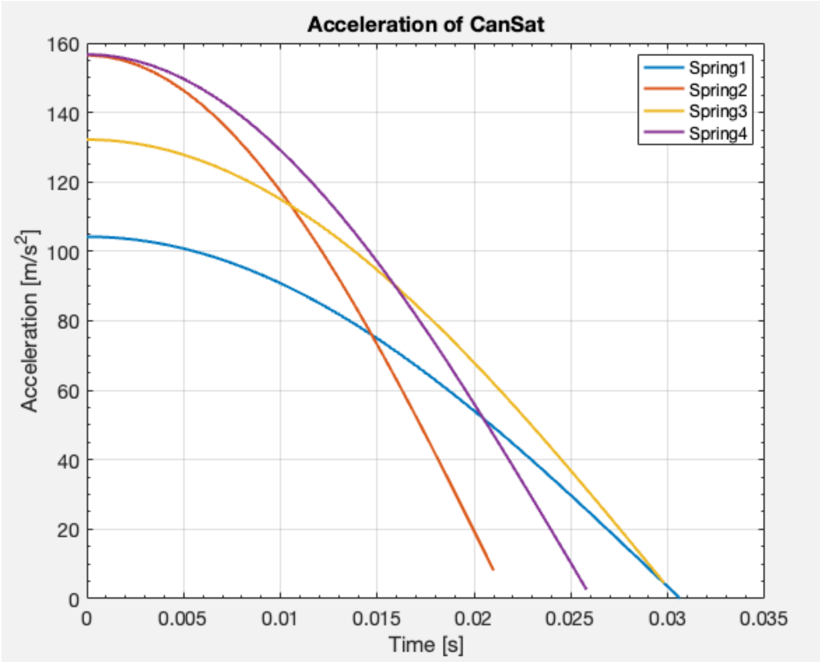
According to these limitations four springs were chosen with their parameters summed up in table 3.1

Tab. 3.1: Table showing the maximum force exerted by the spring, the compressed length, neutral length, diameter and the spring's constant

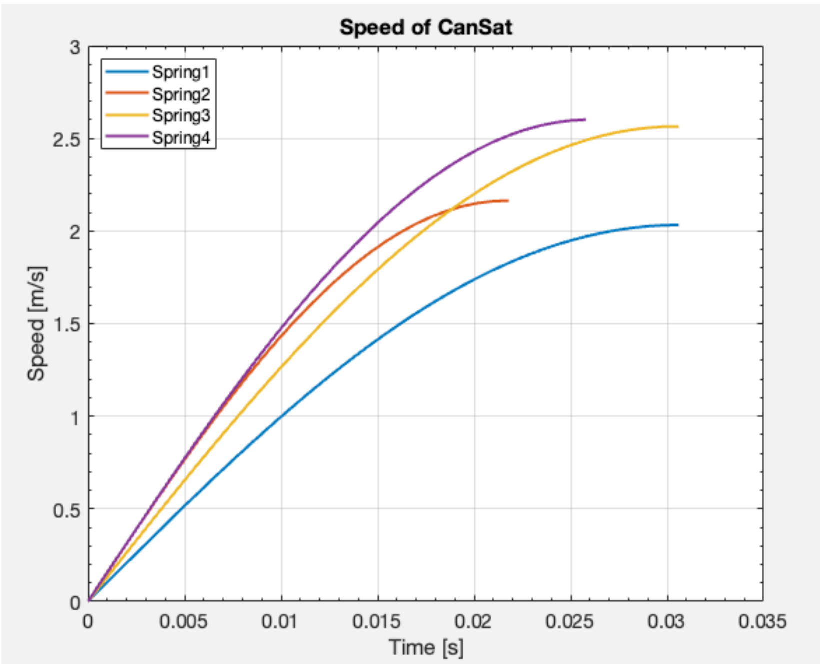
	F_{max} [N]	Ln [mm]	L0 [mm]	D [m]	k [N/mm]
Spring1 [14]	36.7	16.2	56	17.3	0.92
Spring2 [15]	54.9	18	48	21.6	1.83
Spring3 [16]	54.9	17.1	67	26.7	0.93
Spring4 [17]	54.9	23.7	67	21.6	1.27

For these selected springs a simulation with CanSat weighing *350 grams*, which is the maximum weight permitted by the rules, was performed. The results are shown in figure 3.12. Looking at the final velocity two springs stop at around *2 m/s* and two a little above *2.5 m/s*. Since both of the springs numbered *3* and *4* have maximum force below the limit and result in higher velocity, they are favourable.

Looking at the acceleration graph the differences are larger. Although in all cases the acceleration happens over a short time period, it is still desired to reduce it. The third spring here results in lower peak acceleration and therefore was chosen for further review.



