INSTITUTO SUPERIOR TÉCNICO
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Manufacturing of a Joined-Wing Sensorcraft

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Jury:

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Resumo

Desde que os UAVs começaram a sulcar os céus, evoluíram substancialmente até ao ponto de serem uma grande ajuda para várias tarefas. Este facto, estreito à invenção e evolução dos materiais compósitos, permite a criação de aeronaves cada vez mais leves e resistentes.

Através do conceito Joined Wing e dos materiais compósitos criou-se um UAV com capacidades de realizar tarefas de radar. Para se fazer o estudo de uma aeronave é feita uma modelo à escala 1/9, para se estudar o seu comportamento e mais tarde para se extrapolarem os resultados para a aeronave real.

Para se produzir esta aeronave foi criado o programa Catia. A partir deste ficheiro foram criados os moldes necessários para a construção do exterior da fuselagem e para a entrada e saída de ar. Para além dos moldes, as anteparas da fuselagem são feitas usando o processo de impregnação e o processo VARTM, consistindo de um processo a vácuo. A tarefa mais complexa da montagem é a junção das anteparas com o exterior.

Além da fuselagem, são construídas as asas, a cauda, o trem de aterragem e outros elementos necessários às aeronaves. A tarefa final da montagem consiste na incorporação de componentes electrónicos e, por último, os testes de voo.

Palavras-Chave: Compósitos, Joined-Wing, Fabricação, SensorCraft, UAV.

Abstract

Since the UAVs began furrowing the skies, they have evolved substantially up to the point of being a great help for varied tasks. This fact close to the invention and evolution of the composites materials allow realizing increasingly light and resistant aircrafts.

Using the Joined Wing concept and the composite materials is realized one UAV capable of doing tasks of radar. To do a study of the aircraft is done a 1/9 scale model to study its behaviour and later to extrapolate the results to the real aircraft.

To realize this aircraft is arranged a Catia program design. From this file is realized the moulds necessary for the construction of the skin of the fuselage and of the air inlets and outlets. Besides the moulds, the bulkheads of the fuselage are realized using the impregnation process and the VARTM process, consisting in a vacuum process. The more complex task of the assembly is the joint of the bulkheads and the joint of the bulkheads with the skin.

Beside the fuselage, are built the wings, the tail boom, the landing gear and other elements necessary to the aircrafts. The final task of the assembly consists on the incorporation of the electronics components and finally the flight tests.

Keywords: Composite, Joined-Wing, Manufacture, SensorCraft, UAV.

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Acronyms

CNC – *Computer Numerically Controlled*

HALE – *High-Altitude Long-Endurance*

IST – *Instituto Superior Técnico*

PU foam – *Polyurethane foam*

RPV – *Remote Piloted Vehicle*

UAV – *Unmanned Air Vehicle (or Unmanned Aerial Vehicle)*

UCAV – *Unmaned Combat Air Vehicle (or Unmanned Combat Aerial Vehicle)*

VARTM – *Vacuum Assisted Resin Transfer Moulding*

Chapter 1

Introduction

1.1 UAV

An Unmanned Aerial Vehicle, UAV, is an aircraft that doesn't require the presence of a pilot on-board. It can be remotely controlled by a pilot on a ground site or autonomously according to pre-programmed flight plans. Since there is always a need to have a ground station and other systems besides the aircraft, the Federal Aviation Administration has adopted the more generic term of Unmanned Aircraft System, UAS.

UAVs are used in a number of military roles including reconnaissance, providing real-time battlefield intelligence, logistics and attack. This last task is performed by a UAV designed specifically for combat missions, the Unmanned Combat Air Vehicle, UCAV. They are also used in "target and decoy" missions where they provide ground and aerial gunnery a practice target that simulates an enemy aircraft or missile.

Although the main role of UAVs has been played with the military, there have been a growing number of civil applications, mostly in logistics and surveillance [1]. These range from tracking seals displaced by melting Arctic ice to monitoring evacuation routes in the paths of hurricanes. UAVs are also being used in observation by the police in civil disturbances and crime scenes.

The first UAV was designed by Archibald M. Low in 1916 during World War I [2]. The "Aerial Target" was a remotely operated drone plane built to deliver explosives behind enemy lines. Design improvements were made during World War II, including the use of jet powered guided missiles, like the German V-1 used during the blitz attacks to England and Belgium. The technology was improved and put to use in UAVs such as the Teledyne Ryan Firebee of 1951 (see Figure 1.1).

Figure 1.1: Teledyne Ryan BQM – 34A Firebee.

Although there were some improvements in UAV technology they were little more than remotely controlled airplanes during the years after World War II. Significant changes in UAVs only emerged during the 1980s and 1990s with the maturing and miniaturization of applicable technologies. Interest by the military in UAVs grew stronger since they were a cheaper and more suitable alternative to regular aircrafts in certain missions, without risking aircrews. UAVs such as the multi-role General Atomics Aeronautical Systems MQ-1 Predator [3] (see Figure 1.2) were put in the battle field to provide reconnaissance but were later fitted with weaponry to neutralize enemy units that they might encounter, thus becoming the first UCAVs.

Figure 1.2: General Atomics Aeronautical Systems MQ-1 Predator armed with AGM-114 Heelfire missiles.

Nowadays, high-altitude long-endurance, HALE, surveillance is provided by UAVs equipped with the latest technology in avionics and sensors like the RQ-4 Global Hawk (see Figure 1.3), which was first put to use in the War in Afghanistan in 2001. The Global Hawk can cruise at 650 km/h at 65000 feet for 36 hours, making this aircraft a necessary addition to the growing need for real-time intelligence in war situations.

Figure 1.3: Northrop Grumman RQ-4 Global Hawk.

Even now, new UAV concepts are emerging taking advantage of the most recent advances in aerospace technology such as stealth [4]. One example of such an aircraft is the Boeing X-45A UCAV technology demonstrator [5]. This aircraft is manufactured by Boeing Integrated Defence Systems and is part of the Defence Advanced Research Projects Agency's Joint-Unmanned Combat Air Systems project.

Among the new generation of UAVs one can also find European UCAV projects like the EADS Barracuda [6] and the Dassault nEUROn [7], both of which employ the latest technologies in stealth, avionics and light-weight materials.

Another concept that has recently been put to use in UAVs is the joined-wing configuration.

1.2 The Joined Wing

The joined-wing is an innovative aircraft configuration with a rear wing that has its root attached near the top of the vertical tail and a tip that sweeps forward to join the trailing edge of the main wing, as seen Figure 1.4. The rear wing is both used for pitch control and as a structural support for the forward wing [8].

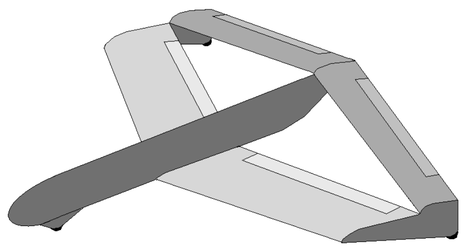


Figure 1.4: Example of a joined-wing aircraft.

Wolkovitch patented the first joined-wing design in 1976 [9], claiming that the aircraft would have a lighter yet stiffer structure when compared with a conventional wing-tail configuration. This claim was later confirmed by Samuels in 1982 [10]. By 1986, Wolkovitch extended the list of advantages of a joined-wing aircraft. Joining the tail to the wing allows the tail to act as a strut, relieving wing bending moment inboard of the wing-tail joint. Another important feature is the reduction of induced drag due to the use of non-planar lifting surfaces. The use of two lifting surfaces has a significant advantage in flight control redundancy since control surfaces are doubled, while enabling the use of certain agile flight manoeuvres like rapid pitch-up motion and moving sideways without rolling, as seen in Figure 1.5.

Kroo developed a rapid method for evaluating structural and aerodynamic characteristics of a joined-wing aircraft to study the fundamental advantages attributed to this aircraft concept [11]. The technique involves a rapid aerodynamic analysis using LinAir, a vortex lattice prediction method developed by Kroo, and a simple structural optimization.

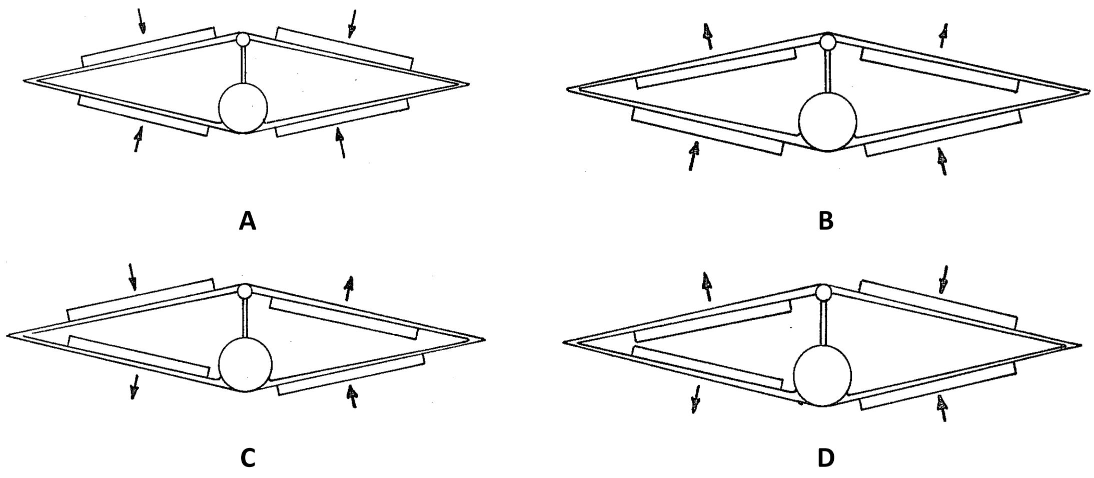


Figure 1.5: Joined Wing Control

A - Pitch Control; B - Direct Lift Control; C - Roll Control; D - Direct Side Force Control.

Several configurations were studied, varying the span ratio of the front and rear wings and the distance of the rear wing to the centre of gravity. Different structural alternatives were also studied, choosing the shape of the spars from symmetrical and asymmetrical box beams. The results were compared to a medium-range transport aircraft with T-tail and aft-mounted engines. The results suggested that joined wings with the inboard joint location at 60-75% of the span, with both surfaces of similar aspects ratios, were optimal for the design conditions. The use of asymmetric material distribution in the spar is important to fully exploit the potential of the joined-wing concept, leading to a substantial reduction in cruise drag at fixed structural weight. For symmetrical spar designs, a wing layout with a greater chordwise extent of the structural box would further reduce drag at fixed weight. The best lifting systems achieved drag reductions at fixed weight of 5% with symmetrical spars and 11% with asymmetrical spars.

Gallman studied the possibility of optimizing a joined-wing aircraft to be used as a medium range transport aircraft. Maximum lift and horizontal tail buckling were identified as critical joined-wing design issues. They found that due to this buckling constraint which could only be surpassed by rendering the structure heavier, operating such an aircraft would be around 3% more expensive when compared to a Boeing 727.

Rasmussen introduced the concept of a joined-wing Sensorcraft as a response to the United States Air Force need for a new generation of UAVs that could perform advanced, long-endurance tactical surveillance using current and future sensor packages. This UAV is still in its early stage of development but the authors claim that the joined-wing configuration might have improved radar capabilities, increased aerodynamic performance and structural weight savings.

Major Vanessa Bond made an extensive study on aero elastic behaviour of this aircraft and was intended to determine the nonlinear response of an aeroelastically scaled model and to prove that exible wing twist could be used to control the pitching motion of the aircraft.

