Escola Tècnica Superior d'Enginyeries Industrial i Aeronàutica de Terrassa
UNIVERSITAT POLITÈCNICA DE CATALUNYA

ETSEIAT
Grau en Enginyeria en Tecnologies Industrials

Design of a bench to allocate accelerometers and gyroscopes on a sailplane

Memory

Author:
Oscar Castro Ruiz

Director:
Ricardo Villar
Co-director:
Rafael Weyler

[12-06-2015]

Agradecimientos

Agradezco la amabilidad y disponibilidad ofrecida por Rafael Weyler durante la realización del trabajo, por enseñarme el aeródromo pero, sobretodo, por el vuelo en planeador que me ofreció.

A Ricardo Villar por su amabilidad en las consultas realizadas a lo largo del período de realización y redacción del trabajo.

A José María Castro, mi padre, por la ayuda ofrecida a la hora de buscar materiales y herramientas.

A Dolores Carrero por su paciencia y ayuda ofrecidas durante la redacción de la memoria.

Escola Tècnica Superior d'Enginyeries Industrial i Aeronàutica de Terrassa
UNIVERSITAT POLITÈCNICA DE CATALUNYA

Index

Figures included in the document

Tables included in the document

1 Introduction

1.1 Aim of the project

The aim of this project is designing a bench in order to hold some devices to collect data from the forces during a sailplane's flight. These devices could either be accelerometers or gyroscopes.

1.2 Justification

This project appeared owing to the need of another one. The idea of it is to designing a cockpit instrument to detect the wing flex and recognize the position along the air space followed by the aircraft during its flight. However, for doing so, it is necessary to measure the forces of the aircraft once in airborne.

In order to measure them, accelerometers and gyroscopes are provided. Because of the complex geometry of a glider surface there are not attachments available for these types of gadgets. So, they have to be specifically designed to adapt them. For doing so, apart from the fact that there is not much space left to operate in a sailplane wing tip. Another aspect that must be taken into account is that, the aileron is near and its movement cannot be interrupted for safety reasons. In the empennage fuselage case the weight will be crucial in order not to displace too much the centre of gravity.

1.3 Scope of the basic engineering

This project includes all the aspects needed to design the bench and prepare it for being installed on a sailplane.

The bench has to be the devices holding, guarantee the stability of them even in extreme conditions and ensure a good attachment with the wing or the fuselage.

After studying and knowing the advantages and disadvantages of some utensils available in the market, they may be acquired from external stakeholders in order to ease the design process.

A prototype of the final design has to be done to verify its dimensions and weight.

It is important to take into account that a space to introduce or hold a memory to record the sensor's data may be available or, in case it is not, study the communication with them.

1.4 Basic requirements of the project

The bench must ensure the following requirements:

- A good attachment between the sailplane and the devices that enables to fly in non-optimal conditions such as through the characteristic turbulences provoked by thermals. Actually, this is the usual kind of flight.
- Being as small as possible for not interrupting the airflow and affecting the aerodynamics.
- In order to maintain the aircraft's centre of gravity in the same position, the bench must be as light as possible.
- The contact between the bench and any of the control surfaces is strictly forbidden.
- The interaction between the bench and the sailplane structure, such as the use of screws in positions that are not prepared for holding them is strictly forbidden.
- A security system to avoid possible loses of the equipment.

2 Overview

In the following pages the solution will be described. This solution has been found after considering which are the most important aspects of a sailplane that must be taken into account during the design as well as the familiarization with the type of aircraft and the devices that will be attached to it.

Then, a brainstorm has been made to suggest different types of designs as well as to analyse its advantages and drawbacks. Once we have chosen one or more, it will be designed to see which has the best performances.

Finally, a prototype has been done to identify, in further steps, its actual strengths and weaknesses.

3 General information about sailplanes[1,2]

There are some aspects about sailplanes that are important to take into account when doing some modifications on it such as its performance or the aerodynamics. Here, some of them are explained.

3.1 Centre of gravity

Generally speaking, the centre of gravity, CG is allocated on the fuselage's wing section of an aircraft. However, it is permitted to move it within a given CG's limit.

There are two main kinds of problems to avoid, the ones associated with a CG moved forward and the others associated with it moved backwards:

- With the first ones the pilot feels the nose of the aircraft heavier and has to apply more pressure on the stick pulling it up. The possible causes are that the pilot exceeds the maximum weight or that there is too much ballast weight.
- With the second ones, the tail tends to fall and the aircraft stalls more easily due to the increased angle of attack of the wing and its speed loss. The causes of these ones are that there is insufficient ballast weight on the cockpit or that the tail wheel digger is not removed.

It is important to take into account the weight of the aft fuselage attachment to ensure a good handling of the sailplane. Nevertheless, its mass should not be as heavy as having to put ballast weight to trim it.

3.2 Drag

The resistance the air produces when an object pass through it, is called drag and it actuates contrary to the direction of the glider. There are two main types of drag; parasite and induced drag.

Parasite drag

This is the amount of the form, the skin friction and the interference drag.

- The high pressure on the leading edge and the low pressure on the trailing edge produce the form drag that caused a force contrary to the movement of the wing.
- A polished skin is very important in order to have a boundary layer between the wing surface and the air. The microscopic holes on the surface trapped the air. This air slows the layer above it, this new

one slows the layer above it again, and so on. The interaction between them creates friction and slows the airspeed. The boundary layer usually has a thickness of 1 mm and very small object as little as insects or rivets can disturb the airflow.

- Finally, the interference drag happens when different airflows interact in a point. This creates drag.

Induced drag

In order to generate lift, the wing must be in a certain angle of attack. Due to this angle a high-pressure zone is created on the lower surface (intrados) and a low-pressure one on the upper surface (extrados).

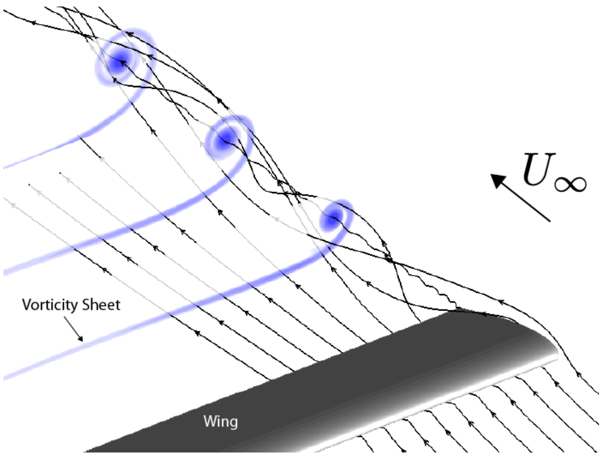


Figure 1. Vortices generated on a non-winglet wing.

The interaction between these two zones creates a vortex of wasted energy on the wing tips that creates drag as well. To avoid this problem, there are available wings with wing tip devices or winglets.

The wing attachment is designed for being installed on the wing tip for two reasons. Firstly, due to the fact that the wing tip is one of the plane's zones more fared from the CG, it experiences more rapid moves and the wing flex is more significant. Secondly, the aerodynamics there is not such important than the other parts of the wing due to the induced drag. Nevertheless, it is important to take into account that an object such an attachment there can provoke a moment from its weight on the longitudinal axis or other from its extra drag generated on the vertical axis.

4 Specifications of the LS1-d[3]

The bench designed in this project will be installed on a sailplane Rolladen–Schneider LS1-d.

The LS1 family has been produced between 1968 and 1977 and it has several numbers of variants. In total, more than four hundred gliders of this type have been produced. It was succeeded by other variants such as the LS2 and LS4 in the late seventies. The high wing aspect ratio and the new airfoil *FX 66-S-196* allow the aircraft to fly gently at low speeds. It was made with glass fibre, polystyrene, GRP and PVC foam. Specifically, the –d variant was the first of its class to carry a water ballast.