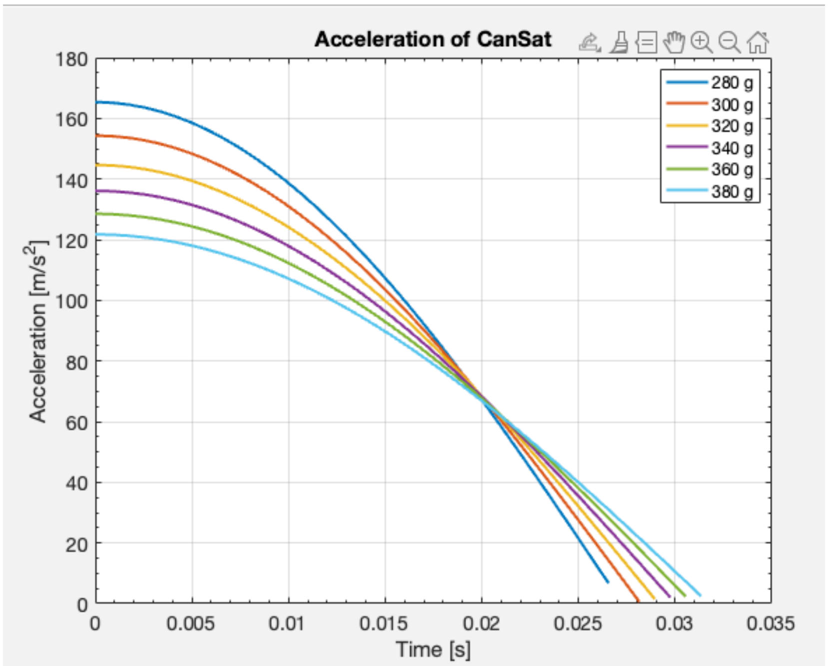
(*a*) *Acceleration*



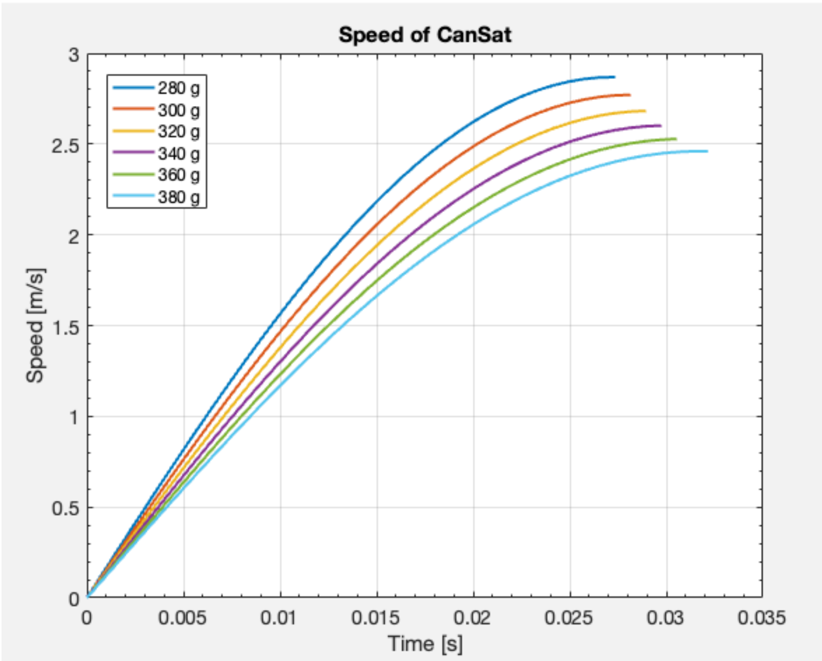
(*b*) *Velocity*

Fig. 3.12: *Acceleration and velocity modeled for four different springs with CanSat weighing 350 grams*

For the chosen spring a simulation was ran once again now with different CanSat weights and the resulting graphs are shown in figure 3.13. Maximum exit speed is ranging from around *2.5 m/s* to around *3 m/s* which is sufficient. Acceleration is spread over a larger area again with values for the lightest CanSats reaching over *180 m/s*^{2}. Since it is almost a shock acceleration and not occurring over long time period it is not of a great concern and this spring is therefore suitable for use.



(a) Acceleration



(b) Velocity

Fig. 3.13: *Acceleration and velocity modeled with the chosen spring with CanSat weights ranging from* 280 *to* 380 grams

3.3.2. Main body

The central part of the release system to which every other component connects is the main body made from bent aluminium sheet. Contrary to the rest of the system, this part remained unchanged throughout design and testing. As a main structural part it is designed to transfer loads from the spring to the body of the rocket. It is also required that it is stiff enough so as little energy is lost from the spring as possible. Since the skin of the rocket is made by rolling and riveting *0.6 mm* thick aluminium, it was used for this part as well.

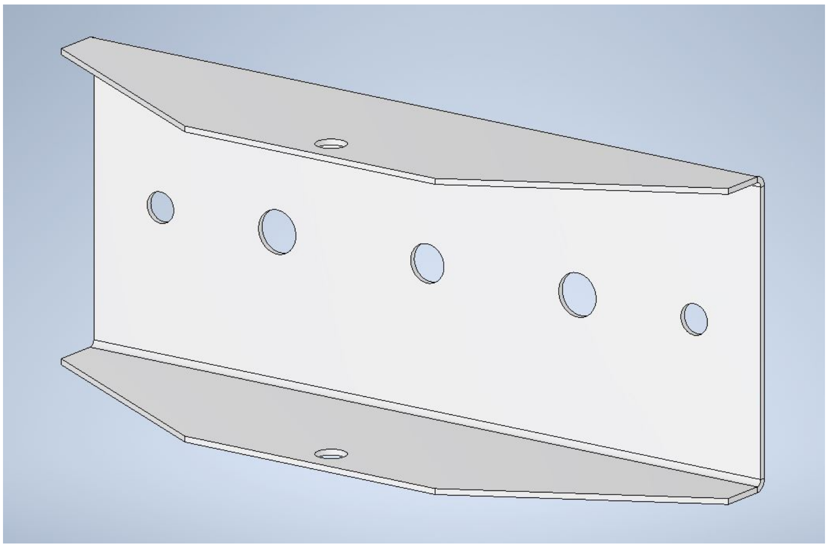


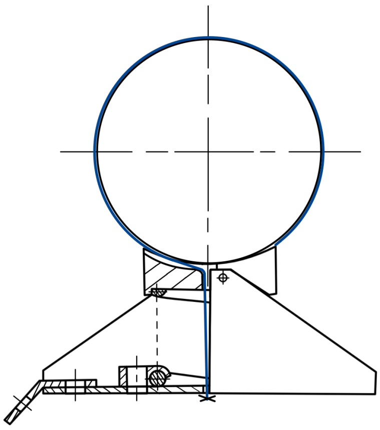
Fig. 3.14: *Main body made from bent aluminium sheet*

3.3.3. CanSat Adapter

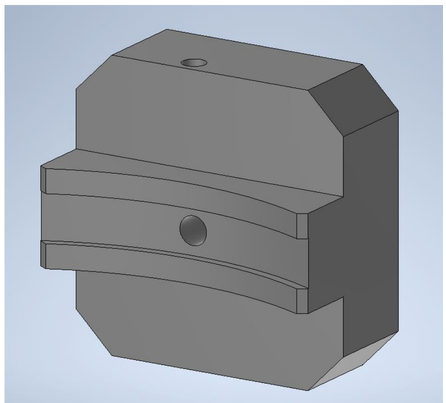
Probably the most important part of the design is the connector between the ejection spring and CanSat. The main functions it must fulfill are to create secure interface between the spring and the CanSat and allow for the nylon line to run through it. It must also be sturdy enough to allow the split pin to securely hold it in place. Because it needs to be precisely manufactured, lightweight and several prototypes were expected, 3D printing was the chosen type of manufacturing. As each test-fit revealed new design or assembly issue, it went through several iterations that are listed below.

First iteration

For the first iteration it was expected of teams to figure out how to attach the nylon line themselves. The adapter consisted of one part, with circular attachment point for spring on one side and curved interface for the CanSat to lean against on the other. A hole was running through the middle with added grooves so the nylon line would lie flush with the surface. This was necessary if teams chose to not tie down the line, but to loop it around the surface and bring back to the release system as seen on figure 3.15.



*(**a**) Concept drawing of CanSat attachment with the nylon line wrapped around it*



*(**b**) 3D model of the CanSat adapter with a groove for nylon line*

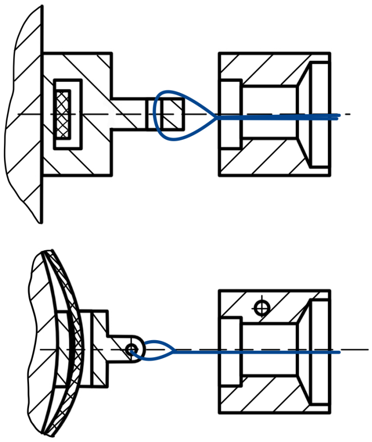
Fig. 3.15: *First iteration of the CanSat adapter*

After releasing the adapter would stay attached to the spring and only the CanSat would be ejected. However it was decided that universal attachment would be a safer option as it would limit improper connections. Inspired by the looping around the CanSat a second iteration with proper connection to CanSat was developed.