Wind tunnel testing was performed to evaluate the influence of different configurations for the incidence angle of the rear wing: +15º, 0º and -15º.

1.3 The Sensorcraft

The aircraft design usually starts with the airframe and then the sensors are chosen to integrate within its constraints. In the Sensorcraft [12] the opposite happens: the sensors are firstly chosen according to the project purposes and an optimum mix and only after that the vehicle design is moulded around the systems.

Sensorcraft [12] is a concept aircraft initiated by the Air Force Research Laboratory to inspire innovation and technology that addresses the United States most pressing military capability gaps.

This project has the objective of creating a completely new design that could address all the sensing capability that the United States Air Force (USAF) currently have. The Sensorcraft capability requirement for a high-altitude long-endurance (HALE) unmanned air vehicle capable of providing greatly enhanced coverage with radar and other sensors, 30-hour endurance, 3000Nm range to in the end replace the Airborne Warning and Control System (AWACS).

A series of contracts over 4 years, were conduced between USAF and the United States' largest airframes, Northrop Grumman, Lockheed Martin and Boeing, and they produced preliminary design details for 6 different aircrafts. An ambitious plan was proposed to the airframes that demanded them new challenges: they have to reach a very high endurance time; achieve an outstanding aerodynamic performance; providing great payload capacity; power and cooling, to support a next-generation intelligence, surveillance and reconnaissance (ISR) sensor suite. In most of the goals proposed the airframes have to go beyond the actual engineering capabilities, research in new fields became a necessity to meet project considerations. The evolution of nonlinear aeroservoelastic, non-linear aeroelasticity, new structural and sensors technology are some of the examples of the technologies that have to be developed.

1.4 Boeing Joined-Wing Sensorcraft

The work developed in this thesis is related to the *Joined Wing* concept. The main goal in the Joined Wing Sensorcraft project, as in any other aircraft project, is to build an airplane that flies safely. However, despite of joined wing configuration be a 30 years old concept, it still has not been much developed. Some studies have already been performed in order to design the aircraft. One of the objectives of this thesis is to manufacture the Joined Wing Sensorcraft (see Figure 1.6) as it has been designed.

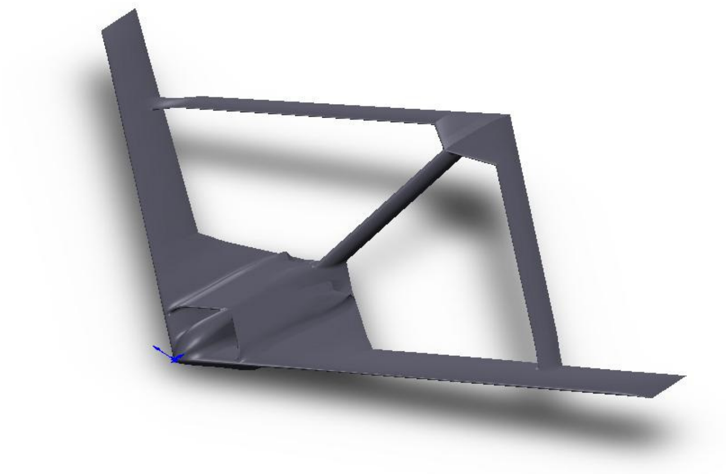
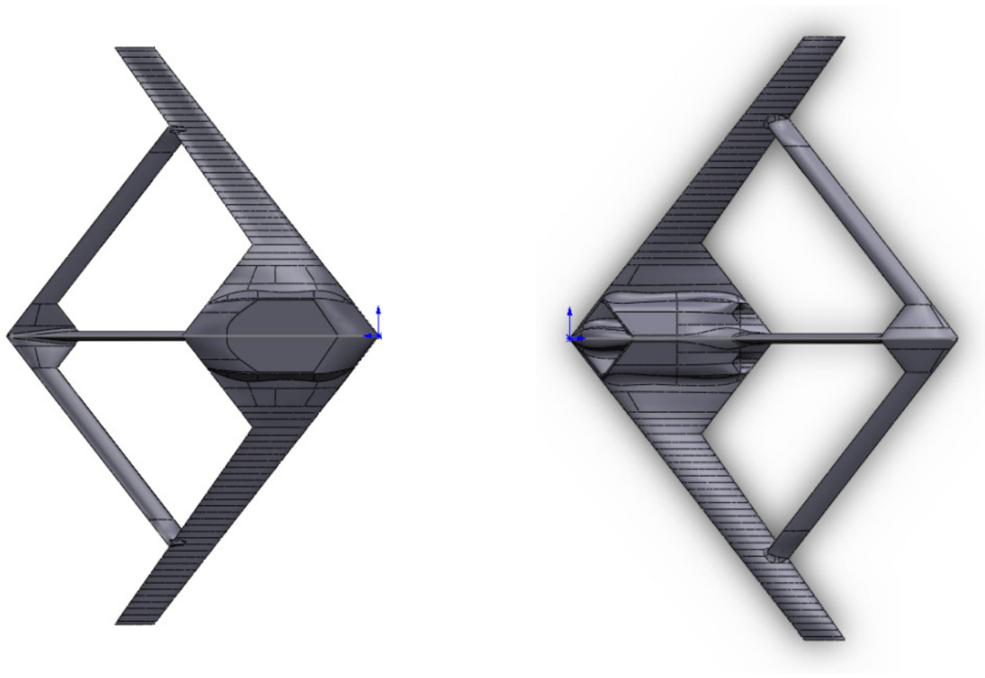


Figure 1.6: Joined Wing Sensorcraft.

In Figure 1.7 and Figure 1.8, one can see different views of Boeing Joined Wing. It is a 5m span model that has been scaled to have 1/9 of the full scale. The goal is to build the fuselage, wings (front and rear) and boom and assembly all the parts.



(a) (b)

(c)

(d)

(e)

Figure 1.7: View Joined Wing Sensorcraft: (a) bottom view, (b) top view, (c) side view, (d) front view; (e) rear view.

1.5 Thesis layout

This thesis starts in the first chapter with an introduction to the UAV's, the Joined Wing Concept and to Sensorcraft, which gives the reader a general overview to these themes. The second chapter is presented the composite sizing of the Joined components. In Chapter 3 one can see the procedure which the mould has been built. The Chapter 4 introduces the reader into the composites worlds and explains with detail all the steps which the fuselage, the rear wing and the tail-boom of the Joined Wing have been constructed. At the last Chapter are presented the future work on the Joined Wing Sensorcraft Project and the conclusions of this work.

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Chapter 2

Composite material sizing

The Joined Wing must be capable of resist the loads that suffers during its manoeuvres to not break in flight. To ensure the resistance of each component has been performed a finite element analysis using Ansys – see Figure 2.1.

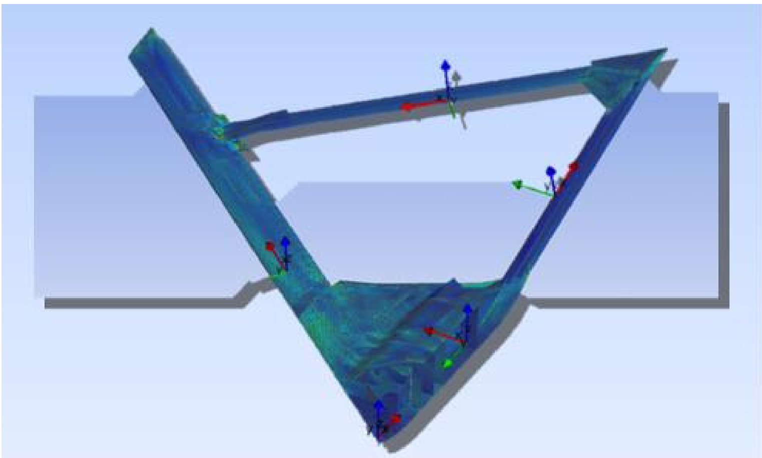

Figure 2.1: Finite element Ansys analysis.

For this analysis [13] have been sized the composite materials that are used in each component of the aircraft: Fuselage, rear wing, forward wing and tail boom.

The materials used to realize each component are: sheets of plain weave carbon of 5.7 oz., sheets of uni-directional carbon of 5.7 oz., epoxy resin and Divinicell core material.

A common piece in all the components is the bulkheads and there are two types of bulkheads: the thin and the thick. The thin bulkheads are made by a 6.4 mm. Divinicell core coated by a sheet of plain oriented at 45º and the thick bulkheads are made by a 12.7 Divinicell core coated by a sheet of plain weave carbon oriented at 45º.

To make the fuselage (see Figure 2.2) are used both bulkheads: thin bulkheads (yellow bulkheads) and thick bulkheads (grey bulkheads). Both above and below the bulkheads that are joint at the forward wing are coated with three layers of uni-carbon oriented at 0º to a better transmission between the bulkheads. To make both upper and bottom skin is used first a layer of plain weave carbon oriented at 0º and then four layers oriented at 45º to give to the skin the same properties in all directions (isotropy).

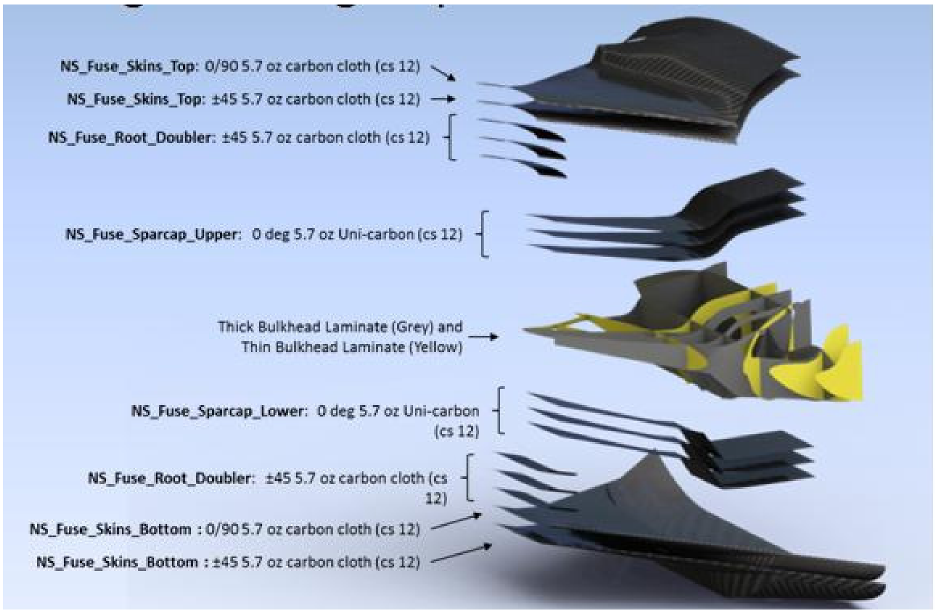

Figure 2.2: Fuselage stacking sequence.

To the forward wing (see Figure 2.3) is used both thin and thick bulkheads coated symmetrically. First the bulkheads are coated by three layers of plain weave carbon oriented at 45º angle to give to the wing isotropy then is all covered by four layers of uni-carbon for a better transmission of the efforts along the wing and finally all is covered by two layers of plain weave carbon oriented 45º to give isotropy.