Type:	Single-seat
Water ballast:	60 kg
Length:	7,20 m
Wingspan:	15 m
Height:	1,37 m
Empty weight	200 kg
Maximum Gross Weight:	341 kg
Max. airspeed:	240 km/h
Glide ratio:	37:1

Table 1. LS1 general specifications and performances

5 Ideas for the wing's attachment

5.1 What we have to date

Suction cup and adhesive[4,5]

After doing some research, it has been found that there are already some benches available in the market but their purpose is slightly different, they are designed to hold a camera. Hence, it would only be necessary to design a new adapter for the devices.

There are two types of benches, one with a suction pad and the other with adhesives.

The problem with the suction pad is that the devices would be useless due to the fact that the pad may soften small movements or vibrations of the wind. The desired accuracy will not be achieved.

The other system avoids the problem with the small movements but, the adhesive is so strong that and if the user retires would the bench for some reason, the wing paint would be damaged.

The damage of the paint is a problem that the sailplane's owner must avoid, especially if the aircraft is made with glass fibre, since it performs as an external layer that protects the fibre from ultraviolet rays from the sun.

5.2 Brainstorming

5.2.1 Adapted skid

Most of the sailplanes have the landing gears placed in tandem in order to avoid possible fuselage damage in a possible off-field landing where the terrain is unknown.

This disposition has the problem that when the aircraft is almost stopped, one of the wing tips has to touch the ground.

In order to protect the extreme of the wing in both sides, there is a skid that avoids the wing tip to touch the ground directly. Furthermore, due to the fact that the aileron arrives almost to the extreme, the skid also protects the aileron to touch the ground when the pilot does a roll to equilibrate the aircraft at low speed during in the take-off.

Moreover, the skids are installed on the wing by two screws and an adhesive; this means this is a very secure system to avoid a loss of the object once in airborne or when it touches the ground.

The idea is to take the most of the object and its disposition system with screws. A new skid must be designed in order to hold the devices.

Figure 2. The wing tip must touch the ground for the rest position.

5.2.2 Design of a winglet

Figure 3. A winglet

Place a dispositive like a bench with an object on the wing may affect its aerodynamic. It could be seen as a small permanent spoiler but put on the wing tip, this means the momentum generated is greater than a normal spoiler, which is usually placed on the middle of the wing.

A winglet is a continuity of the wing tip disposed almost vertically. This extra object improves considerably the aerodynamics since it avoids the generation of a vortex that creates drag.

A design of a winglet-bench for the devices could avoid the spoiler problem and could also increase the aerodynamics. It would be an empty winglet to hold the devices on it and an external door might be placed for introducing the sensors. This way, the sensors would be protected from weather elements or direct impacts to strange objects.

Sailplanes that provide this type of advance are substantially more expensive, so the majority of the gliders seen have not incorporated it. However, some sailplanes can disassemble the wing tip so it can ease the installation on it.

5.2.3 A solid attachment

Another option proposed is taking into account that most of the gliders do not have winglets. It consists of a solid cover attachment made of a polished material to reduce drag on the outside part, and rubber to increase the friction between the wing and the attachment on the inside part.

The sensors may be put on the upper side of the bench in order to be checked by the pilot during the flight and to protect it from impacts during the landing.

The problem is that the geometry of the wing tip is very complex. Therefore, it is quite difficult designing an object to adapt it and maintaining the plane's aerodynamics performance as equal as possible, as well as choosing the best materials.

5.2.4 Fibre made clamp

In order to ease the design of the idea above, the same system has been considered but, with the difference that this one would not have a solid attachment that covers all the wing tip.

Instead, this is a clamp made with the same materials of the one above attached with screws. The sensors would be placed on the same position of the solid attachment. The skid will be useful if it is placed on its inner part in order to avoid possible losses of the equipment.

5.2.5 Velcro® adhesive

The idea is thought to ease the put and quit system.

The bench will only be attached to the wing by an adhesive Velcro®. The part that stays permanently on the wing will be glued with impact paste and fixed with seal tape to improve the aerodynamics.

Figure 4. Seal tape used to fill the gaps on a glider surface.

Taking into account all the ideas above, it has been decided that the best option for the attachment of the wing tip is the design of an adapted skid. The reasons why this is the best choice to protect the devices is because the skid itself can perform as a shield, protecting the sensors from the hits against the ground. Besides, it has a solid attachment with screws and adhesive that prevents the loose of the equipment and it is an easily removable part, which does not require any complex design. Moreover, the design will require a larger skid than the usual ones so that it can perform as a protection to prevent the contact within the aileron and the ground during take-off or landing.

6 Ideas for the fuselage's attachment

The idea of the sensors is to detect the movements of the aircraft and the places where these are more noticeable are as far as possible from the gravity centre (GC).

Wing tips and the tail are the most fared places of the sailplane from the GC.

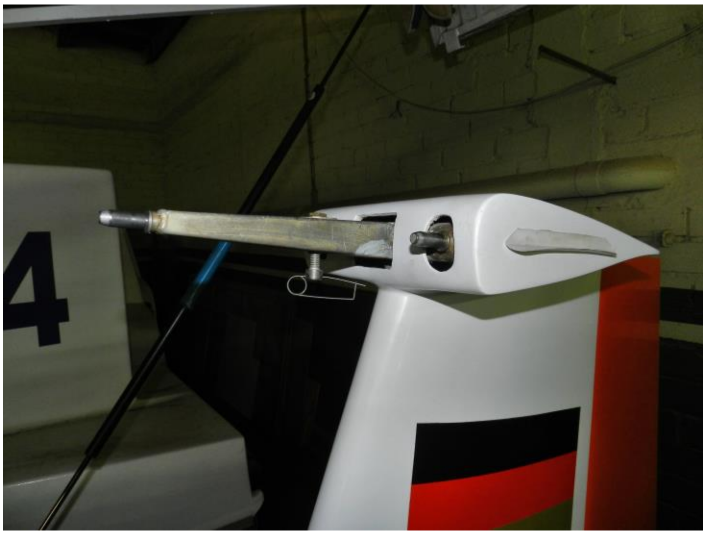


Figure 5. Fixed part of the tail, notice that the bar enables the aircraft to pitch.

Our glider tail has a T shape and the elevators are the horizontal stabilizer itself. This means that all is a single piece that moves to control the pitch of the sailplane, the most important movement of an aircraft.

Therefore, it is important to put the devices in the fixed places of the tail. It makes no sense to put it in a moveable part and it is very dangerous too.

It is important to take into account the idea of a tail strike because it could damage the system. However, here it is not considered due to the fact that it would cause a much bigger and pretty much expensive problem to solve.

Seeing the figure 5*,* we can think of several ideas to put the attachment there. Some of the wing ideas are applicable here, such as the adhesive or the Velcro® ones.

Finally, it has been decided that the best idea here is the Velcro® one, owing to its simplicity.

Still, there is another zone of the tail's fuselage where the attachment could be installed. This is the region where the empennage begins as it is shown in the figure 6.

The idea is to fix the sensor with an adapted platform for the fuselage and a ribbon. It must be strongly fastened in order to avoid movements and whereas the gadget is installed there, the device is completely protected against hits or losses.

The main advantage of using this method is the simplicity of putting and deputing it from the plane.

Figure 6. Aft fuselage section where it is possible to attach a sensor.

7 Sensors information

7.1 MSR 255 datalogger[6]

This is a device created by 'MSR® Universal data loggers'.

Datasheet

Housing:	Anodised Al (standard IP60 or IP67), snapper top-hat rail snapper (TS 35)
Size & weight:	78 x 62 x 38 mm, aprox . 222g
Memory capacity:	Over 2,000,000 measurement parameters
Operation:	Two keys for selecting functions and collecting data recording
Display:	Four row LCD matrix display
LED:	3 colour LED to indicate data recording, alarm and charge condition
Integrated sensors:	Selection of different sensors for temperature, relative humidity, pressure, light and 3-axis acceleration/position
Measurement rate (MR):	1/s to every 12h (acceleration up to 3200/s)
Storage rate (SR):	1/s to every 12h (acceleration up to 50/s)
Power supply:	Rechargeable lithium polymer battery 2300 mAh
PC software:	Free Setup, Reader, Viewer- & Online Software (Windows XP / Vista / 7 / 8)
Interface:	USB (Mini-B)
Operating conditions:	Temperature from -20 to 65°C
Storage conditions:	Temperature from 5 to 45°C (ideal condition for the battery) From 10 to 95% relative humidity, non-condensing
Standards:	EU-Directive RoHS/WEEE

Table 2. MSR 255 datalogger datasheet

It can be seen that the gadget incorporates five different sensors. However, the most important for the project is the 3-axis accelerometer that has a working range of ±15g, with an accuracy of ±0.15g at 25°C.