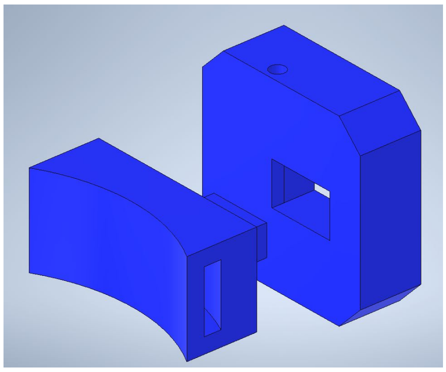
Second iteration

To ensure fast and secure connection a two part adapter was created with a rubber band attachment to the CanSat. This rubber band is inserted into the part during the printing process and is therefore closed inside as seen on figure 3.16. Eye attachment is printed to attach the nylon line. This connection fits inside the second part, that is connected to the spring and allows the line to be guided through the middle.

Since the adapter is split into two parts, the spring can be compressed and secured regardless of the CanSats preparedness which reduces the time needed to prepare for launch on site. When the team is ready to install the CanSat the rubber band is simply wrapped around at a desired height, the nylon line is attached and connected inside.



(a) Concept drawing of the principle of connecting the nylon line to the first part of the adapter on the left and guiding through the second part, shown in side and top view



(b) 3D model showing the necessary offset of the nylon line guide and the split pin hole

Fig. 3.16: Second iteration of the CanSat adapter

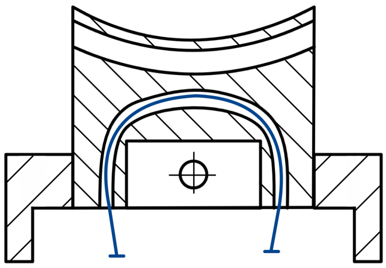
The rubber band connection worked well and secured the CanSat in place without the need of much changes from the teams. However when guiding the nylon line through the middle of the system it was prone to getting stuck and slipping through gaps between parts. Another issue was the location of the split pin as it needed to be off the center line to allow for the nylon line attachment and that allowed the spring to bend around it.

Final iteration

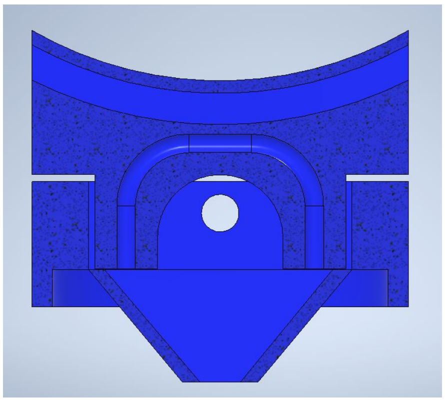
Since the enclosure for rubber band worked so well a similar approach was used to upgrade the nylon line attachment. The protrusion in the middle used to loop the nylon line through was split into two, allowing for the split pin hole to be centered. Into the protrusions a hole was designed following a u-shaped spline through which the nylon line is pushed through as seen on left part of figure 3.17.

To further speed up the installation and make it easier for the nylon line to get to the other side of the main body a guiding chamfer was added to the second part of the adapter. The leading edge sits flush with the middle hole and leads the line to it as can be seen on the right side of figure 3.17.

Additionally a hole for a string was implemented into the second part to tie it to the rocket. This was done because the press fit on the spring was sometimes not enough to hold the adapter in place and before touchdown it fell of due to high vibrations.



*(**a**) Drawing of the two part adapter showing the inside tube used to guide nylon line*



*(**b**) Cross section of the 3D model with guiding funnel*

Fig. 3.17: *Final iteration of the CanSat adapter*

3.3.4. Nylon line attachment

As the nylon line is guided through the middle of the spring to the other side of the aluminium body, it needs to be securely tied down. This connection is very important as it is the only anchor point holding the CanSat in place when the split pin is removed. This connection is therefore exposed to manipulation shocks when the rocket is moved to the launch pad and to high vibrations during launch.

Using the nylon line proved problematic as it is very difficult to tie it down as the simple knots slipped free. More advanced knots, used by fishermen for example, are suitable, however they tend to take longer to properly secure. This resulted into several smaller iterations which are summed up into two larger steps described below.

First iteration

Since the attachment point must be on the backside a set of bolts used to retain the spring may be utilized to secure the part in place. This part is also 3D printed as it allowed for fast changes and odd shapes. As can be seen on figure 3.18 two square holes were added for four-sided nuts to fit in and round hole in the middle for the line to run through. The rectangular cutout in the middle is designed to allow connecting the resistor wire to the nylon line.

From the beginning the main trouble was to securely attach the line without it snapping on sharp edges or simply slipping out of a knot. A fast and simple solution was found using a bolt. This allowed for very fast and repeatable connection. Another issue in this design was poor access to the nylon line to properly connect the resistor wire and its electrical connection as it is difficult to solder these wires.

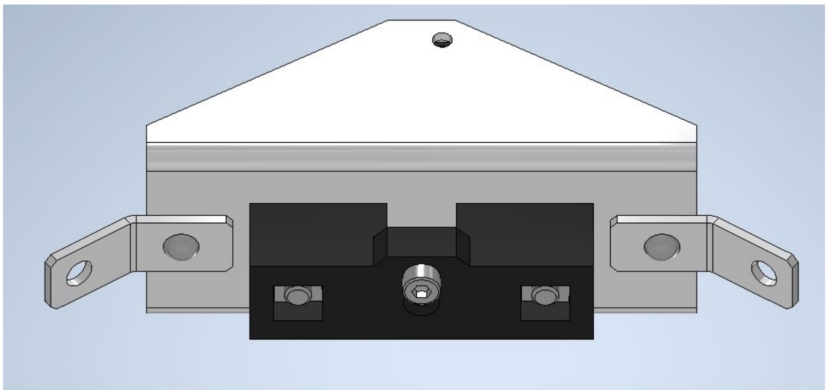
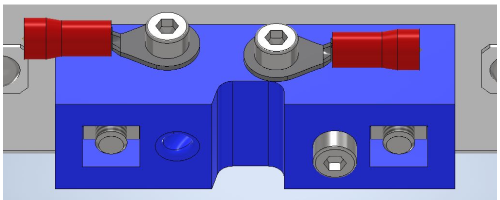


Fig. 3.18: Nylon line attachment part with M3 bolt in the middle to connect the line and a rectangular cutout to connect the resistor wire

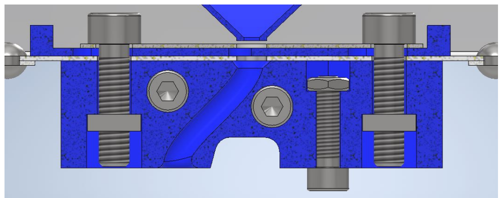
Second iteration

The main upgrade for the second iteration was connection of the resistor wires. Simply winding them around cables was not sufficient. A very similar solution to holding down the nylon line created a secure connection. The wire is wound around the bolt and tightening the bolt presses it against a ring terminal connected to power cable.

Better solution for the nylon line guide is portrayed on the right side of figure 3.19. A channel that follows a spline is printed inside the part to guide the nylon line off-center. This allows for a cutout that exposes the line as it is tied to a bolt seen on the right. Resistor wire can therefore be already in place before the line is tied down. To prepare the CanSat for launch the wire is twisted to create a loop through which the line is pushed and that creates a solid connection.