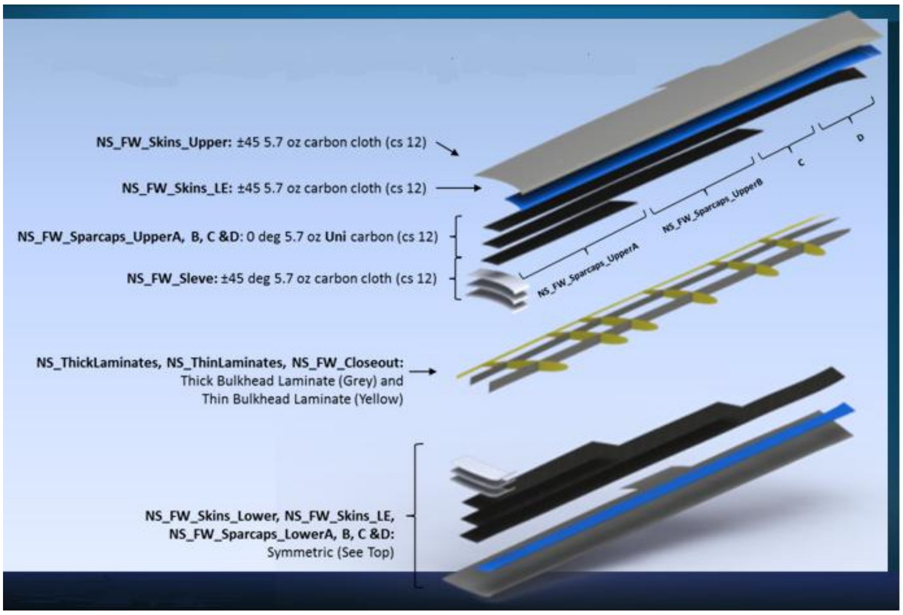

Figure 2.3: Forward wing stacking sequence.

To make the rear wing (see Figure 2.4) is used a bulkhead core using thin bulkheads (yellow at Figure 2.4) and thick bulkheads (grey at Figure 2.4) covered with two layers of uni-carbon to give properties in the axis along the wing and with a layer of plain weave carbon oriented at 45º to give isotropy.

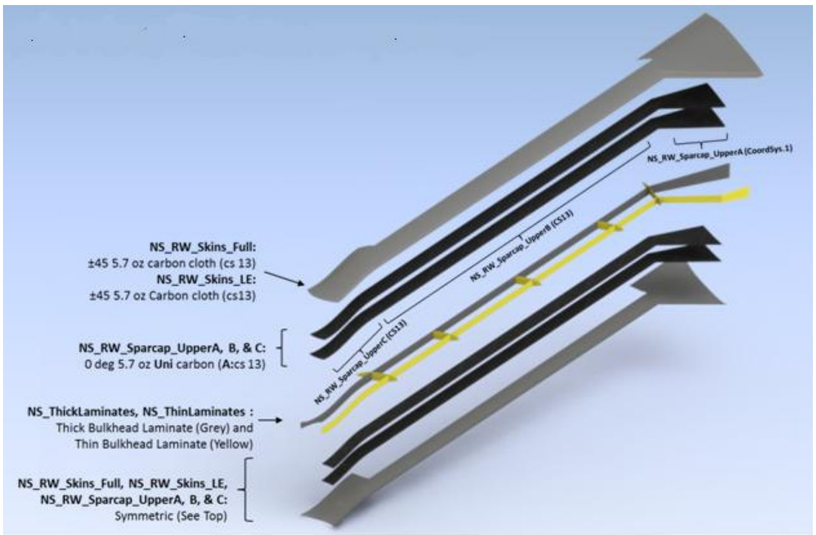

Figure 2.4: Rear wing stacking sequence.

The last component is the tail boom (see Figure 2.5). Is the easiest component because of is realized by only one core of thin bulkheads coated symmetrically by two layers of plain weave carbon at 45º.

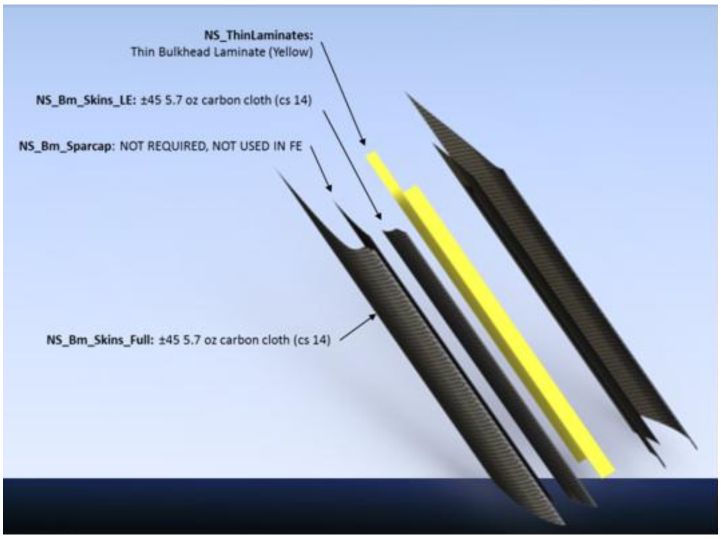

Figure 2.5: Tail boom stacking sequence.

The worst conditions are taken to do the calculations. Even in these cases the composites sized support all the efforts. The only problem after make the calculations is that on the joint between both wings appears a high stress points (see Figure 2.6).

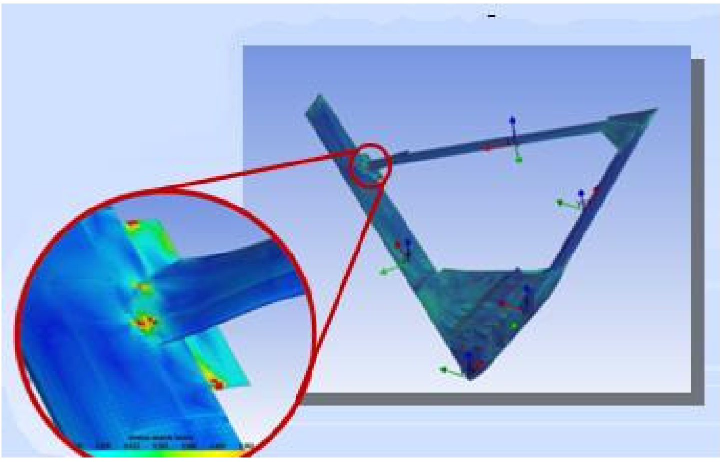

Figure 2.6: Detail of the joint between both wings.

To reinforce the zone affected (see Figure 2.7) is chosen four solutions. First is put an additional layer of uni-carbon at the rear wing. Second s added milled carbon-epoxy slurry at the tip of the rear wing (blue at Figure 2.7). As third solution two bulkheads (green bulkheads at Figure 2.7) are changed by two made by aluminium and finally the joint by ½" aircraft grade bolt.

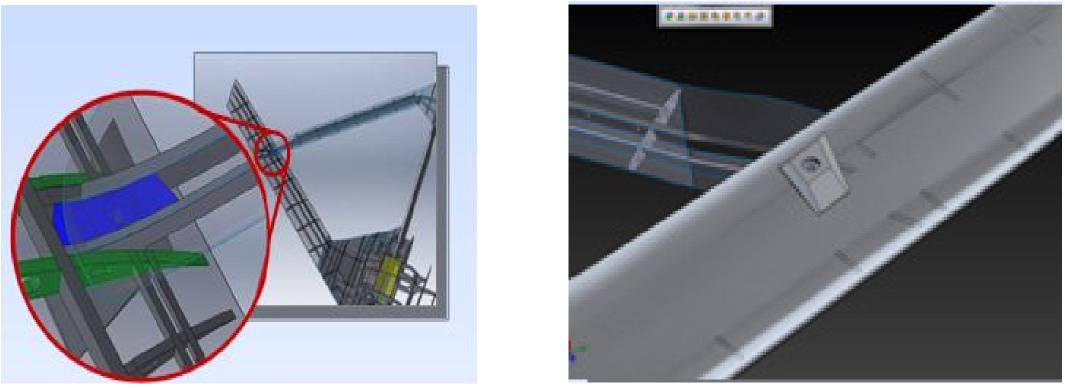

Figure 2.7: Reinforcement of the joint between the rear wing and the forward wing.

Now one can do the manufacture of the aircraft.

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Chapter 3

Manufacture of Fuselage Moulds

3.1 Moulds fabrication

To fabricate the fuselage skin (Figure 3.1) one creates female moulds. These moulds have been built using Computer Numerically Controlled machinery (CNC) due to their complex shape.

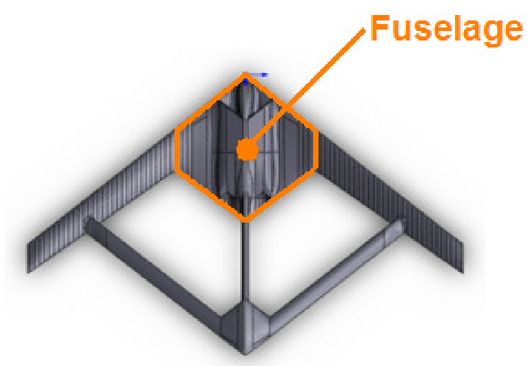


Figure 3.1: Fuselage of the Joined Wing.

A low density polyurethane foam is chosen as the plug's material, because it is very easy to machine and does not require roughing paths to remove large volumes of material.

The tool-paths are created from supplied data from Catia V. Figure 3.2 below shows the generated tool-paths, as well as a simulation of the machining process for the top left section of the fuselage.

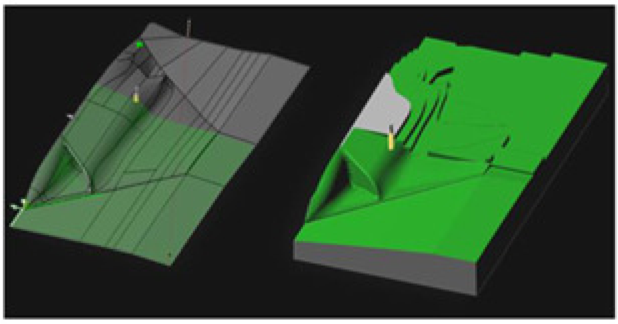


Figure 3.2: Tool path and Simulated Machining Process.

The resulting foam plug has large ridges due to the big step over distances used between tool-paths. These ridges are removed using sandpaper to within and small error of 1mm more of less. One can see in Figure 3.3 below the plug after sanding is completed.

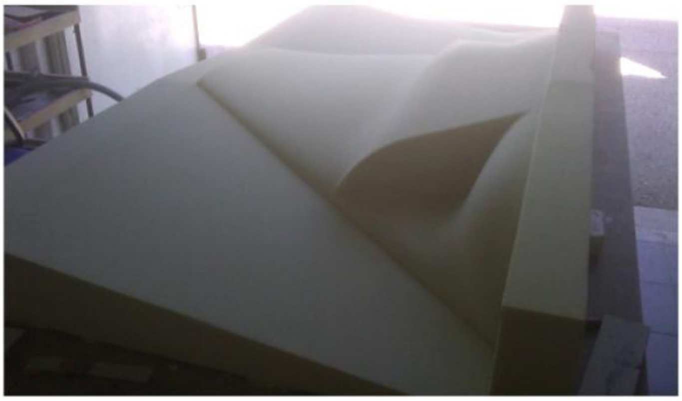


Figure 3.3: Plug after sanding.

Therefore the next step requires sealing the plug. Firstly in the sealing process, in order to fill the pores, is made slurry consisting of epoxy resin, thickened with fiberglass microballoons to achieve some consistency.

Figure 3.4: Micro slurry application.

Once this layer has gelled, another layer is applied and a fiberglass cloth is draped over the part. Peel-ply is applied to the entire surface to prevent the epoxy from flowing and also to ensure a suitable surface for the primer to adhere to when resin is cured.