Moreover, the measurement rate is up to 3200Hz, which is perfect for very short or shock movements and the storage rate is up to 50Hz.

The memory can hold up to 2 million parameters, it means that the device can collect data more or less during 11~12 hours. We can see the concordance of the information: $\frac{2 \cdot 10^6 \text{ parameters}}{50 \text{ Hz}} \cdot {}^{1}/_{60\text{s}} \cdot {}^{1}/_{60 \text{ min}} = 11\text{h } 6\text{min}$ while the manufacturer states 12 hours.

The MSR 255 has an energy-saving mode that is programmable with software via PC. The power can be automatically turned on before collecting the data. This way, the sensors have enough time for the warm-up period.

Figure 7. MSR255 datalogger.

The battery capacity is 2300mAh or it can be connected with a 6V external supply. Obviously, in the project, it would only be used the incorporated battery.

The device can also incorporate more sensors with its four additional inputs and a LCD screen to make it easier to read the information of data and battery status. Nevertheless, this is not important because it would be impossible to see the screen once in airborne.

Whereas all the information above is relevant, the weight of it is very significant, especially if it is placed on the wing tip, where the momentum generated is greater:

$$7.5\ m \cdot 0.222\ Kg \cdot \frac{9.8m}{s^2} = 16{,}3\ N \cdot m$$

It must be warned that this result does not take into account the weight of the attachment.

The size is also another problem, 78 x 62 x 38 mm, which might be too big for placing it on the intrados Thus, it is not protected, not to mention the drag generated with these dimensions.

Despite of its availability and its price of €630, an attachment for it should be designed.

7.2 x-IMU[7]

This is a device designed by 'XIO TECHNOLOGIES'.

Datasheet

Size:	33 x 42 x 10 (57 x 38 x 21 with plastic housing and battery)
Weight:	12g (100g with plastic housing and battery)
Power:	LiPo battery - Charging via USB External source (3.6 to 6.5)V Consuption - (50 to 150)mA (130µA sleep mode)
On-Board sensors:	3-axis 16bit gyroscope - MR up to 2000o/s 3-axis 12bit accelerometer - up to 8g Magnetometer Thermometer Clock (can be programmed to turn on at a given time)
On-Board algorithms:	Provide real time measurement of orientation relative to the Earth
Memory:	SD card
Software:	Matlab / Microsoft Excel
Communication:	USB or Bluetooth

Table 3. x-IMU datasheet

Despite the accelerometer of this gadget is not as accurate as the MSR 255's, it has a gyroscope that make it more useful.

The size is much smaller than the other one as well as the mass, since it only weights a half of the previous one.

Figure 8. x-IMU

As well as the MSR 255's, this one incorporates a clock to control the battery's turn on and off for saving energy.

One significant advantage is the ability to transfer information wireless via Bluetooth. This means that the information collected might be seen on a screen in real time. One application, for example, is having a two-seater sailplane and while one is the pilot in command the other can read the data with a laptop or tablet. Furthermore, the information can be processed with common software.

The memory capacity can be changed and it uses a common SD card mode.

The price of the board is of £249, or £309 with the housing and battery.

8 Sensor attachment design

Due to the fact that the "Departament de Resistència dels Materials" from UPC of Terrassa already has the two types of sensors, there are two different types of skids designed, one for the x-IMU and another for the MSR255.

8.1 x-IMU design

8.1.1 Horizontal disposition

The current skids available in the market consist of a solid piece of metal attached to the wing by two screws and an adhesive. The skid attachment is taken into account during the wing design so two holes are made to hold the mentioned screws.

Figure 9. Common skid shape and length.

The screws prevent the skid to slide when colliding with the ground and the adhesive thwarts the piece to detach during airborne.

The skids' shape is a tear made with iron on the ground plan whereas on the top view plan, a hold is placed between the screws supposedly to save material and reduce weight.

The idea of the hold between the screws has been taken into account for the new design. It consists of holding the device in there. This way, the gadget is shielded against impacts and the material surrounds it preventing possible drops.

The distance between the two screw's holes must be the same so the room available for the device is limited. Only the x-IMU is small enough for being introduced in there. Moreover, this device has the sensors needed, an accelerometer and a gyroscope within others. The data can be collected wireless via Bluetooth and on top of that, it is the cheapest one.

The design itself protects the device against impacts. However, two curved protrusions in the screws area are put. The contact with the ground is located there.

The gadget is put inside the skid laterally and a cover must be put once in there. Despite of the fact the ideal cover would be a plastic one, there is not any that meet the measures needed available in the market. The alternative is putting a home-made metal cover fastened with two little screws[8], whose holds can be observed in figure X.

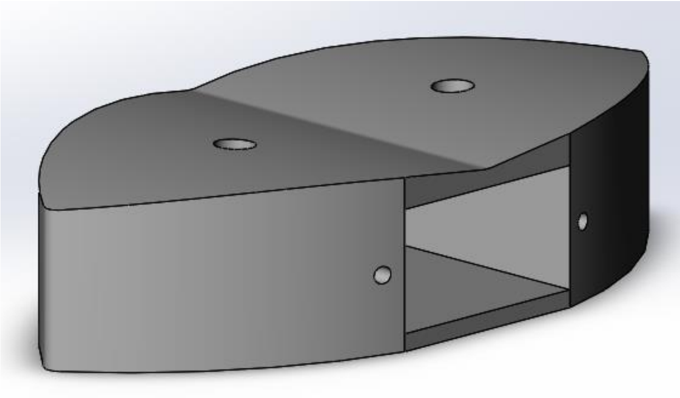


Figure 10. Dimetric view of the skid design

8.1.2 Vertical disposition

With the previous design, the skid would generate too much drag. That is why another option is to dispose the x-IMU vertically due to its better aerodynamics.

Taking into account the dimension of the gadget (57 x 38 x 21) and the separation between the screws' holes (50 mm), it is seen that it can be perfectly fixed there.

Basically, the main idea is the same of the other disposition. Nevertheless, the skid would be higher but quite less wide. It has the same protrusions to dissipate the possible impacts to the ground. The device is put inside by the upper part. This way, it is more protected against losses than the previous design. Moreover, a cover is also available to fix the gadget better and avoid vibrations as much as reachable by the skid.

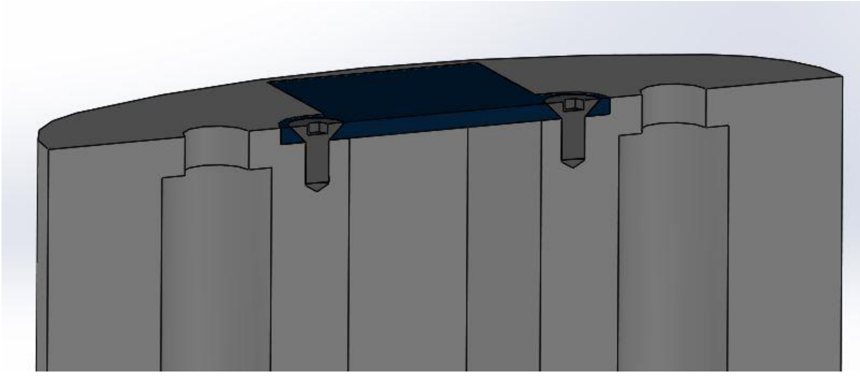


Figure 11. It is shown the upper part of the x-IMU's skid, its cover and its two screws. The fared holes are there to put the other screws that are attached on the wing.