(a) 3D model showing ring terminals used to connect the resistor wire



(b) Cross-section of the model displaying the spline channel for the nylon line

Fig. 3.19: *Final iteration of the nylon line attachment*

3.3.5. Mechanical connection

The mechanical interface between the main body of the release system and the structural U-beams of the rocket had to be light and sturdy. A rectangle made from the same aluminium sheet as the rest of the parts was used as a stand-in solution until proper connection was designed. However when flight proven it performed well and there was no need for it to be upgraded. The rectangular pieces are riveted to the sheet metal and bent to the necessary angle to sit flush with the U-beams as can be seen on figure 3.20.

3.3.6. Final iteration of the system

The final form of the CanSat release system can be seen on figure 3.20. The spring is retained using 3D strip to prevent the nylon line from shearing as well as allowing adjustments to the position. CanSat adapter consists of two parts out of which one is attached to the CanSat by a rubber band and fits into the second part. The second part is connected to the spring and to allow for easier manipulation a hole for split pin to retain the spring in compressed position is added. It also features guiding chamfers for the nylon line.

When the nylon line is pushed through to the other side, it is guided inside a channel off the center-line. This allows for a cutout where the resistor wire can be connected without touching the sidewalls. The nylon line is then attached to a bolt that is tightened. The resistor wire is also connected by tightening a bolt with added ring terminals for the cables. The whole system is riveted to the structural U-beams of the rocket via rectangular aluminium plates.

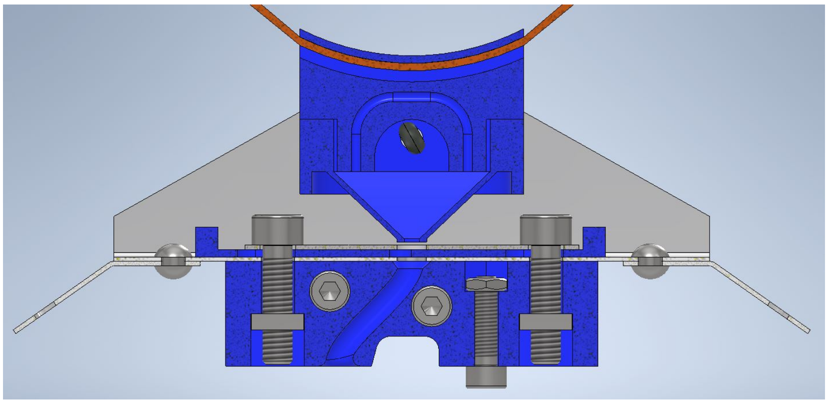


Fig. 3.20: *Cross-section of the final model that took flight during CanSat Finals on 1. 6. 2022*

3.4. Manufacturing and testing

In this last chapter the manufacturing process of the release system is documented. Each part has its own section with tests that were undertaken, if necessary. The final section is dedicated to the flight tests.

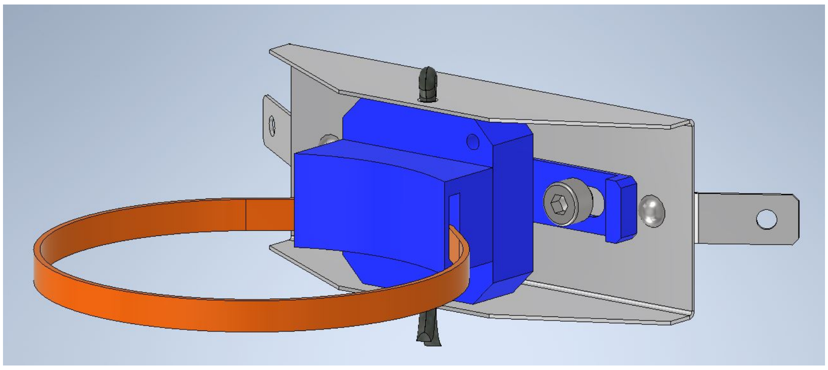


Fig. 3.21: *Final assembly model of the CanSat release system*

3.4.1. Aluminium parts

Starting with the simplest part, the rectangular connector shown in figure 3.21 is made from the same aluminium sheet as the main body. Since at least three rockets needed to be made a large number of these connectors had to be manufactured. Starting from a two by one meter large metal sheet a strip was cut to the desired width with large sheet metal shears shown on the left side of figure 3.22. Each piece was then cut from the strip on smaller bench metal shear. The sharp edges were rounded by a file and a hole was drilled for the rivet.

(a) Metal sheet shears *(b) Metal sheet bender*

Fig. 3.22: *Large metal shears and metal sheet bender used to create the main structure of the release system*

The main body was made according to the drawing in figure 3.23. The cuts were again made on the large metal shears. After the cutting, all holes were drilled on a drill press and the part was then bent using sheet metal bending machine shown on the right side in figure 3.22.

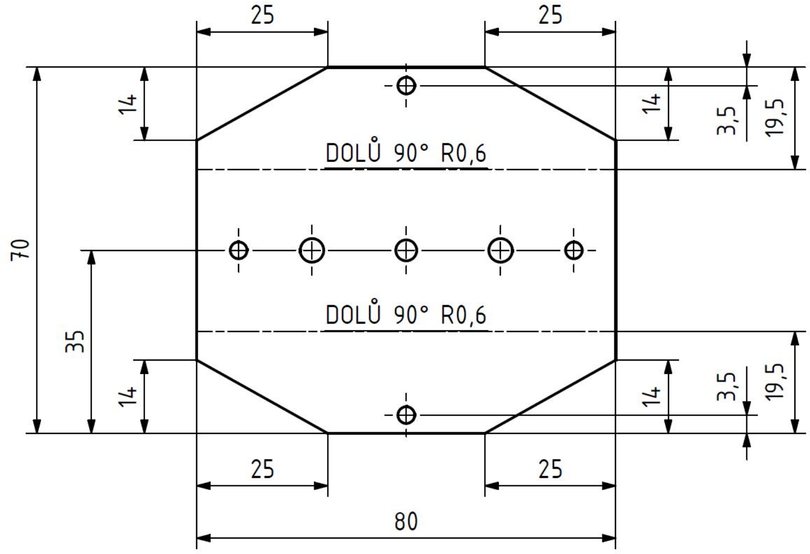


Fig. 3.23: *Drawing of the metal body*

Both connectors were then riveted to the main body and as such the system was ready for the spring and 3D printed parts installation. The second hole used to attach the system into the rocket was drilled during the integration process to ensure correct alignment. The bending of the connectors was also done during the installation for the same reason.

3.4.2. 3D printed parts

Most of the parts used in the CanSat release system were designed to be 3D printed. Although many additive manufacturing methods exist, the most widespread today is *Fused Deposition Modeling*. This method became very popular in the past few years and most importantly it is affordable and relatively simple. The printing material is supplied in the form of wire most commonly with the diameter of *1.75 mm*. This wire is called "filament" and it can be bought in wide range of materials each with different strengths and weaknesses.