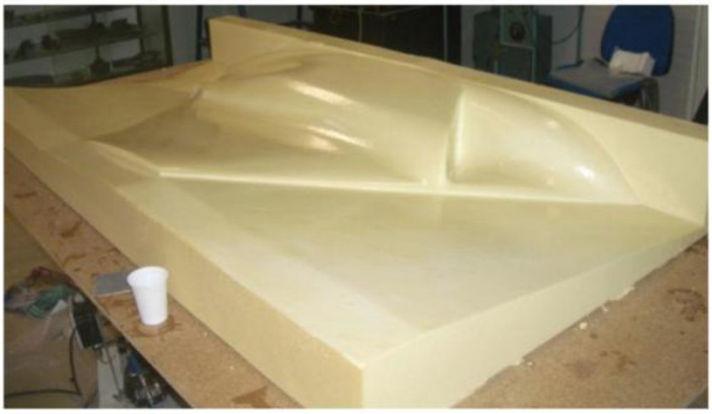


Figure 3.5: Plug after application of fiberglass layer.

After the peel-ply is removed (see Figure 3.5) three layers of automotive sealer spray paint are applied. This is then sanded to remove any blemishes in the surface. The procedure of painting and sanding is repeated again. Ten layers of mould release wax are required for this “green” mould. The resulting plug is shown in Figure 3.6 below.

Figure 3.6: Finished plug.

Once sanding is complete a “wall” is built around the plug. This allows a vertical face to be built into the female moulds that give added rigidity to the final mould, which experiences substantial forces when the parts are formed using vacuum process. Since the moulds are half parts (two top and two bottom parts), these walls allow the moulds to be attached to each other.

The final step in building the moulds is to lay them up. This is achieved by first applying two coats of epoxy based gel-coat to the plugs. When gelling is finished, a layer of fiberglass cloth and epoxy is then applied and allowed to gel. Next two layers of fiberglass matt and epoxy are applied. This process is repeated with two more layers of matt and once gelled, a final layer of cloth is applied. In Figure 3.7, is shown the female mould curing on the male plug and in Figure 3.8 one can see the same mould after being removed from the plug.

Figure 3.7: Fiberglass mould curing.

Figure 3.8: Female mould.

Now with the moulds completed it is necessary to bolt the left and right halves together. This process is described in the following section.

3.2 Mould Joint

The first stage, in order to manufacture the fuselage skin, is the construction of the adequate chassis. Besides the need of have no twist or bending in the moulds that this frame provides, it should also guarantee a good joining of the moulds. Initially, it was decided to build a steel frame however this would became more expensive, since it require machinery to weld the steel pieces and that machine the laboratory of Aerospace Engineering at IST don't have. Then it has been decided to construct a wood frame. The wood is cheaper than the steel and easier to work with. It doesn't require expensive machinery, just a saw, hammer, drill and some screws and nails.

Several boards stacked are used to build the chassis as one can see in Figure 3.9.

Figure 3.9: Wood chassis.

The fuselage halves moulds are bolt together with some bolts. They are also bolted with four “L’s” which are bolted to a wood board. This board is also bolted to the wooden box with two “L’s” one at each side of the box. At the lateral sides of the fuselage moulds another four “L’s” are bolted and in the inside of the moulds a piece of wood is used to don’t damage the moulds when screwing. This side “L’s” are used with the endless screw, that are fixed to another board bolted to the wood box, to adjust the twist and bending of the fuselage moulds to zero (see Figures 3.10 and 3.11).

Figure 3.10: Halves of the moulds bolted.

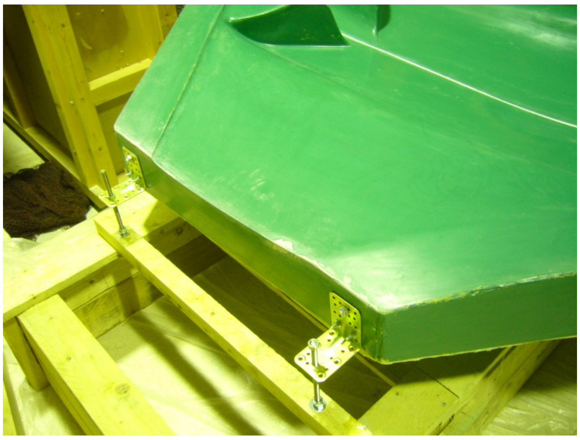
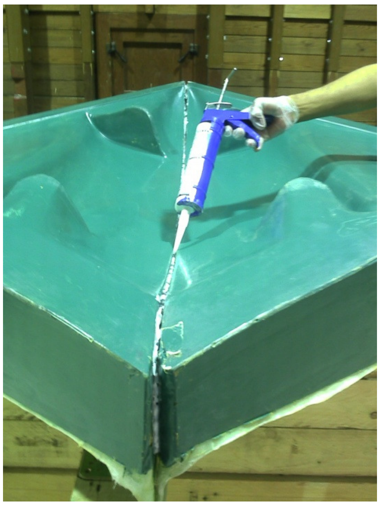


Figure 3.11: Endless screw.

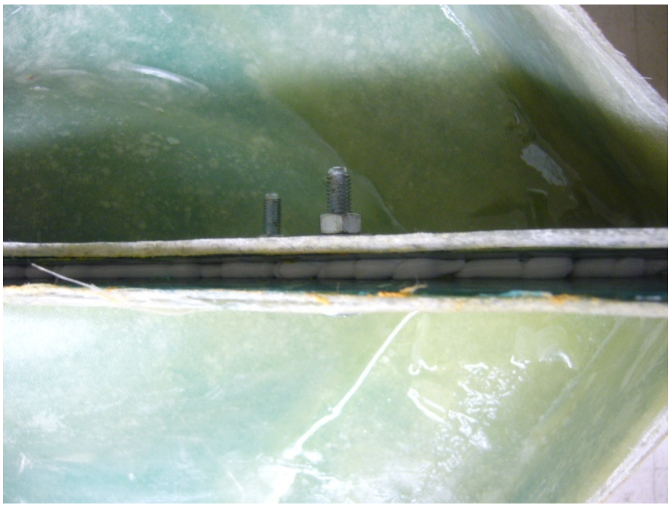
The process used to ensure that the fuselage moulds aren’t twisted or bended has been the following: first is measured the distance from the front top and rear top of the moulds. Since they weren’t the correct distances some wedges were used to adjust them the correct position. After that the endless screws are screwed to adjust the fuselage sides to the correct position, also measuring from the top of the moulds to the floor. The same process is repeated in the other moulds.

However, even with the wood frame now completed, the fuselage skins cannot be already manufacture because between the halves there are still some spaces that in the vacuum process will became leaks. It is necessary to don’t have them. Different solutions have been tested to prevent the leaks between the halves of the moulds.

In the first solution tested, the two halves were "glued" with silicone, as one can see in the Figure 3.12 below. The silicone is placed between the moulds, as shown in figure, and then the screws are fully bolted.



(a)



(b)

Figure 3.12: Gluing the moulds: (a) top view; (b) bottom view.

However, when testing the vacuum there were leaks between the halves of the moulds which means that the fuselage skin wouldn't be compressed by the vacuum bag against the moulds. Then, in the top of the moulds, the two halves union has been taped and the vacuum tested once more. Although there were fewer leaks they were still there – see Figure 3.13. So a second solution has been tested.

Figure 3.13: First vacuum test.

In this second attempt instead of use just silicone between the fuselage moulds also a bag has been placed under the fuselage moulds to prevent the appearance of leaks between them – see Figure 3.14.

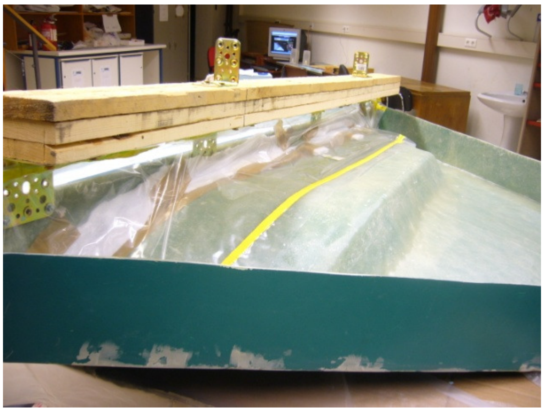


Figure 3.14: Bag on the bottom of the mould.

This second solution has been a better solution since the previously leaks disappeared. But that just happened for the bottom fuselage moulds. In the top moulds despite of most leaks disappeared there were a few still there. So a third solution has been tested just for these two top halves moulds.

In the third solution the moulds have been really glued together with epoxy. The resin and the hardener have been mixed with microballoons. This mixture has then been placed between the moulds as in the first case. Before place the mixture, the silicone of the moulds has been removed and the surfaces cleaned. When the vacuum test was performed there were no leaks. This solution is faster and easier to accomplish than the second one. It has only the disadvantages of the two halves are now glued and cannot be transported separately.

With the moulds glued together and in the correct position, with no torsion or bending, they can now be prepared to the fuselage skin manufacture. After the moulds are completely clean and dry, ten layers of mould release wax are applied. Between each layer the moulds are rubbed to become smooth and bright, and the next layer of wax is only applied when the previous has already dried. These layers of release wax are used to the skins fuselage can be removed from the moulds otherwise the resin will glue the fuselage skin to the moulds.

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Chapter 4

Manufacture of Joined Wing

The construction of the aircraft starts with the fuselage, followed by the construction of the wings and the boom. The last stage is the integration of the engines and avionics. All the parts that constitute the airplane are transported to the runway separately and there are assembled to forming the Joined Wing Sensorcraft.

4.1 Materials and methods used on the construction

Before starting to explain the manufacture and construction of Sensorcraft, it will be done a small explanation of the materials and methods used in this thesis.

4.1.1 Composites

A composite material is defined as a material made of two or more materials also with different physical properties. Its materials constituents should not be miscible, chemically compatible, with complementary mechanical properties resulting into a material which characteristics are a result of the proportion of it constituents, with a better structural performance in specific conditions than the others individually.

The use of this new material should be an advantage in the mechanical view, such as the increasing of stiffness and strength, better fatigue response to cyclic loads, lower weight.

4.1.1.1 Composites used in this project

The choice of composite materials is on the glass and carbon fibers in a matrix of resin, and foam or wood. The fuselage skin is made with layers of glass and carbon fiber. The wings and the tail boom have a skin of glass fiber with a core of foam. The wings spars and the fuselage bulkheads are made in a sandwich composite – carbon and glass fibers with a foam core or wood core. In order to join the bulkheads is used an epoxy resin with fibreglass microballoons.

Also is used peel ply which will give some roughness to the material which is applied and allow an easy gluing on it. Peel ply is not a composite material but it is a commonly used material in this thesis.

Using these materials the aircraft will be lighter than using metal or other materials.

4.1.2 Methods used in manufacturing process

Low cost manufacturing is a key issue of developing the new aircraft. Vacuum assisted resin transfer moulding (VARTM) method which is a composite manufacturing process, is one of the candidates to achieve this. The dry fibers are laid up on the tool and covered with a vacuum bag. Then the air is evacuated by a vacuum pump and liquid resin from an external reservoir is drawn into the component by vacuum. The liquid resin is infused into the component.

Another method has also been used, the impregnation process. In this technique the fibers are laid up on the tool one by one and between each one they are wet resin with a brush or a roller. At the end are covered with the vacuum bag.

4.1.2.1 VARTM

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In the VARTM (see Figure 3.1) the bomb creates vacuum inside the bag and after that the resin is sucked to inside the vacuum bag covering the fibers. To prevent the resin excess to go to the bomb and damage it a bottle is placed in the way between the bomb and the moulds. When doing that the tube connecting the bomb to the bag should be bended to not allow any air come inside the vacuum bag. Then the vacuum bomb is turned off and the bottle can now be deflated.