The installation is described below:

1- Previously to the installation on the wing, the skid should be prepared for its purpose, allocating a device inside. Hence, the x-IMU should be put inside.
2- The hole for allocating the device is roofed by the cover.
3- At this point, two little countersink screws M-3 (s/DIN 7991) must be provided to ensure a good fasten of the cover.
4- Optionally, in order to have a more secure attachment to the wing, the upper part of the skid can be covered with impact adhesive. This adhesive avoid the skid to fall vertically once in airborne.
5- Finally, the skid must be fixed to the wing tip by two more screws. These ones are the same available for usual skids to ease the installation and avoid requiring specific ones.

In spite of its better aerodynamics performance, there is a drawback. In some cases the pilot loses the control or has to put a wing on the ground due to an emergency stop. If the wing on the ground is the one that holds the customized skid, it might be a problem. Its height generates a greater moment than the other design disposed horizontally, and it can break.

During a usual landing, it is advisable that the wing that touches the ground is the one that do not have the device in order to increase its working life and, especially, to avoid possible damage on the nuts for the skids' screws. Nevertheless, it is without saying that safety is always first and in an emergency landing or an emergency during the breaking it must be prioritized the pilot's and nearby people's safety.

8.2 MSR255 design

Having the two devices, future investigators could make the most profit of them. Remember that the x-IMU not only has an accelerometer but also a gyroscope where it is more interesting to put it in the CG of the plane to collect data from pitch, roll and yaw movements. Whereas, the MSR255, which only has an accelerometer but with more precision, should be attached on the wing tip or on the fuselage's empennage section.

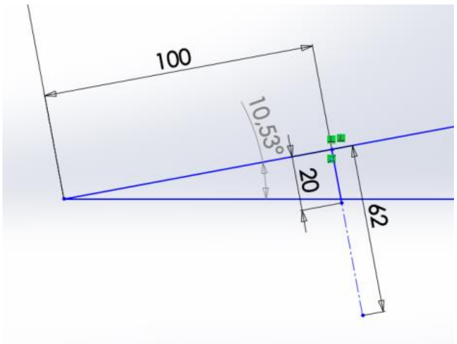


Figure 12. Approximated wing tip diagram

The angle of 10,53º showed on picture X is the angle that the wing would have with the ground if there were not any wing tip device. Notice that the skid already attached is about 20 mm high avoiding the wing to make contact to the ground. The device is about 62 mm high therefore, the skid is not enough. A skid of these characteristics would be too big and it is thought of a wing tip wheel as an alternative due to its larger height. The sensor is fixed to the wheel bench simplifying the installation itself.

Doing a market research and taking into account the size and the price, it has been thought of the '*Wing tip wheel short & sharp*'[9] from the on-line shop '*www.wingsandwheels.com*'. It has a size of 175 mm long, 75 mm wide and 65 mm height, the last size is the most suitable for the application and, furthermore, is one of the cheapest.

The problem with the wing tip wheel is the material that is made of, which usually is fibre glass and resin, what means that it cannot be drilled. In the case that it is made of plastic, another problem that could appear while attaching the MSR255 is that there would not be enough space to allocate the screws.

8.2.1 Wing tip attachment design

The idea is designing a new bench capable of surely attach the MSR255 and, at the same time, protect it avoiding the problems mentioned above this section.

As said before, a bench with specific characteristics for the larger sensor is not possible due to its friction to the air and weight. So, the skid design is declined. An alternative to solve the problem has to be thought.

It must be taken into account that the most suitable place to have the sensor protected against hits is on the extrados, which is the most fared site from the ground. Therefore, a clamp is thought to hold it. However, the wing tip shape is conical, with its imaginary vertex far away from the tip. This means that, if for some reason the clamp loosen in the air it will be impossible to fasten it again, meaning a loss of the system.

It is important to remember that one of the aims of this project is to prove the viability of the sensors by attaching them on specific sailplane's zones. Therefore, the designs should be as simple as possible in order to ease the manufacturing of the bench.

The next idea is based on the previous argument. Hence, a platform has been thought designed to be put on the extrados and fastened with ribbons. These ribbons must be held between the skid and the wing, making the most profit of the screws and having, this way, a point of solid union with the aircraft. Now, the problem of the equipment loss is avoided.

It is not necessary to put a plastic or metal-made supporting platform to hold the ribbons on the gap between the skid and the wing, but making holes on the ribbon having concern of the distance between screws would be viable. Then, it should be put a metal ring in each hole to protect the ribbon against rips. The junction is secured with the skid itself.

It is obvious that the wing's aerodynamics effectiveness will worsen. Nevertheless, it is installed on the wing tip where the aerodynamics is quite useless due to the fact that the LS1-d does not have a winglet.

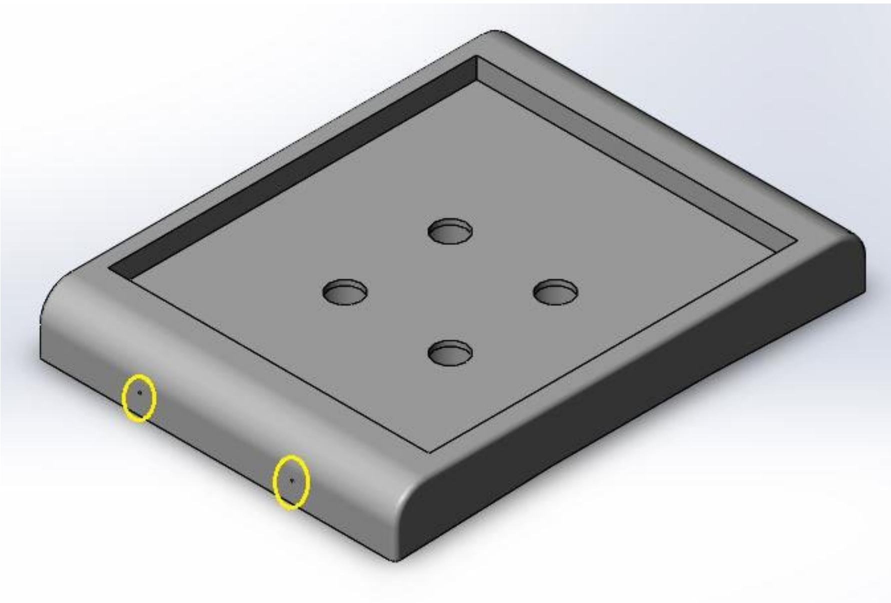


Figure 13. MSR255's attachment. It is thought to be put on the upper part of the wing tip.

First of all, looking at the bench itself, it is seen a big rectangular hole, this is made in order to perfectly allocate the MSR255. The sensor's dimensions are (78 x 62 x 38) mm, as the hole, having the larger dimension pointing on the direction of the aircraft.

Two identical metallic protrusions are put on the anterior and posterior part of the wing tip attachment (two small holes, in yellow, are in the images to allocate these items). These are for holding the ribbons and fasten the gadget. It is thought to have metallic holding rings in order to ensure a more resistant material, it would be very difficult to create a shape like in figure 14 in wood and it would be not enough to sustain the tension of the ribbons.

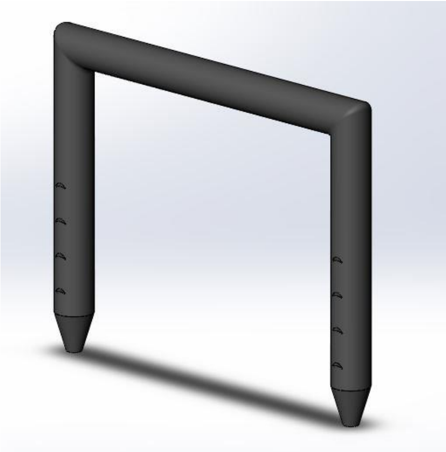


Figure 14. Ribbon ring

Another significant aspect is that it has a big radius circumference shape on the lower part. Its function is to allocate, in the best manner, to the upper part of the wing. Furthermore, to ensure a better grip and to compensate the wing tip's complex geometry, it will also include a glued layer of neoprene. The layer should be glued with a strong adhesive so that it is an immoveable part of the bench besides. It will also include four holes to allow the installation of the screws.