To create the printed part the filament is pushed through a heated nozzle that melts it and deposits it in desired location on print bed. A pair of stepper motors moves the printing head in *X* and *Y* directions and a third motor controls the third axis. After the filament is deposited it cools and hardens creating the desired part.

This printing is done in vertical layers to prevent the printing head from hitting the part and this has to be considered in the design process.

Printing process

After the model is ready to be printed it needs to be *sliced* so a 3D printer can print it. This is done using slicer program and in this case *Ultimaker Cura* [18] was used. In slicer the parts are firstly rotated and positioned on the print bed. The software then slices the part according to print settings. These print parameters are crucial to create working parts as each printing material requires slightly different settings. However for the commonly used materials such as *PLA* or *PETG* these parameters have been well tested and are available freely. These settings usually result in "good enough" prints as each brand of filament requires slightly different parameters and therefore *PETG* was selected as the printing material. Compared to *PLA* it can be more easily sanded and has higher UV resistance as well as resistance to impacts.

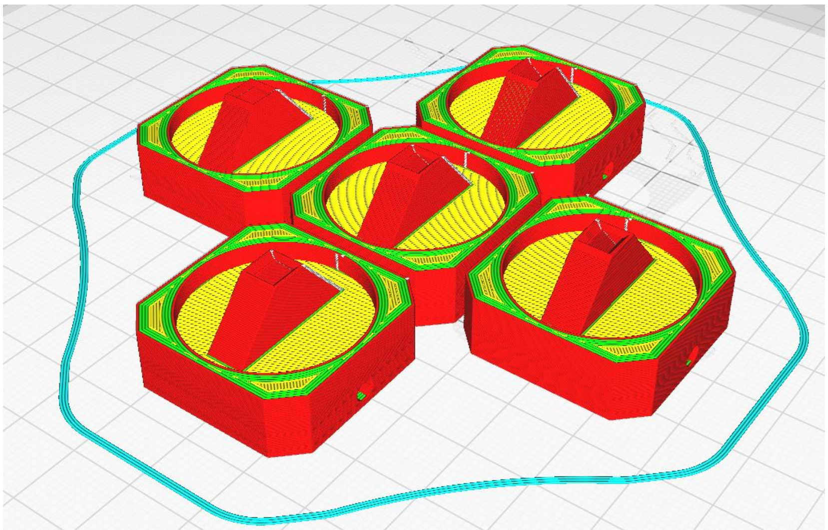
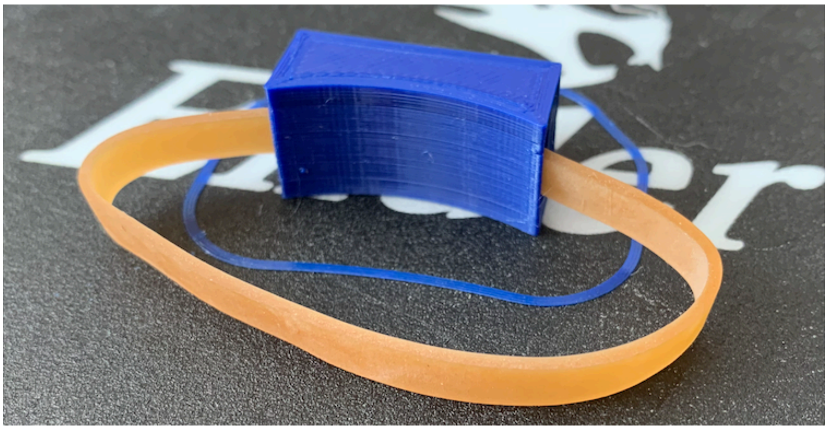


Fig. 3.24: *Picture from slicer with five CanSat adapters sliced into layers*

The 3D printer used was *Creality Ender 3* [19] with printing space of *220x220x250 mm* which allowed for the printing of more parts at the same time. This makes the print itself take longer than it would when printed separately, however it eliminates delay in between prints and therefore it shortens the total time of printing.

As already mentioned the printed parts had to be sanded down, specifically on the CanSat adapter the legs through which the nylon line runs, to easily fit into the second part. Also the holes for split pin and the safety cord were drilled through afterwards as the inside layering was preventing the split pin from sliding in properly.

(a) Picture taken while the printing process was paused to allow for rubber band insertion



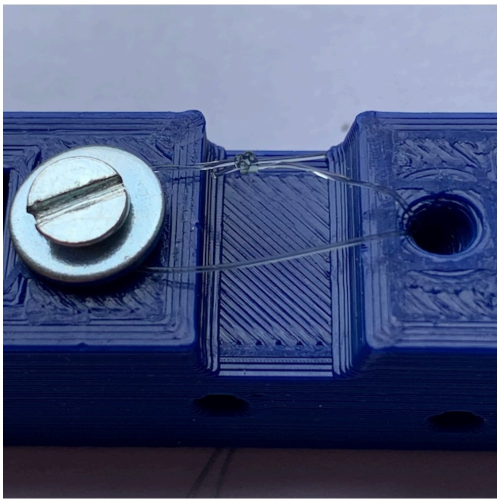
(b) The resulted print with the rubber band enclosed in the print

Fig. 3.25: *Printing process of the CanSat adapter with the rubber band*

3.4.3. Nylon line attachment

As mentioned above the anchor point for nylon line proved to be problematic and required several tests to determine its safety of use. The nylon line that was chosen is *Colmic Fendreel POWER* with rated carry weight of *12.7 kg* and a diameter of *0.35 mm*. At first a few tests with classic knots were performed, but quickly it was determined, that they cannot be used. Since the nylon line chosen is used for fishing, knots used by fishermen were tested. Without proper experience however, it proved difficult and lengthy to ensure a decent attachment.

Brass tubing is also another method used by fishermen. This can be used as a stop to prevent the line slipping through a hole or to connect two lines together. It works simply by pinching the tubing at the desired location and squeezing the lines together. It is faster compared to tying a knot, however without proper pliers it can be difficult to guess how much to depress the tubing. Although it would be possible with enough experience to assure a good connection, the consumption of tubing would be high and therefore a different method was desirable.



*(**a**) The simplest knot used by connecting two loose ends*

*(**b**) Brass tube used to crimp two ends of a nylon line*

Fig. 3.26: *Possible attachment methods for the nylon line*

Since the connecting of resistor wire to the cable using ring terminals worked sufficiently a similar approach was considered for this application. Using a *M3* bolt with a washer running through the 3D printed part the nylon line was wrapped around it and after tightening the bolt, it was held in place. After trying several different configurations it was found, that it is desirable to get rid of the washer as it was splitting the nylon line after tightening down and reduced the loading capacity significantly.

The best approach was to leave about half a millimeter under the bolt's head for the nylon line to slide under it. This eliminated the possibility that the line would get caught in the thread of the bolt and would be dragged in the bolt hole, which would result in almost certain failure. Wrapping the line multiple times was also undesirable as it required smaller force to cut the line when tightening the bolt. The torque with which to tighten down the bolt was also a result of experimenting similarly to the brass tubing, however it had a much larger margin for error and therefore was suitable for use.