If the resin and hardener initially mixed are not enough more should be mixed. However it is necessary to be aware not to leave air go inside the vacuum bag through the tube connecting the recipient with resin and the vacuum bag because that could cause bubbles in the fuselage skin. And these bubbles may decrease the resistance of the composite.

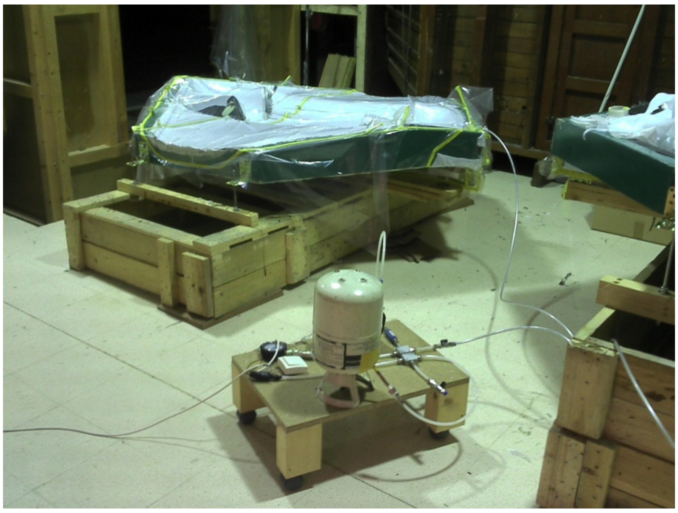

Figure 4.1: VARTM process.

4.2 Fuselage manufacture

Once the mould is realized it is possible to start building the aircraft. The first step is to implement the fuselage, which is the part that is going to take more time to be built. The fuselage performing can be divided in different parts: to do the skin, realization of the individual bulkheads and the air ducts, and finally the joint between the individual bulkheads and of the skin and the whole bulkhead.

4.2.1 Fuselage skin manufacture

The fuselage skin can now be build. First is done the bottom skin, it consists of several layers of carbon fiber and fiberglass. They are stacked in the following order: a layer of fiberglass (bidirectional) at the bottom, two layers of carbon fiber (bidirectional) and another layer of fiberglass (bidirectional). The fact that the fibbers direction is bidirectional is for having the same properties on the transverse and longitudinal directions of the skin.

At the top will be a layer of peel ply, over the peel ply is placed a net that allows the resin to travel throughout the mould during the VARTM process. Finally the vacuum bag is fixed to the mould with plasticine – see Figure 4.2.

Figure 4.2: Detail of the plasticine to fix the vacuum bag.

The bag is inspected looking for any existing leaks and then when there is none the resin can be introduced. In Figure 4.3 one can see the bottom fuselage skin after being all covered with resin.

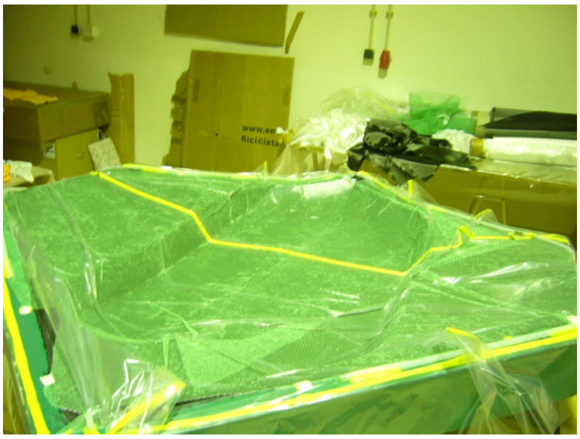

Figure 4.3: Bottom fuselage skin before the introduction of the resin

The vacuum bomb stays working during all night. After that the piece is removed from mould (see Figure 4.4) as the peel ply, the net and the resin excess.

Figure 4.4: Removing the peel ply, the net and the resin excess.

In Figure 4.5 is shown the final piece of the bottom fuselage skin.

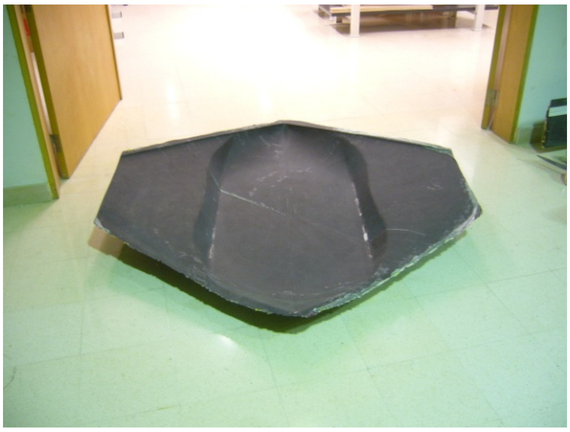

Figure 4.5: Bottom fuselage skin.

Once is finished the bottom skin, one can start the manufacture of the top skin. It has to take in care that the inside of the aircraft has to be accessible for different tasks of maintenance such as changing batteries or refuelling. This means that it is also necessary to manufacture reinforcements for the access panels. There will be two panels: one at the nose and another at the middle of the top fuselage. In Figure 4.6 one can see the front access panel being built. In order to build the access panels, it is done the same procedure as the bottom skin manufacture.

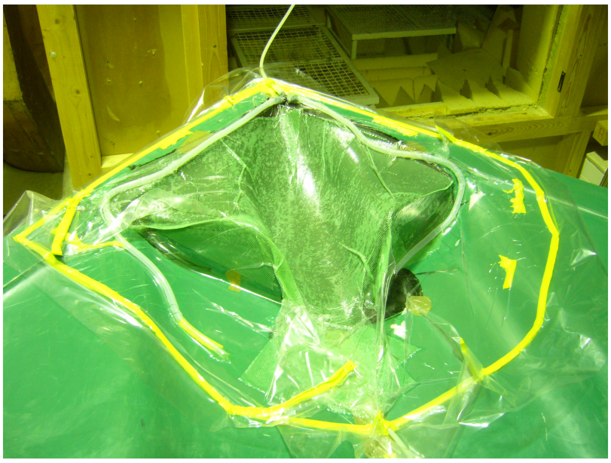

Figure 4.6: Manufacture of the front access panel.

Before laminate the access panels it has been trace its contour on the top of the moulds. After removing the laminated piece the contour goes to the laminate. Then the access panels can be cut with the correct geometry.

The Figure 4.7 shows the pieces built after taking out from the moulds. They are then cut with a Dremel machine and after glued to the moulds as shown in Figure 4.8.

Figure 4.7: Access panels.

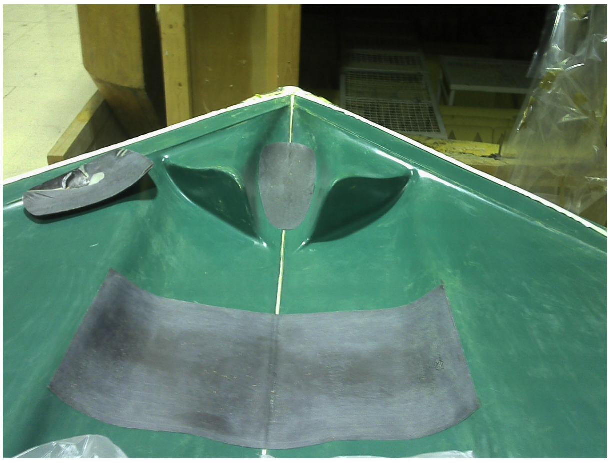

Figure 4.8: Access panels glued on the mould.

As the central panel is large, it has not so stiffness, which involves multiple not desired vibrations due to the air friction. In order to bring more stiffness to the central panel is chosen to put a polyurethane foam core coated with fiberglass following an impregnation procedure – see Figure 4.8. With this procedure the rigidity is augmented as well as the weight, but the weight is a critical specification so it must be controlled. In order to do that lighter without losing the rigidity is decided to mark some little circles in the core to take out the material of these sections, without crossing the panel with the Dremel.

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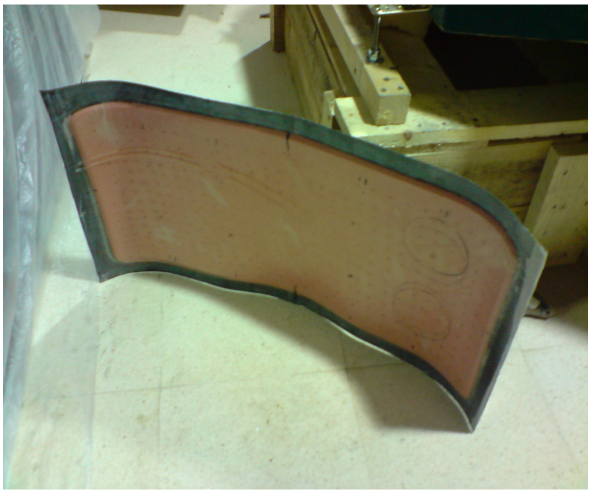


Figure 4.9: Reinforcement of central access panel.

After this the top mould is painted with gel coat (see Figure 4.10) and then the fibers of glass and carbon are collocated above the mould.

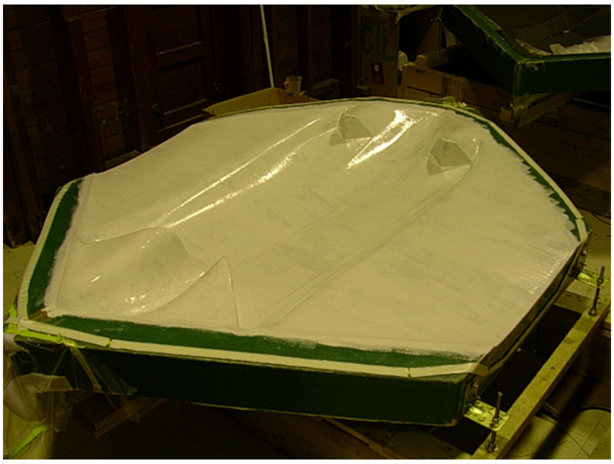


Figure 4.10: Mould covered with gel coat.

Doing the same procedure as the bottom skin it is done the top skin. The result can be seen in the Figure 4.11.

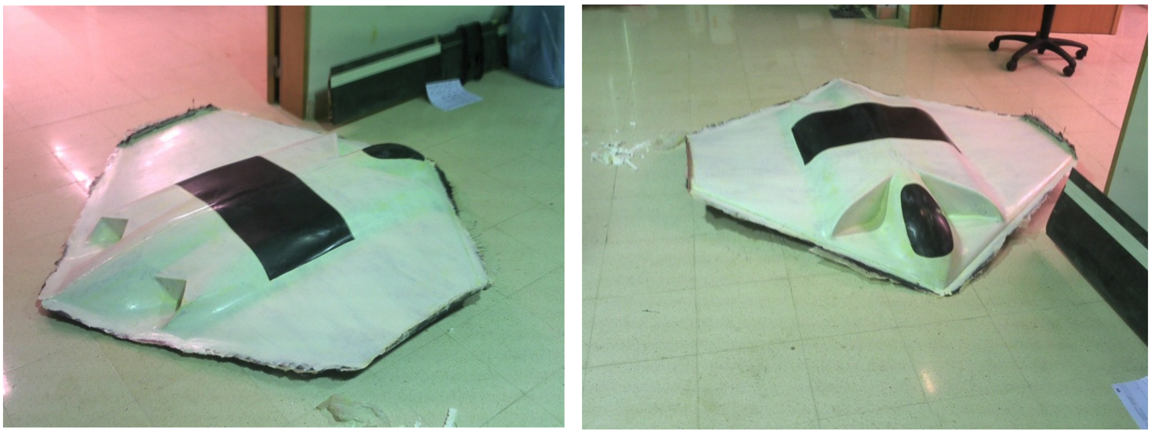


Figure 4.11: Top fuselage skin.