8.2.2 Fuselage attachment design

For the ease that offers the second idea proposed before (in section 'Ideas for the fuselage's attachment'), it will be designed.

Experimentally, it is determined that the perimeter of the aft fuselage, at the beginning of the empennage is about 560 mm. This means that:

$$Perimeter = 2\pi r => r = {}^{Per}/_{2\pi} = {}^{560}/_{2\pi} = 89.13mm$$

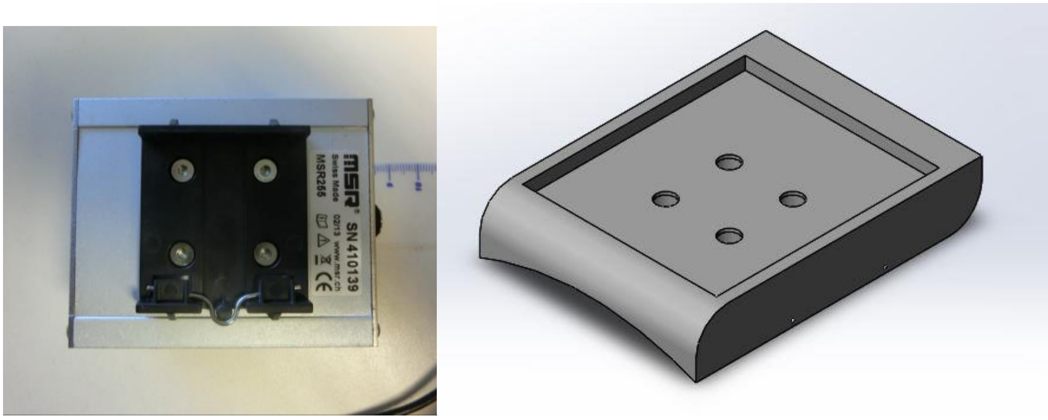


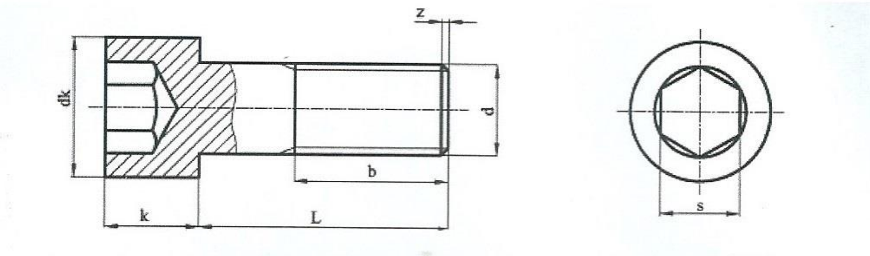
Figure 15. MSR255's bottom and its attachment. Here is where the screws fasten the device

So the fuselage attachment should have a curvature of this radius in order to adapt to the surface and the ribbon may have a length above 560mm to be able to adjust and to have the tension required.

In order to protect the paint of the glider and ensure a more secure attachment with the fuselage a piece of a material, which has a high friction coefficient, is put on the curve area of the bench. They could be neoprene, foam, etc. This will be joined with any kind of adhesive since the external coating is permanently united as well as the surrounding bench.

In the bottom of the MSR255 there are four holes to allocate screws, figure 15. It would be convenient to take profit of it. Thus, the design has these four holes as well.

The screws that the MSR255 incorporates are the 'DIN 912 M-5'. This means that the bottom part of them, where they are tighten by an Allen wrench, has a normalized size.[10]



d	M-3	M-4	M-5	M-6	M-8	M-10	M-12	M-14	M-16	M-18	M-20
z	0.50	0.70	0.80	1	1.25	1.5	1.75	2	2	2.5	2.5
b	18	20	22	24	28	32	36	40	44	48	52
dk	5.5	7	8.5	10	13	16	18	21	24	27	30
s	2.5	3	4	5	6	8	10	12	14	14	17
k	3	4	5	6	8	10	12	14	16	18	20

Figure 16. Cylindrical screw with inner hexagon (Allen type) s/DIN912

The screws used are M-5, which means that the threatened part has Ø5mm and so on with the other measures. 'k' is the height of the upper part and this must be taken into account while designing and building the bench due to the fact that the whole part must be inside the bench. Whereas the diameter of the threatened part, the smaller holes (see MSR255-attachment plain number 4) have one of Ø6mm in order to ease the installation.

9 Material for the benches

Firstly, the two basic types of designs have been separated according to their different requirements. Asbhy diagrams as well as some basic information of interesting materials for this application are included in Annex I obtained from the database 'CES EduPack'. Some properties that the materials selected must comply have been considered in order to ensure a good performance while flying. We have four different diagrams to be base; the 'Density-Hardness', the 'Density-Price', the 'Yield strength-Elongation' and the 'Embodied Energy-CO_2 foot print'.

9.1 Material for the X-IMU

The main characteristic of these benches are their allocation. In both cases (horizontal and vertical disposition) the attachment for the sensor is installed on the intrados (the inferior part of the wing) so the hardness is very important.

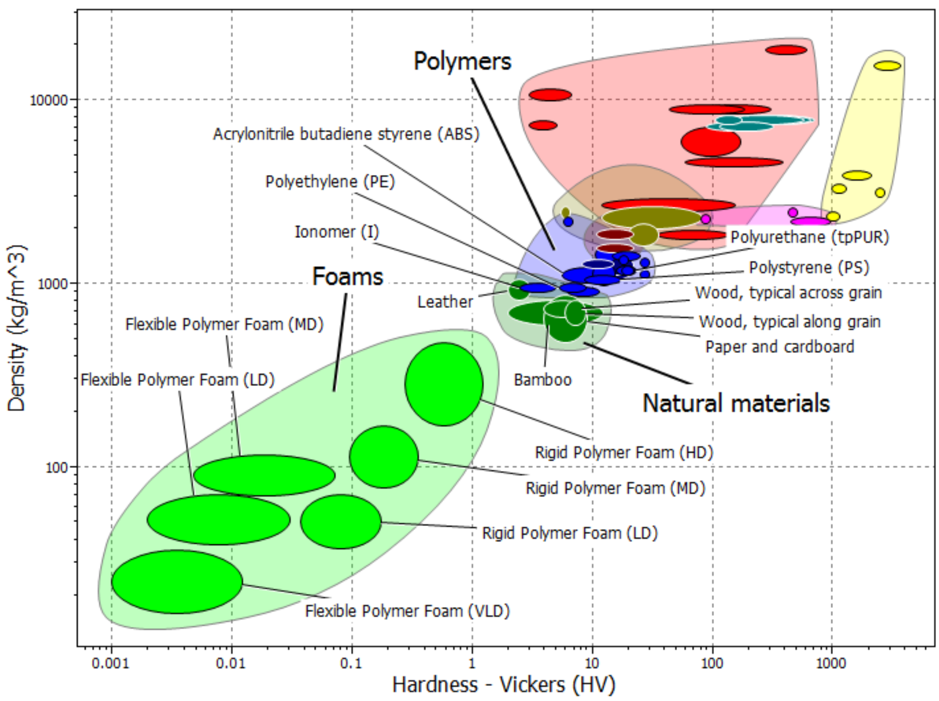


Figure 17. Asbhy plot (Density-Hardness)

On the first diagram, it can be observed that the best materials to comply the two characteristics are polymers, since their have a hardness is between 3 and 13 HV (Vickers). Besides, despite the fact that they have the highest density in comparison with other materials other materials in comparison, it is not too high for discarding it (1000 – 1100 kg/m^3). Taking into account the volume of the benches $87\,mm * 43\,mm * 64\,mm \simeq 2.4 \cdot 10^{-4}\,m^3 => V * \rho \left(1000\ {}^{kg}/_{m^3}\right) \simeq 240\,g$, a weight which is not too high.