Fig. 3.27: *Final nylon attachment part shown in use on the release system prepared before ejection test*

When testing the nylon line with the ejection system as a complete module, another issue was revealed. When removing the split pin the spring would often get squeezed to one side as the nylon line was pulling on it. This in turn meant that the string could touch the sharp edges of the aluminium body. When induced to vibration, it caused the line to break and release the spring prematurely. This was fixed by changing the spring retainer from sheet metal to 3D printed part that has a smaller diameter of hole to protect the line. It was also designed with oval holes instead of round ones, so that it could be adjusted to center the nylon line.

Fig. 3.28: *3D printed spring retainer shown in blue with oval holes to adjust springs position relative to the center hole*

3.4.4. Electronics

Important part of the design was the resistor wire used for melting the nylon line. The wire used in both systems mentioned in section 2.2.3 is made from nichrome. This is a affordable and available option as it is used in electronic cigarettes. However a limitation comes from the switch as it can only close the circuit. It is not controlled by avionics, but it is tied to the opening of the panels by mechanical switch that can be seen on figure 3.29. The pin is tied to the panel by the green string and when the panel reaches angle that allows for the release of CanSats, the pin is pulled closing the circuit. Two switches are used each for one panel and they are connected in series so both panels need to be opened.

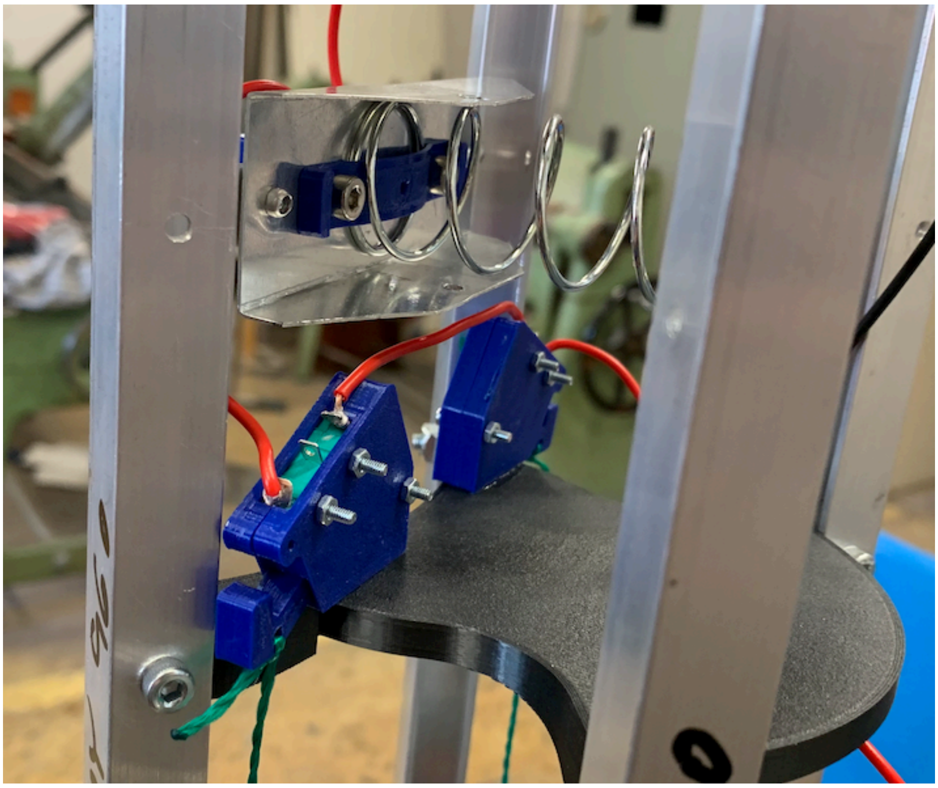


Fig. 3.29: *Serially connected switches with pull pins used to trigger the release mechanism*

The nichrome wires are only available with diameters above *0.3 mm* and while heating up properly, they do stay intact. This means that once the circuit is closed it keeps draining the battery until its empty or disconnected. This is not desirable as for each launch a new battery would be necessary.

Therefore a wire with smaller diameter that burns through when exposed to the battery was required. Three different materials were used for testing and are summed up in table below.

Tab. 3.2: *Tested resistance wires*

Material	**Resistance [Ω/m]**	**Diameter [mm]**
Konstantan	18.5	0.18
Kanthal	53.1	0.18
Isotan	20	0.18

For the test four segments of resistor wire were used in series, each with the length of *10 mm*. To connect these a copper wire was used with the length of *200 mm* (fig. 3.30) simulating the conditions expected in the rocket. As the amp-meter a digital multi-meter *Vorel 81780* was used. Even though the tests are short and the update time of the multi-meter is significant, the amperage serves only as a supplement value. The important value is the time needed to melt the line and if it burns the resistor wire, resulting in circuit opening. The resistance of the connecting wires is *0.85 Ohm/m*. The time needed to melt each line was determined from video feed. The power source is rated for maximum current output of *2 A*. The wires were tested from *3 V* to *12 V* with *3 V* steps.

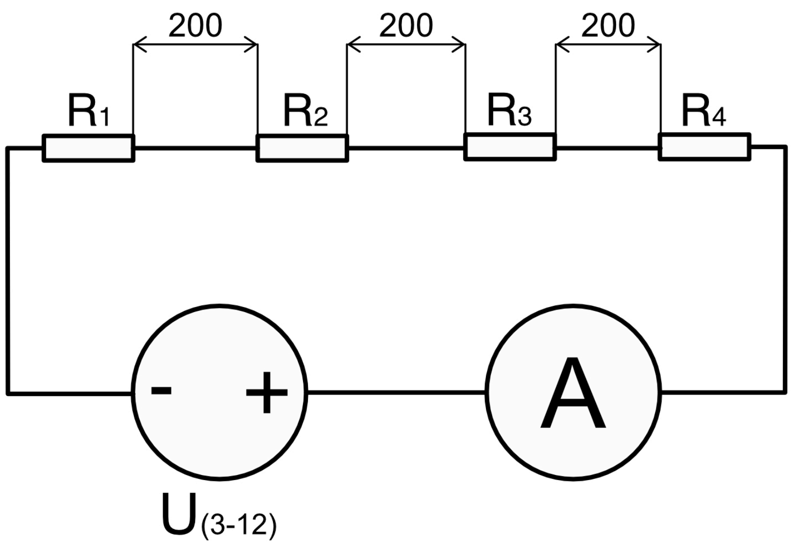


Fig. 3.30: *Diagram displaying the resistor wires connected in series separated by low resistance wires supplied by voltage source*

Tab. 3.3: Values measured during the tests

Material	Voltage [V]	Current [A]	Time [ms]	Wire cut
Konstantan	3	1	>6000	no
	6	2.1	150	no
	9	2.8	100	no
	12	2.8	instantly	yes
Kanthal	3	0.4	x	no
	6	0.8	1000	no
	9	1.3	100	no
	12	2	instantly	no
Isotan	3	0.2	x	no
	6	1	3000	no
	9	1.7	350	no
	12	2.7	instantly	no

As can be seen from the table above, at the lowest voltage *Kanthal* and *Isotan* did not melt the nylon line with the *Konstantan* taking more than 6 seconds. With increasing voltage the times drop dramatically for the *Konstantan* and are almost the same for all three wires with source at *9 V*. Melting times around *100 ms* were sufficiently fast, however none of the wires burned through the wire opening the circuit. The only wire suitable for use was the *Konstantan* as it melted the wire almost instantly when supplied by *12 V* and it burned through opening the circuit. As a power source a *3S Li-Po* battery was chosen with capacity of *450 mAh*.