The two skins are finished. The next stage is the bulkheads manufacture.

4.2.2 Bulkheads manufacture

The fuselage skins are not rigid enough to support all the loads in flight. The pieces that occupy the interior of the fuselage skins give it the rigidity that it needs. They are called bulkheads. In Figure 4.12 are shown a view from the top side of the bulkheads of the Sensorcraft.

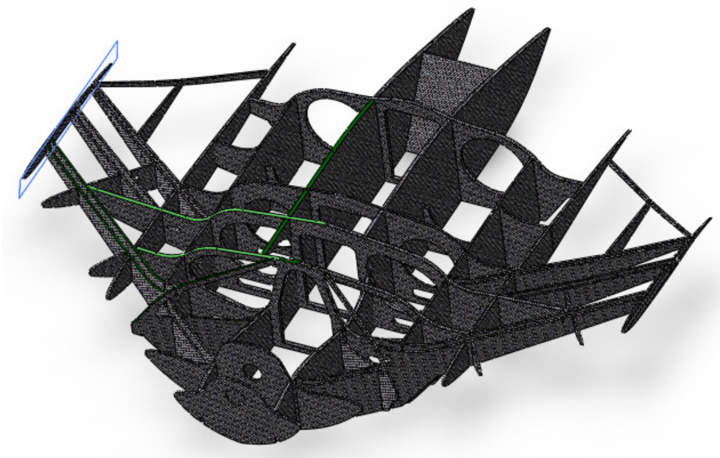


Figure 4.12: Sensorcraft bulkheads.

The fuselage bulkheads are in sandwich composite. They are made of laminate sheets formed using VARTM techniques. These sandwiches have in the core a sheet of polyurethane foam (PU foam). Holes are drilled over the entire area of the sheet to allow the transfer of resin through the foam to ensure the fabrics on both top and bottom surfaces are wet out evenly. It is used PU foam with two different thicknesses – 3mm and 10mm – because there are bulkheads with two different thicknesses.

Since the laminate shells are planar it is used a flat counterplot (see Figure 4.13) to manufacture the plates from where bulkheads are cut off.

Figure 4.13: Flat counterplot.

Before starting to lie up the counterplot has to be waxed as in the case of the fuselage moulds. The layers of the composite plates have the following order: one layer of fiberglass, one of carbon fiber, the PU foam, a layer of carbon fiber and one of fiberglass. The fiberglass and carbon fiber cloths are the same used for the fuselage skin. At each side of the sheet is placed peel ply to remove when the plate is done. At the top is also placed perforated plastic and a respirator to absorb the resin excess, and finally the vacuum bag. The technique used to manufacture these sandwich composite plates has been the impregnation process. In the Figure 4.14 one can see a final plate.

Figure 4.14: Sandwich composite plate

Once are completed these sheets, the bulkheads can be cut. They are cut out using a CNC machine.

The CNC machine of the IST is small and hot wire –see Figure 4.15-, wherefore it cannot cut strongest materials as the sandwich, so is needed to use another CNC machine.

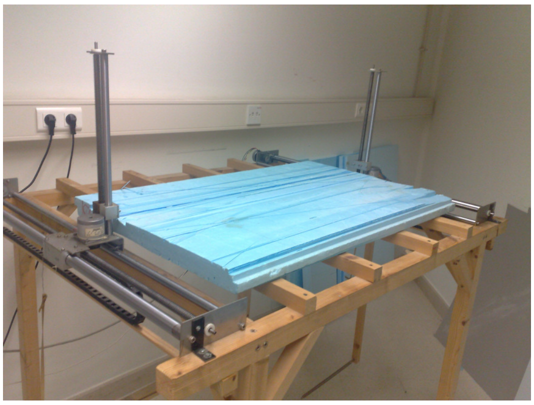


Figure 4.15: CNC machine of the IST.

The CNC machine used from *Força Aérea Portuguesa* can only cut pieces in the envelope of 700mm x 900 mm. Once the chosen machine is available bulkheads are cut from the Catia data, where the individual measurements are detailed and stored. Some bulkheads have to be cut in halves and after glued together because they are bigger than the envelope of the machine. In Figure 4.16 below is shown a bulkhead being glued. To gluing the bulkheads has been used a mixture of resin, hardener and microballoons.

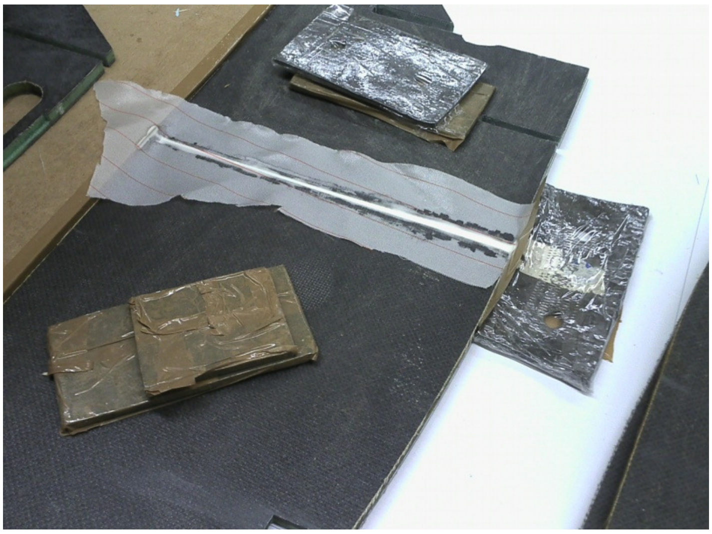


Figure 4.16: Pieces being glued.

Once the pieces are cut it means that all the needed tools are available for start the assembly. Before starting the process is needed to sand the pieces in order to obtain a soft edge and remove impurities. Because the machine that build the pieces is not so accurate, and neither the mould, it is needed to sand the piece in the assembly process in order to adapt it to the mould.

4.2.3 Air intakes manufacture

The air inlets and outlets cannot be done with the composite sheet realized because them are not flat and have a complex shape, so it is going to be needed a mould as well as in the case of the skin.

This necessitates the use of separate tooling for the air intake and outlet pass troughs. The Figure 4.17 shows the locations of the outer mould line which cannot be produced using the female fuselage moulds alone. Both the inlet and outlet, shown in yellow and red respectively in the Figure 4.17, require their own separate tooling.

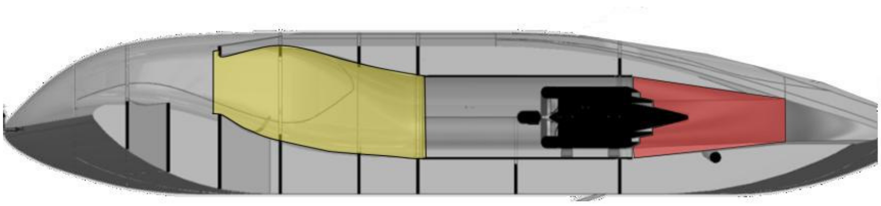


Figure 4.17: Section of intake and outlet in the fuselage.

This tooling is produced as a male plug or mandrel and the composite skin is laid up on it – see the moulds on Figure 4.18. Due to the complex shapes of these tools, they are constructed using many 2D contours stacked on one another and then sanded to a fair surface. This foam core is then sealed with layers of fiberglass and finished with primer.

(a) (b)

Figure 4.18: Intake and exhaust mould: (a) intake mould; (b) exhausting mould.

To manufacture the intakes and exhausting outlets the tools are covered with gel coat to provide a smooth surface where air passes through. After that a fiberglass cloth and a carbon cloth are laid upon it respectively. At the end it is also laid peel ply to remove excess of resin and give a roughness surface.

Due to the complex shapes of the inlets and outlets the part cannot be removed from the mandrel without cutting it off. The parts are cut down their length and then re-bonded after removing from the mandrel – see Figure 4.19. They are re-bonded with two strips of fiberglass.

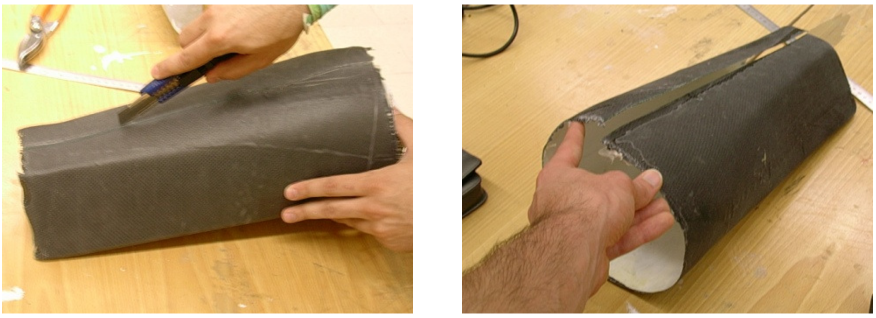


Figure 4.19: Cutting the exhausting outlet from the plug.

The hot exhaust gas leaving the engines must be routed through the outlet while still allowing cooling air to flow around the engines. Figure 4.18 shows how the cooling air passes over the engine and exits the outlet while the hot air is routed out through an insulated exhaust tube.

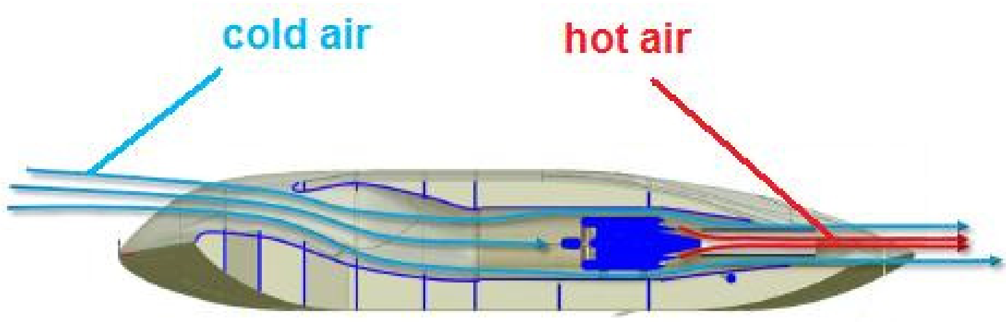


Figure 4.20: Cross section showing the engine locations and the inlets and outlets routing.

This exhaust outlet must be insulated in order prevent damage to the composite fuselage. It is constructed as a double walled tube with a corrugated internal structure. The material is titanium as shown in Figure 4.21 below.

Figure 4.21: Double wall exhaust duct.

This double tube doesn't correspond to the duct of the Joined Wing, but is an example. When finishing the thesis this has not been realized yet, so it is a future work expected to the final work process of the Joined Wing.

4.2.4 Bulkheads assembly

Once the bulkheads and the air inlets and outlets are available (see Figure 4.22) it is possible to start the structure assembly.

Figure 4.22: Bulkheads and air ducts.

Before start the assembling process it is needed to sand the pieces with a fine sandpaper to remove the impurities in order to be able to paste the pieces when needed. When the pieces are sanded it is done the needed slots at each bulkhead to fit each one assuring a good junction. These slots are done with the Dremel and sanded later.

When the slots are made the next step is to assembly it according to Catia planes available (see Figure 4.23). At this first step it Is only developed the assembly of the fuselage central part, and with this part assembled it is possible to put the outside bulkhead, it is those ones nearest to the fore wings.