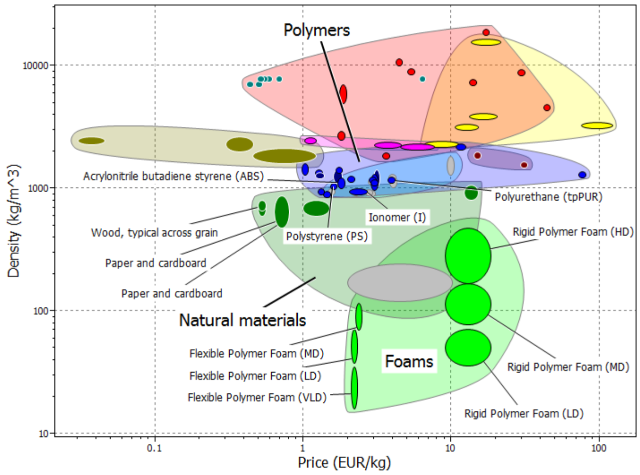


Figure 18. Asbhy plot (Density-Price)

Taking a look on the 'Density-Price diagram' it can be seen that the three types of materials compared have a similar price; therefore, it is not very useful.

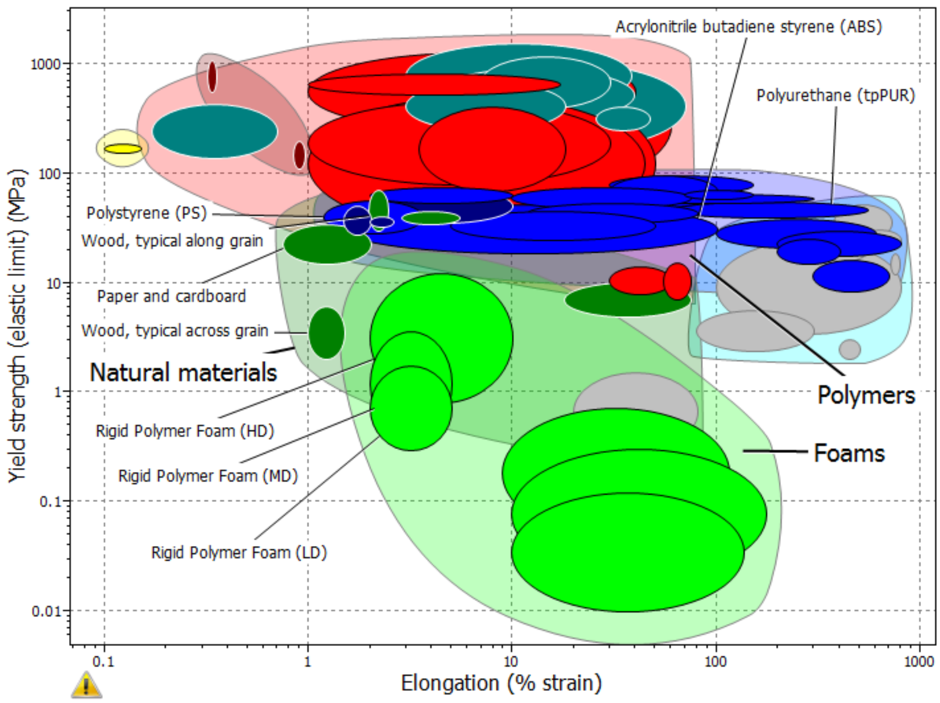


Figure 19. Asbhy plot (Density-Hardness)

On the third one, it can be noticed that depending on the polymer, the elongation is very small or large, but quite stable on the yield strength.

Nevertheless, on this type of benches, the yield strength is not so important as on other types. As a consequence, natural materials could be a suitable solution. In this case, however, the best materials are the Rigid Polymer Foams as seen on figure 19. The problem is that it is not good enough for other characteristics such as its high price.

Taking into account all the aspects mentioned above, it is clear that Polymers and Natural materials are the best candidates; let's see which of these types is the best choice.

For the Natural materials, the best option is wood along grain. However, for the polymers, there are there are different candidates for the polymers, Polystyrene (PS) and Acrylonitrile butadiene styrene (ABS).

The advantages of the PS are that it is easily molded and, by adding butadiene, it is possible to achieve a high impact variant. However, it cannot support a high mechanical load. Due to be a skid, it has to support hits to the ground. Hence, this option is discarded.

The ABS, however, has the highest impact resistance of all polymers. Furthermore, it is possible to integrate metals inside, which is good for the MSR255 benches that have the metal ribbons ring incorporated. It is also UV resistance, ideal for outdoor applications, even if it needs a protective coating against sunlight. Manufacturing could be either by extrusion or molding.

Between the wood and the ABS, the best option is the last one due to its high performances and the fact that the wood has the problem of shatter. It could not be a problem for the MSR255 benches but it could be a problem for the x-IMU.

9.2 Material for the MSR255

Due to the fact that the specifications of the MSR255 are more or less the same of the x-IMU, the material choice would be the same.

Nevertheless, since the application of the benches is providing the viability of the sensors, it makes no sense to have producing only a few benches with ABS. This would involve a very high sum of money that can be avoided using wood. Moreover, the x-IMU model will not be produced and we do not have the shatter problem with the other sensor bench, which is installed above the wing.

10 Environment analysis

In the event of using ABS, it must be considered to use virgin or recycled ABS. Naturally, the second one is the cheapest one but, does its properties maintain during the recycling process?

The most common recycling process when different objects arrive to a factory is the previous separation of different materials and plastics, since each one has a different recycling method. Then, it passes through a magnetic field to repel the metallic impurities. On this step the ABS is shredded and, the flakes are ready, they are put on a water suspension tank to separate the different types of plastic from its density. After that, they are washed and air-dried. Now, the recycled ABS pellets are ready. Then, the final step is to put it on an extruder or injector to obtain the new product, since the ABS is a thermoplastic that melts when heated.

On the manufacturing of the new product, the ABS made from, is a mix within virgin and recycled ABS so the properties are not loosen too much.[11]

One study[12] by the University of Bordeaux and the Univesity of Mondragón states that the material properties are not affected after a recycling process. Furthermore, it concludes that the recycling process enable the polymer to recover from the impact strength after some time in use. Hence, all the statements mentioned before justify the use of recycled ABS.

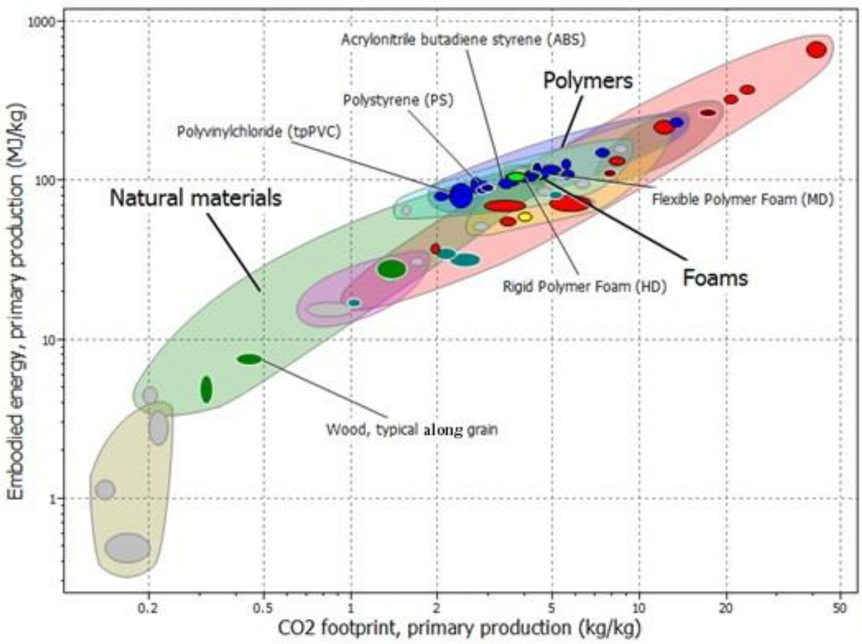


Figure 20. Asbhy plot (Embodied energy–CO_2 footprint)

Despite the advantageous recycling process that the ABS has, it consumes too much CO_2 on its production. As seen in figure 20 it has CO_2 footprint of 3,5 kg/kg, which is far more than wood a natural component. The same happens with the embodied energy that refers to the total energy consumption in MJ that has enrolled 1 kg of the material in study, in this case the ABS.