3.4.5. Assembly

Assembly of the system is a straightforward process since the metal parts are already riveted together. Firstly the *M3* nuts are inserted into the 3D printed part used to hold resistor wires and nylon line. The spring and its retainer are positioned inside and bolts are inserted in respective holes. On the other side the nylon line attachment part is installed and secured with four-sided nuts. During the tightening the spring must be positioned so it is inline with the center hole. Ring terminals and resistor wires are then attached using *M3* bolts. The bolt for holding on to the nylon line is inserted as well. Lastly the first part of CanSat adapter is added on the other end of the spring, which is then compressed and secured by split pin.

In this form the system is ready for the installation of CanSats and is safe to transport. This makes the integration on launch day much faster as only the nylon line with CanSat needs to be attached.

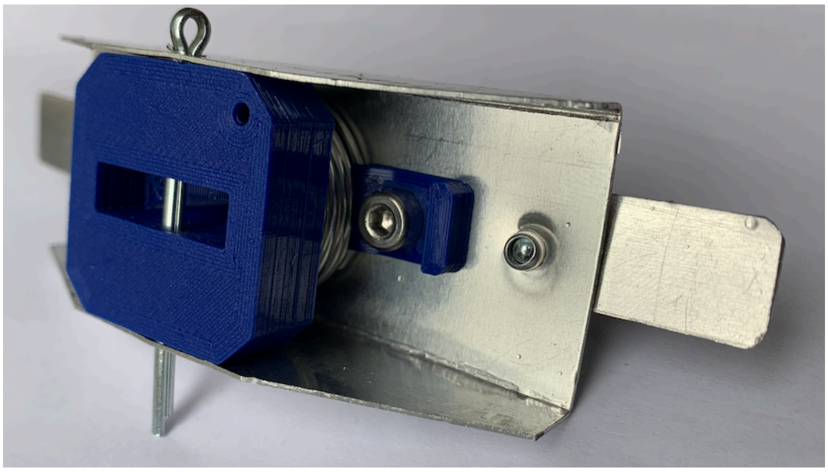


Fig. 3.31: *Assembly of the whole system without the second part of the CanSat adapter*

3.4.6. Ejection test

After the assembly of each ejection system, they were installed inside the payload area of the rocket alternating the direction they face. Connectors on each side of the system were bent in the required angle and drilled through to make a hole for the rivets. Although the attachment by rivets is sufficient, the aluminium sheet is the weak point of the connection. Bending of the sheet metal helped with the stability, however it was still able to rotate around the joint. This turned out to be an advantage, because it allowed for small correcting adjustments of the position that were necessary due to poor manufacturing precision.

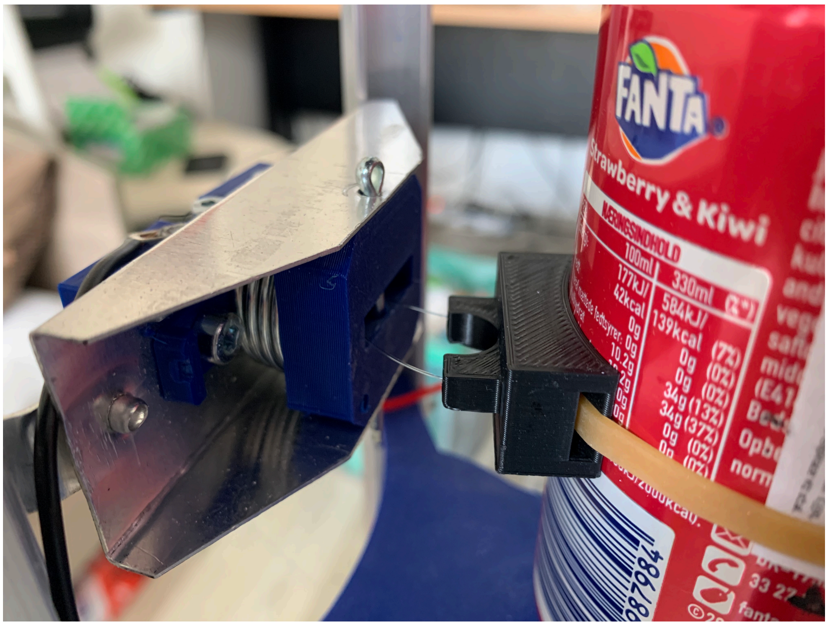


Fig. 3.32: *CanSat dummy being attached to the ejection system*

For the ejection test all of the systems were equipped with nylon line and resistor wires, but the ones without mass dummy were locked with safety pins. Only the payload bay was used in this test without the parachute system, other mass dummies and without the heaviest part of the rocket - the motor, therefore it was secured at the top and bottom to reduce lateral movement. A ruler was taped to the wall right behind the CanSat dummy to measure the exit velocity from the video. The recording was done on *iPad Pro 2020* utilizing the *240 FPS* slow-motion camera and a dummy with the weight of *335 g* was used.

(a) Frame 1

(b) Frame 2

(c) Frame 3

(d) Frame 4

Fig. 3.33: *CanSat dummy ground ejection test showing the lateral movement of payload bay, a ruler is taped to the wall for exit speed estimation*

The sequence in figure 3.33 above shows a successful launch of the CanSat dummy. All of the nylon lines were melted almost instantly after connecting the battery and importantly, one of the resistor wires burned through opening the circuit and protecting the battery. Visible from the two first frames is the unwanted lateral movement of the payload bay. This reduced the spring's effectiveness and lowered final speed of the CanSat dummy which was measured to be around $0.6\ m/s$. This is significantly less than predicted by the model in section 3.3.1 which predicted the speed to be around $2.4\ m/s$.

It is possible that this is due to the movement of the payload which will be lesser during the flight as the rocket has more mass and the CanSats launch in alternating direction at the same time. Another test was performed trying to eliminate this motion, however unsuccessfully yielding the same result. A stronger spring could be an option to increase the speed, but the loading process would need to be redesigned as even this spring was difficult to hold in place while the split pin was installed. Although the space around the system seems large, it is just big enough to fit one hand holding the spring compressed and the other hand to install the split pin. A different, more accurate model should be created to better predict the final speed.

Even though it was under performing, there was no time for a redesign to implement larger spring and because the ejection was deemed as sufficient, the design was continued to flight tests.