Figure 4.23: Central bulkheads assembly.

As seen in Figure 4.23, the central structure is divided in two separated longitudinally symmetrical parts, because the CNC machine where the bulkheads are developed, as said previously, was not able to make parts as large as the two transverse bulkheads, so it is decided to divide it in two parts. Furthermore, the machine and the mould precision are not as accurate as expected, but exists a little tolerance margin. By this way it is possible to perfectly adapt the central structure to the mould. A complex sand process are followed in order to correctly adjust the bulkheads casts, doing little pieces arrangements until the pieces are correctly positioned.

When each part has its correct position it is possible to paste them. Besides join them between the slots, they are also glued to avoid movements between them and to have a better junction. Before preparing the resin the objective zone was sanded with a fine sandpaper to remove the impurities of the bulkheads because the laboratory dust or the impurities that appeared when working with them.

The glue used to paste the pieces is epoxy resin with fiberglass microballoons. When the resin is done, it is applied where two bulkheads are joined with a palette knife or with using the hands (see Figure 4.24). When applying the resin it must to be done so that the union remains rounded and using with the just quantity of resin. If it is used a little quantity of resin the pieces will not be well pasted, and if the quantity is higher than expected the total weight will increase.

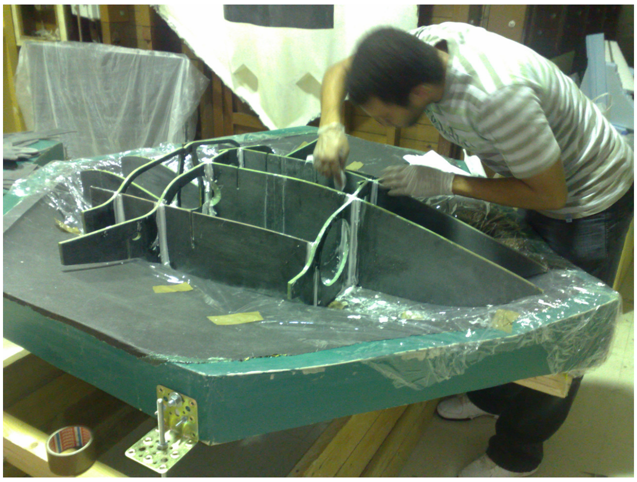


Figure 4.24: Application of the epoxy resin.

Once the resin is applied it needs to dry during a whole night. The next day the central structure is glued (see Figure 4.25). If any place doesn't have enough resin because the gravity effect, which makes the resin to go down across the structure, the process is repeated until seeing all the bulkheads well glued.

Figure 4.25: Gluing bulkheads.

When the structure is well pasted, the joints are sanded in order to avoid resin excess and to have a smooth ended.

After this work the next step is to paste the air inlet into the central structure. This is a hard work requiring lots of cut offs and sanded in the edge part of the conduct entry to get a perfect adjustment with the mould before pasting the structure. To achieve this fact the first step is to glue the piece that is just above the air inlet to the mould (see Figure 4.26), because without this piece the air inlet adjustment would be imperfect and, by other side, it will be impossible to paste that piece later because its inaccessibility. If the air inlet was not sanded and cut off correctly it would cause a gap alongside the whole central fuselage structure in comparison with the mould.

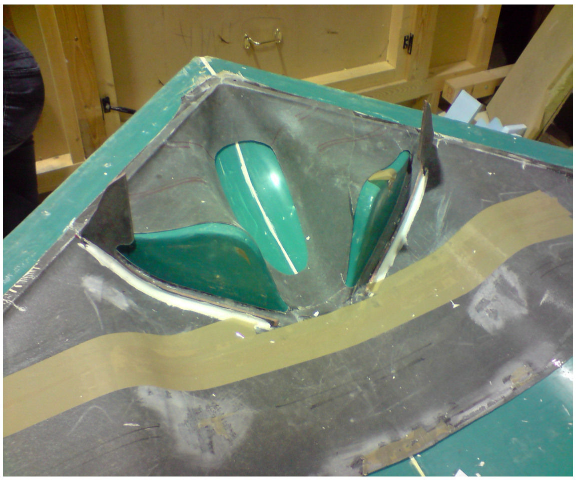
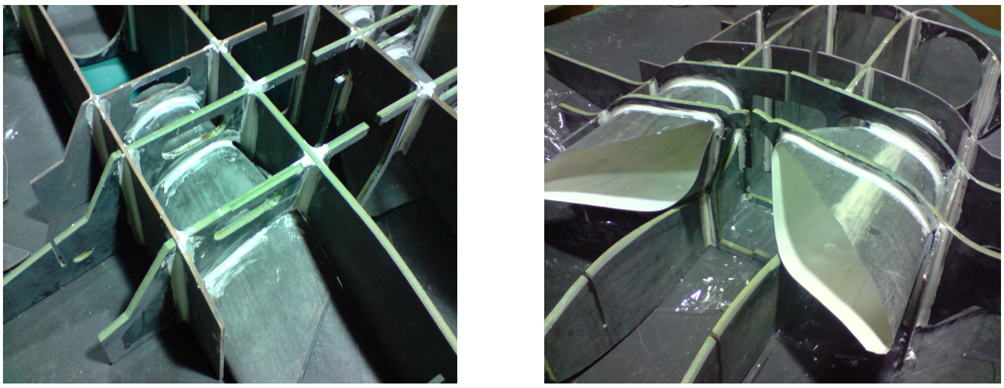


Figure 4.26: Piece glued on the top mould.

Later, once the piece is correctly adjusted, it is needed to glue it to the central structure. For that is used the same method that the one deployed to join the bulkheads; once is glued the air inlet into the central structure, it is glued with epoxy resin with fibberglass microballoons. As said before, the resin needs all the night to be dry correctly. At this moment appeared one problem, because when the resin dried it increases its volume, deforming the air inlet. To solve that it was decided to remove all the glue using the Dremel and sandpaper, redoing another time the pasting process but using less glue. Once it was seen that the piece fit exactly in the mould and that was correctly glued (see Figure 4.27) it was possible to continue with the following tasks.



(a) (b)

Figure 4.27: Glue of the air inlet: (a) Bottom view, one can see the correct adjust to the mould; (b) Top view.

The next step is to join the two symmetrical parts. These two parts are placed in the correct position within the mould and the two front-side bulkheads are placed and pasted using the same procedure that in the previous steps (see Figure 4.28).

Figure 4.28: Glue of the forward bulkheads.

At this moment appeared a problem; between the two symmetrical parts exists a little space because the mould and CNC machine precisions are not as fine as desired. To solve that it was decided to insert at this space a sandwich slice like the bulkhead thickness and paste it with resin, reinforced with a three layers of fiberglass lamination. The result can be observed in Figure 4.29.

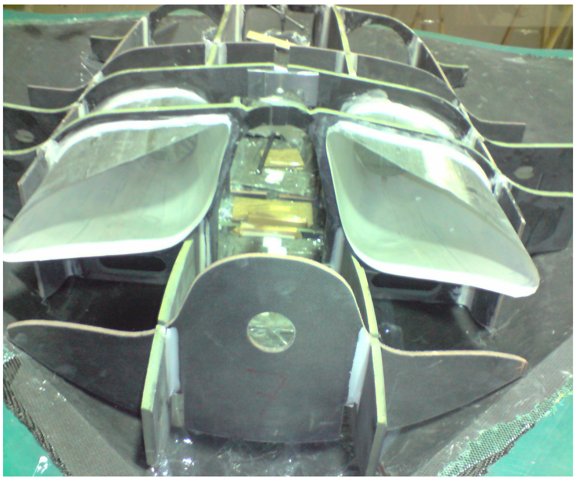


Figure 4.29: Joint of the two halves.

When the central structure is finished, is done the exterior part of the fuselage (see Figure 4.30).

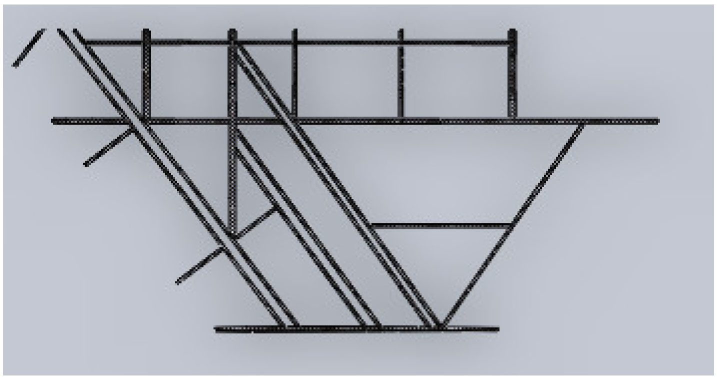


Figure 4.30: Detail of outlet bukheads.

The principal bulkheads of the exterior part are reinforced by plywood's sheet of 3mm. thickness lined by a fibercarbon layer following the impregnation process. These sheets are glued by resin epoxy in the inner part of the bulkheads (see Figures 4.31). The sheets are reinforced by the fact that this part is the one that resists the forces and the moments from the wings. It is possible to see in Figure 4.31 below, the part of the plywood that goes out of the mould will be the one that it does the male role in the assembly between the fuselage and the front wing.

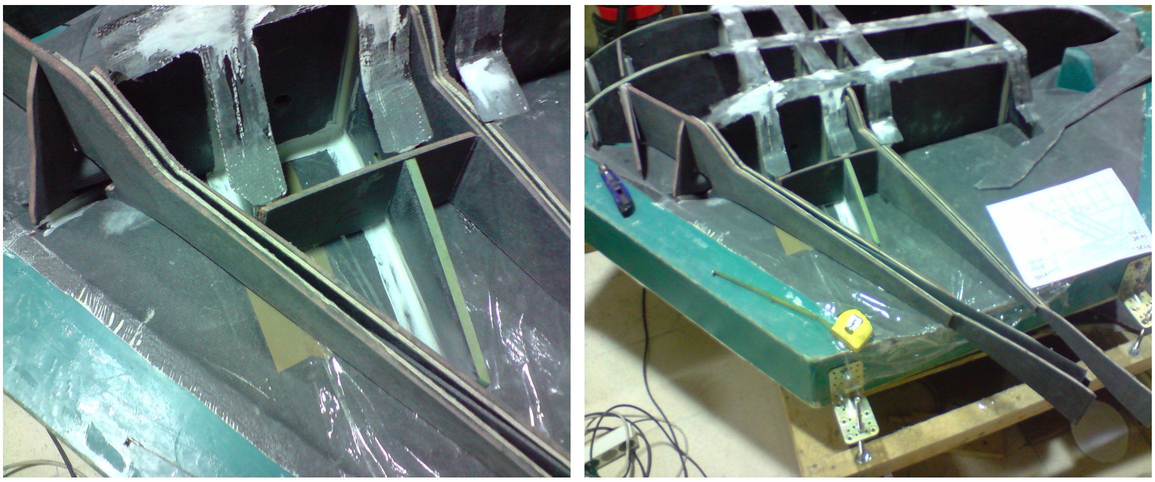


Figure 4.31: Reinforcement of the bulkheads.

The principal bulkheads are already prepared, so they can be glued to the structure following the procedure used in the joint between the bulkheads; are glued with resin epoxy with fiberglass microballoons and later sanded.
Since it is a zone that receives big efforts, the joints of the principals bulkheads of the exterior part with the central structure are reinforced with two layers of fiberglass following the impregnation process – see Figure 4.32.