It is obvious that the natural material is far more eco-friendly than a polymer and this is one more reason to choose it.

The CO_2 footprint and embodied energy for the products are described in the following table:

First of all, it is better to have the weights of each bench and material:

Bench	**m³**	**Wood** [kg]	**ABS** [kg]
x-IMU (vertical)	$1,2 \cdot 10^{-4}$	0,08	0,12
x-IMU (horizontal)	$0,7 \cdot 10^{-4}$	0,05	0,07
MSR255 (fuselage)	$2,4 \cdot 10^{-4}$	0,17	0,24
MSR255 (wing tip)	$2,8 \cdot 10^{-4}$	0,19	0,28

Table 4. Weights of each bench and material

	Wood 0,4 kg CO_2/kg and 10MJ/kg		**ABS** 3,5 kg CO_2/kg and 100MJ/kg	
Bench	**CO_2 footprint** [kg of CO_2]	**Embodied energy** [MJ]	**CO_2 footprint** [kg of CO_2]	**Embodied energy** [MJ]
x-IMU (vertical)	0,03	0,8	0,42	12
x-IMU (horizontal)	0,02	0,5	0,25	7
MSR255 (fuselage)	0,07	1,7	0,84	24
MSR255 (wing tip)	0,08	1,9	0,98	28

Table 5. Ecological analysis of the materials

11 Ribbon's selection

As said in previous sections, ribbons will be used to fasten all the system to the wing tip. In order to avoid the use of metallic rings which can damage the wing and fuselage's surface, a buckle will be used to secure the installation.

It is obvious that not all the ribbons available in the market may have the appropriate properties for the specific use of it in this project. Therefore, it was thought that the best candidates would be climbing ribbons.

As a specific requirement, they have to support at least, a person's average weight (which is 70kg or 687N in Spain). This force should be enough for this kind of ribbons and also for the application in this project.

Anillo Poliamida Rock Empire[13]		
 **Figure 21**	Weight	25 g (equivalent 80,7 g/m)
	Wide	16 mm
	Length	310 mm
	Material	Polyamide
	Resistance	22 kN
	Directive	CE 1019 EN566
	Price	2,85 € (equivalent 9,19 €/m)

Table 6. Rock Empire's general aspects

Korda's Dana 10 Cañones[14]		
 **Figure 22**	Weight	63,1 g/m
	Wide	10 mm
	Length	As required
	Material	Polyamide
	Resistance	27 kN
	Directive	CE EN 1891
	Price	2,46 €/m

Table 7. Korda's Dana's general aspects

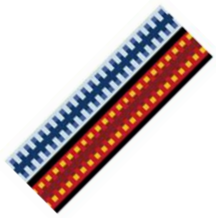
Roca Cinta plana 25 mm[15]		
	Weight	41g/m
	Wide	25 mm
	Length	As required
	Material	-
	Resistance	16 kN
Figure 23	Directive	CE EN 565 / UIAA
	Price	2,30 €/m

Table 8. Roca Cinta's general aspects

After seeing the three comparison tables, it is clear that they have very competitive prices. However, the 'Anillo Poliamida Rock Empire' can be discarded due to its limited length of 310mm, since it may not be enough to surround the wing with a knot.

It may look like the best alternative is the 'Korda's Dana 10 Cañones' due to the fact that is the narrowest one and taking into account the type of knot used to fasten everything. Nevertheless, it must be considered that it will be perforated in order to allow the screws to pass through it. The screw's hole should be, at least of Ø6mm and the ribbon has a width of 10mm. Hence, it would be a weak point.

Considering the resistance of all three ribbons, it can be seen that they have very large values for this application and therefore, it is not an important value to consider. For all the arguments explained before, the ribbon chosen is 'Roca Cinta plana 25 mm' due to its width and low price. The buckle must have the same width than the ribbon.[16]

Figure 24. Buckle type that would be used in the project.

12 Prototype manufacturing

After taking into account all the ideas and designs above, a first prototype has been made in order to see, in forward steps after this project, whether it is reliable and accomplish with all the requirements or not.

The most interesting part of the aircraft to analyze is the wing tip. This is why the prototype is based on the Wing tip attachment design.

The most suitable material to commence with the construction is wood due to its easy machining and its availability. The fabrication of it is described below in bullet points:

1- First of all, it is necessary to have the main material, which is wood. Moreover, to ease the process, it is better to obtain a strip with similar bench's size, at least in one dimension. Then, a rectangle should be cut off with one or two millimeters more from the real size of the piece.

Figure 25. Cutting off of the main piece from a wood strip

2- Once the basic element is made, it is time to begin with one of the largest parts, the big rectangular hole in the middle of the piece. It is highly recommended to draw the floor plan on it with a pencil, so that it can serve as a guide.

Figure 26. Tools used to do the main rectangular hole

3- The hole should be made carefully with any kind of tool available. In this case, a chisel and a motorized high velocity tool was used; in particular, a Dremel® one. This process should last until a plain hole of 4mm deep is achieved, as specified.
4- Now, it is time to shape the large curvature lower part with a rasp. This is the zone where the wing and the bench will have contact.
5- Due to the possibility of having a shattered surface because of the continuously machinery or because of the poor stage of the strip, the whole piece should be filed with a rasp, glass paper and a polish. In this phase, the main square hole should be as plain as possible and the exterior roundings should be shaped.
6- In this stage the four holes that fasten the MSR255 must be made, taking into account that there are two different diameter circumferences in each hole. Once again, by drawing the floor plain on the sample, their position is localised and with a drill the bigger one is made in the first place. This is a critical point of the whole process due to the fact that if there is an overdrilled hole, the prototype will be useless. The big hole must have 5mm deep to allocate the screws. Then, it is the time to make the smaller ones.

Figure 27. Drilling of the first big hole.

7- Here, the ribbon rings must be made. They have been made with a Ø3mm steel wire. A bench and a hammer have been used to shape it. Pointed endings should also be made to ease the assembly. Furthermore, some fissures should be added to ensure a good subjection of the iron with the wood. That way, the wood should be broken to remove the rings and no adhesive would be needed..

Figure 28. Shaping of one of the ribbon ring

8- In the main piece, two small holes should be marked to indicate where to put the ribbon rings.
9- The rings should be introduced on the piece with a hammer, until the external measure is achieved.
10- Finally, a similar colour of the aircraft (white) is used for painting the sample, with the exception of the lower part, where there will be an adhesive.

Figure 29. Painting of the bench

11-Once glued the curveted zone, the external coating should be put and the screw's holes should be made on it.

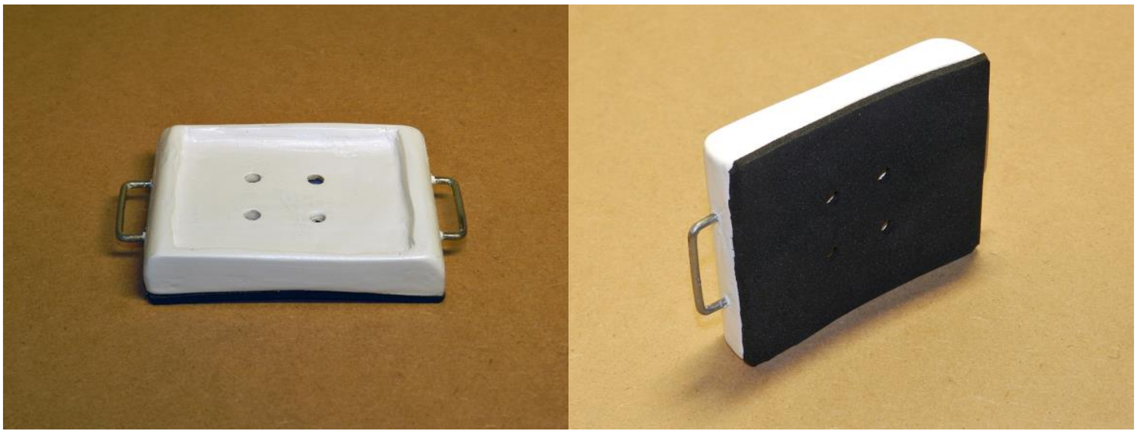


Figure 30. Bench prototype

The final result is a resistance piece of wood, with little parts of metal, capable of being on the extrados to hold firmly the MSR255 by fastening it with 25 mm ribbons.