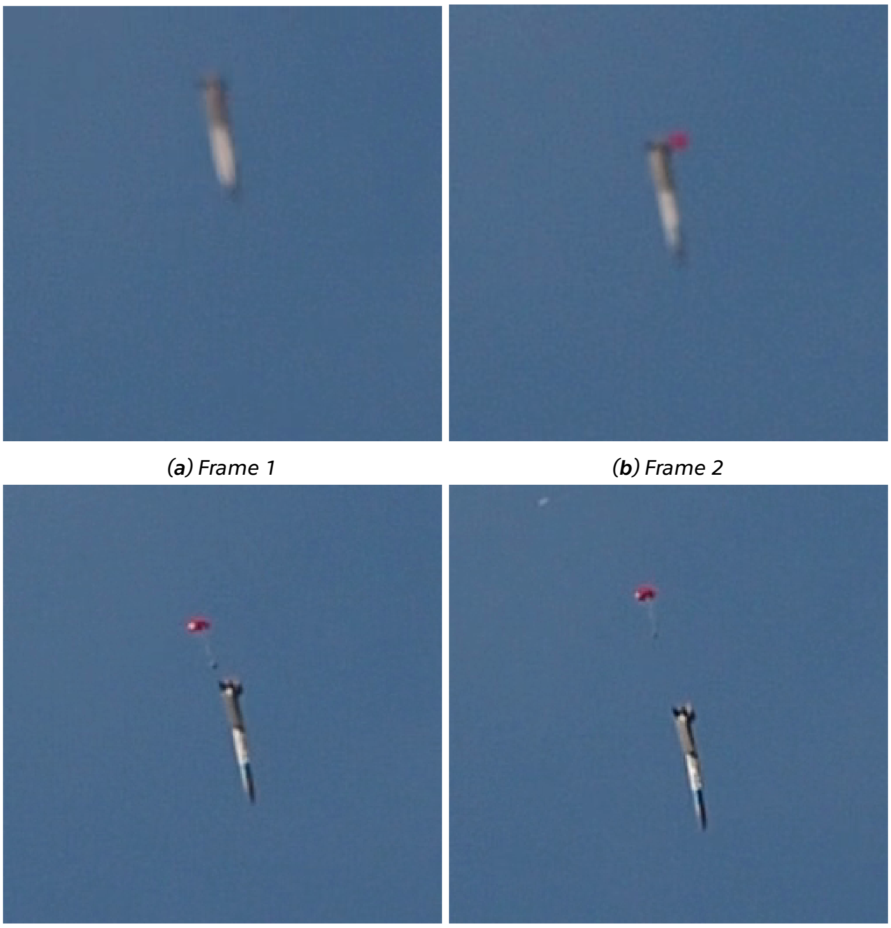
3.4.7. Flight tests

Before the CanSat Finale competition three flight tests were performed, which were necessary for the testing of the whole rocket and the launch ramp. In the first flight the opening of the payload bay was not ready and so only mass dummies were used. This tested the ability of the ejection system and nylon line to hold the CanSat in place. For the second test payload panels were functioning, however an error in avionics resulted in failure to deploy. The panels opened, but before the CanSats were ejected, rocket started descending and the resulting drag closed the panels. Therefore CanSat was launched into the payload doors and did not exit the rocket.

Fig. 3.34: *Picture of released CanSat taken from Avionics compartment*

For the third flight the mechanical switches mentioned in section 3.4.4 were implemented to ensure mechanical link between the opening of the panels and CanSat ejection. This time the sequence took place correctly and the ejected CanSat can be seen on figure 3.34 above. Unfortunately due to high winds the mass dummy could not be recovered as it drifted far of course, so it could not be inspected. However from the pictures recovered and looking at the video footage, it was determined that the CanSat gained enough sideways velocity to miss the rocket fins and it's parachute deployed successfully as can be seen on the sequence shown in figure 3.35 below.

Therefore the system worked as intended, even though this time it only launched a pair of CanSats. The nylon lines were tied in the remaining systems as if they were loaded. Resistor wires were connected as they would be in case of fully loaded payload. All nylon lines were melted and the resistor wire burned through correctly. This flight also proved that any number of CanSats can be launched as long as they are positioned in such a way that they keep the center of mass in the correct margins relative to center of pressure of the rocket.



(a) Frame 1 *(b) Frame 2*

(c) Frame 3 *(d) Frame 4*

***Fig. 3.35:** The first release of CanSat during demo flight 3 of Sherpa rocket*

CanSat Finale

For the CanSat competition six teams signed up and therefore were split into two groups. For the first flight it was opted to launch only two CanSats so that in case of failure the remaining four can be released from a backup airplane.

The first launch resulted in partial failure of the payload system. One of the payload doors while opening got stuck on launch guide and did not open. This meant that only one of the pins designed to close the ejection circuit was pulled and therefore CanSats were not released. On the ground following a successful recovery on parachutes the payload area was examined and upon freeing the door and letting it fall to the ground, the CanSats were ejected. This incident was then only caused by the door mechanism and not the ejection system itself.

Since the second rocket was slightly different from the first one and the same failure could not happen, the remaining four CanSats were loaded and prepared for flight. This time the payload doors functioned as designed and opened just before the rocket reached apogee. A pair of springs pushed the panels away from the rocket helped by drag from oncoming air. When the panels reached desired angle a string connected to them pulled out pins in the switches and triggered the ejection system. Powered by a 3S battery the resistor wires melted the nylon lines and allowed the springs to eject the CanSats. A still photo provided by one of the teams just after the release can be seen in figure 3.36. All four CanSats are ejected nearly at the same time and the alternating pattern of ejection direction gives more room for the parachutes to deploy.

Fig. 3.36: *Photo provided by MASA CanSat team at the CanSat Finale [20]*

On the launch day it was helpful to have the system prepared as much as possible which reduced the time needed for CanSat integration. Since the spring was compressed, the resistor wire was in place connected on both ends, the only procedure done on the spot was to put the adapter with rubber band on the CanSat. Following that the nylon line was guided through and secured on the other side. This took about two minutes per CanSat and did not slow down the launch process.

What could be improved for the next iteration is the strength of the spring as it was slightly under powered. This could be done by redesigning the connectors to allow for the system to be removed from the rocket for spring compression while also strengthening them to withstand larger forces.

Conclusion

In the first part of this thesis a research was conducted into hold and release mechanisms used is space sector. This included stage separation mechanisms used on rockets as well as payload release systems also used on orbital rockets. The designs of other teams tackling the same issues, together with the sources on nichrome wire release systems were the most important.

After the research few concepts were created out of which one was selected. The selected concept uses a compression spring with a nylon line to hold it compressed. The string is held in place using an *M3* bolt and to release the CanSat it is melted using resistor wire. The resistor wire is connected to power cables by ring terminals and it is powered by a battery. These parts are attached to the main body made from bent aluminium sheet which is riveted to the body of the rocket.

In the testing phase different kinds of nylon line attachments were explored with the final one being the fastest and simplest. The correct combination of resistor wire and power source were tested resulting in the use of *Konstantan* wire with the diameter of *0.18 mm* and a *3S Li-Po* battery. Several flight test were also conducted resulting in design changes.

Even though the system was under performing, all CanSats were eventually released successfully during the Finale. A better model for predicting the final speed of the CanSat is necessary. To further improve the system a stronger spring to increase the release speed would be beneficial.

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