13 Security

The security followed while doing the project is focused on the manufacturing of the prototype.

In the first steps of cutting, as well as during the of polishing process, it was used a mask to breath normally.

Also, during the cutting steps, the hand holding the piece was as far away as possible from the cutting line but near enough to hold the piece firmly.

Security is very important since it is attached on a wing, the main part of a plane. However, if all the steps of the Scope Statement document are followed, the installer and manager will not have any problem.

14 Next steps

In further steps, the prototype should be installed on the wing by following the points described in the document Scope Statements.

Then, it would be time to prove the attachment in flight but, without any attachment or gadget on it. This would prove the stability of the bench.

The next step, lies on the test of holding. To do so, a piece of any material but with the same external dimensions and similar weight of the MSR255 would be attached to the bench. Then, it would be time to fly it on the sailplane wing.

After the approval of the previous step, it would be time to do the same but with the MSR255 sensor. The first data would be collected and analysed.

Moreover, if the sensors demonstrate that they collect data with a determined accuracy, another project should be begun. This one would be in charge to design new benches to only hold the accelerometer and gyroscope chip. This new benches should be attached permanently to the sailplane and should be littler than the designed in this project.

15 Economic analysis

As part of the project, an economic analysis has been done to specify which would be the price to pay by the client to the engineer. Overall, the final price of the project is of €8.655,61.

First of all, the budget has been divided into three different groups. One is in charge of pointing the quantity and the price of each raw material and tools used to manufacture the prototype and the price of the visit to 'Club de Vol a Vela Igualada – Òdena'[17]. A second table is made for the hours expended in the project by the engineer in charge, the cost of each hour and the type of hour it is. Finally, the last table reflects the transport fees during the realization of the current assignment.

The first table makes reference to the materials used to make the wing tip prototype. In this case, the tools rent have a price of €0 since the engineer already owned them.

On the second table, there are different subparts described accurately below:

- Previous engineering is related to the hours spent on the start-up period. For instance, the collection of data or the meetings with sailplane's experts to figure out which would be the possible problems during the realization of the project.
- The brainstorming is the time spent in analysing the ideas thought by this technique.
- The transport time is related to the commuting to the airfield from Les Borges Blanques (Lleida) to Òdena (Barcelona).
- The airfield's visit was made in two different days because of bad weather during the first time.
- Obviously, the designing process, which includes the two types of sensors, is the part of the project that requires the majority of the time due to its workload.
- The realization of the prototype was held during two days. It began from the first wood cut to the installation of the friction coating. This part of the project was held by the engineer and a worker.
- Finally, the closure of the project is related to the final composition of the project itself.

The last part, referring to the transport fees, basically considers the gas consumption in euros. It is based on a database of the last gas prices of 'Gasolina 95 Protección' on Les Borges's gas stations[18]. An average has been done due to the fact that the fuel tank was filled on different days and stations.

16 Conclusions

During the realization of the project, there were sought different options. Until their realization, the engineer could not realize which were the real problems of the design. That is why there are two main benches, the ones in charge to hold the x-IMU and the ones to hold the MSR255.

Firstly, it was thought that the best sensor to have outside the plane was the x-IMU, due to its polyvalent and reduced size and weight, in comparison to the other sensor. However, due to the fact that there are only two types of sensors available, it was said that the x-IMU, which incorporate a gyroscope, is better to put it as near of the CG as possible. Moreover, its design has the drawback of being below the wing, a place that is not the safest one for having a sensor.

Therefore, a new design was thought to hold the MSR255, which is more accurate. Nevertheless, this sensor is quite big and a design below the wing was unviable. The alternative was to put it above the wing fastened with a ribbon. This new design was very suitable because of its adaptable surface, which permits to adjust to different types of airfoils, and its secure system with the bench's screws.

Due to the design of the sensors, there was not necessary to introduce any external memory to collect the data from the flight. This fact eases the design and the installation of the benches.

Since the benches will only be used as a guide to prove the viability of further projects using this type of accelerometers and gyroscopes, they may seem quite big. However, this project was the previous stages of others more specific so, the benches must be lightweight and adaptable to different surfaces.

17 Bibliography

1. Glyding Flying Book, Federal Aviation Administration [pages 5 –36] (2013).

2. El Vuelo a Vela [online] at <http://ocw.unizar.es/ciencias-de-la-salud-1/actividades-fisicas-y-deportivas-aereas/TemaVueloVela.pdf> [seen the 24-02-2015]

3. Gmbh, R. F. & Gmbh, R. F. *Flight Manual LS1-d Flight Manual for the Sailplane LS1-d Edition: 01 Jan ., 2003*. **49,** (2003).

4. Soportes GoPro para tablas de surf [online] at <http://es.shop.gopro.com/EMEA/mounts/surfboard-mounts/ASURF-001.html#/start=1> [seen the 04-03-2015]

5. Ventosa GoPro [online] at <http://es.shop.gopro.com/EMEA/mounts/suction-cup/AUCMT-302.html#/start=1> [seen the 04-03-2015]

6. Setup, F. *MSR 255 Data Logger Robust multi-talent with LCD screen*.

7. Madgwick, S. *x-IMU User Manual 5.2*. (2013).

8. Tornillo hexagonal de rosca métrica DIN 933 - 8.8 [online] at <http://ingemecanica.com/tutoriales/objetos/tornillos/tor005.jpg> [seen the 12-04-2015]

9. Wing Tip Wheel Short & Sharp [online] at <http://wingsandwheels.com/tip-wheel-short-and-sharp.html> [seen the 06-04-2015]

10. Hernández Abad, F., Hernández Abad, V., Ochoa Vives, M. & Font Andreu, J. *Ingeniería Gráfica, Introducción a la Normalización*. (Universitat Politècnica de Catalunya, 2008) 3rd ed. ISBN: 85-609-4659-2

11. ABS Recycling [online] at <http://polymerwastemanagement.blogspot.com.es/2007/11/abs-recycling.html> [seen the 26-05-2015]

12. Recycling Study of End of Life Products Made of ABS Resin [online] at <http://www.jmst.org/fileup/PDF/20s125.pdf> [seen the 26-05-2015]

13. Anillo poliamida Rock Empire (16mm x 30cm) [online] at <http://www.blackisard.com/shop/index.php?route=product/product&product_id=1463> [seen the 20-05-2015]

14. Korda's Dana 10 Cañones Naranja por metros [online] at <http://www.barrabes.com/kordas-dana-10-ca%C3%B1ones-naranja-metros/p-24483?idvariedad=94806&opt=d> [seen the 20-05-2015]

15. Roca Cinta plana 25 mm [online] at <http://www.barrabes.com/roca-cinta-plana-25-mm-metros/p-6460?idvariedad=18192&opt=d> [seen the 20-05-2015]

16. Cuero y Calzado.com [online] at <http://cueroycalzado.com/tienda/product_info.php?cPath=104&products_id=1164&osCsid=a8de4e53f69dfdcbc8638fe7ddae2091> [seen the 26-05-2015]

17. Tarifas | Club de Vol a Vela d'Igualada-Òdena [online] at <http://www.volavela.com/es/tarifas> [seen the 20-05-2015]

18. Gasolineras en Les Borges Blanques [online] at <http://www.elpreciodelagasolina.com/gasolineras/les_borges_blanques:41224> [seen the 20-05-2015]