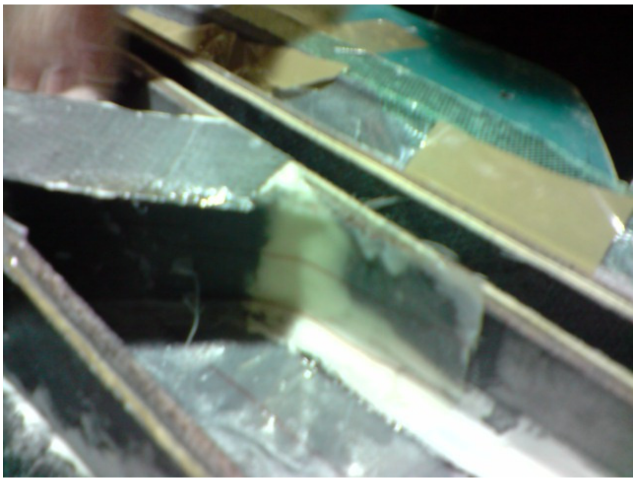


Figure 4.32: Reinforcements of the joints.

For the assembly between the fuselage and the forewing, since the bulkhead with the plywood is not too resistant, it have been done six plates of carbon, one for every principal bulkhead of the exterior part. These plates are done with twenty layers of fiberglass and using the impregnation process – see Figure 4.33. When the plate is completely dry, one of its sides is sanded avoiding that it did not have the same thickness in the whole length and reducing the thickness up to 1mm. If the thickness would be constant, the joint between the forewing and the fuselage would have a big discontinuity of properties on the point the carbon plate finishes and in case of break it would break in this point. Reducing the thickness is avoided this fact. Also is realized both in the carbon plate and in the bulkheads a few holes with a drill to introduce some bolts to have a better fixation between the bulkhead and the carbon plate.

Figure 4.33: Reinforcement of carbon.

The carbon plate is glued between the two plywoods with epoxy resin and the bolts are put– see Figure 4.34.

Figure 4.34: Joint of the carbon and the bulkhead.

To finish the exterior part of the fuselage the plywood and the carbon plate are cut according with the measures for the correct assembly between the forewing and the fuselage – see Figure 4.35.

Figure 4.35: Cutting the carbon sheet and the plywood.

To finish the construction of the structure, are placed the pieces that do not support any effort but avoid the vibration of the skin – see Figure 4.36. The pieces are glued to the structure by means of epoxy resin with fiberglass microballoons.

Figure 4.36: Gluing non-structural pieces.

4.2.5 Skin – bulkheads joint

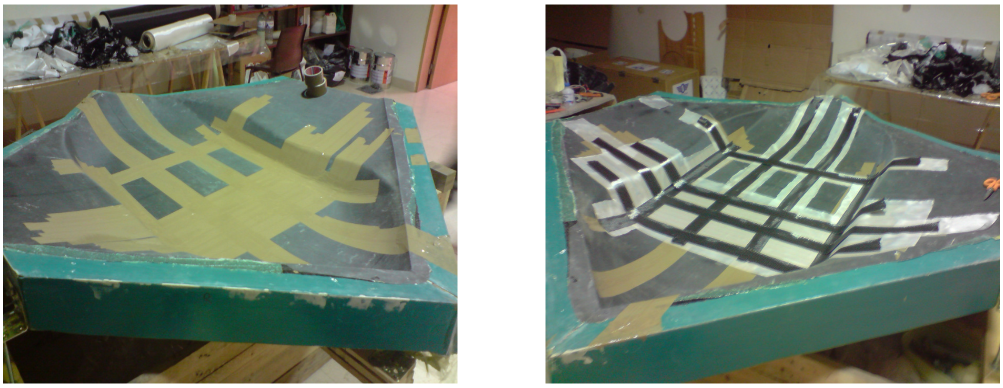
One of the more important tasks of the Joined Wing manufacture consists on the Joint between the bulkheads and the skin. By means of this joint the skin transmits the efforts to the structure that supports them. If this joint is not too strong the efforts not be correctly transmitted and the skin could break.

The major complication of joining them is how to join the low skin when the top skin has already joined or vice versa, since it can not accede to its.

To join the first skin to the structure it is chosen the same system that to join the bulkheads, the components are sanded, are glued with epoxy resin with fiberglass microballoons applied with the hands or spatula and later the joint are sanded. One chooses to take the top skin as the first. By this way when the glued of the bottom skin will do one could verify across the access panels the correct glued between the low skin and the bulkheads. If one does it on the contrary the access to the interior is impossible.

To join the low skin to the bulkheads is chosen by a joint created with sheets of fibercarbon impregnated with epoxy resin. These sheets will be glued both the structure and the skin; to join the sheets with the bulkheads will be used epoxy resin with fiberglass microballoons and to join them to the skin will be used epoxy resin, the skin will be placed over the fibercarbon sheets that are glued to the structure. Once the resin is cured the joint will be strong. These sheets increase the contact area between the structure and the skin, so this produce a better glued.

Before starting to laminate the sheets it is necessary to clean and sand the moult to remove all the impurities –see Figure 4.37. Then it is marked one the mould where the sheets go and is put a layer of peel ply to prevent the gluing between the mould and the sheets and to have a perfect ended. Finally is put two layers of fibercarbon and they are impregnated with epoxy resin – see Figure 4.37.



(a) (b)

Figure 4.37: Skin-bulkheads joint: (a) Preparation of the mould; (b) View of the fibercarbon sheet.

One can see in Figure 4.37 that in the front part it has not put sheets; this is because this zone is left to have a small margin of manoeuvres to close the skin.

One can accede to this zone across the front access panel, so this zone will be joined by means of epoxy resin with fiberglass microballoons.

Putting the sheets on the mould it is assured the perfect fitting to the mould. It means that the bulkheads and the skin have a perfect glued. To avoid the raising of the sheets it is put some weight over them.

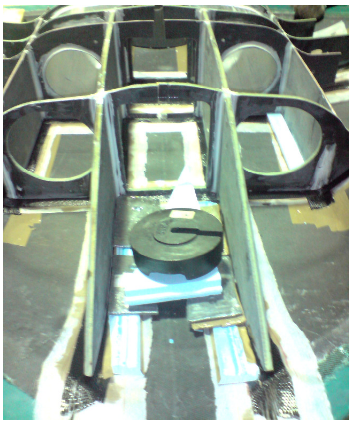


Figure 4.38: Curate process of the sheets.

When the sheets are cured, they are joined at the structure with epoxy resin with fiberglass microballoons – see Figure 4.39. Like in previous cases, when the resin is cured, the joint is sanded.

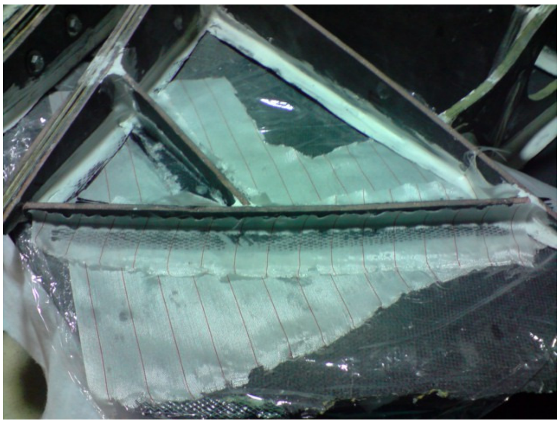


Figure 4.39: Joint of the fibercarbon's sheet and structure.

The final result can be seen at Figure 4.40.

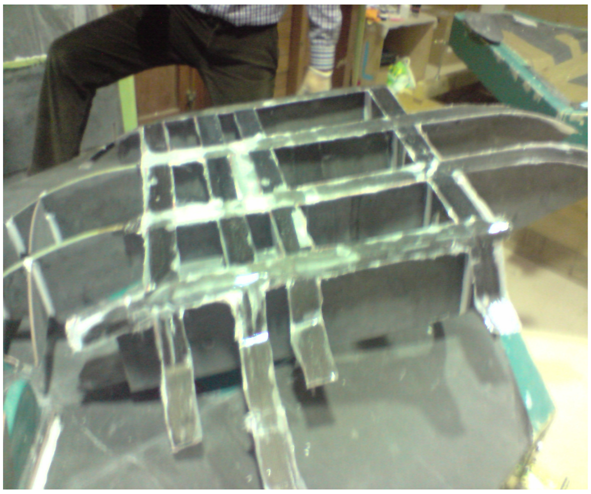


Figure 4.40: Sheets glued to the structure.

This process is realized in parallel by the union of the bulkheads. So like the bulkheads joined, first the procedure is done for the central structure and then for the exterior part of the fuselage – see Figure 4.41.

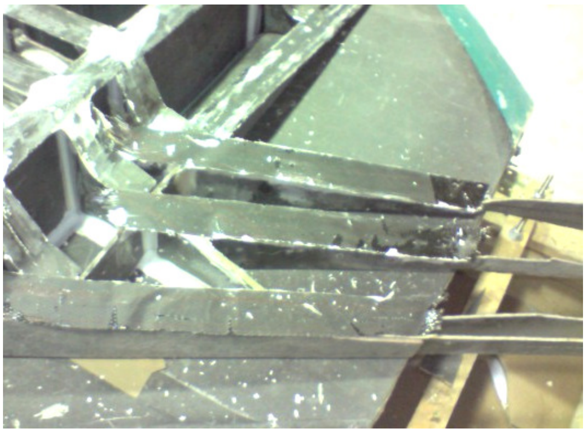


Figure 4.41: Exterior sheets of fibercarbon.

A problem that arises in this step, is that the surface of the sheet of fibercarbon does not remain perfectly smoothed, which provokes that the sheets does not remain completely adapt to the mould. If this problem is not solved, when the glued will realized, it won't be perfect. To solve this problem, the emptiness's are refilled with epoxy resin with fiberglass microballoons. Finally when the resin is dry, the sheets are sanded until those surfaces are completely smooth – see Figure 4.42.

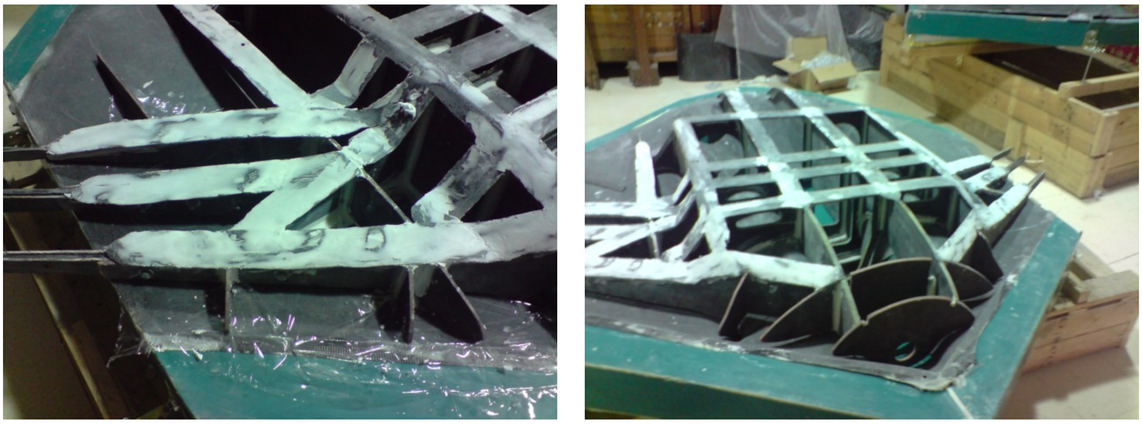


Figure 4.42: Filling the sheet with fiberglass microballoons and sanding it.

With this step the joint between the bottom skin and the bulkheads is finished. In the joint between the top skin and the structure a problem that was not thought at the beginning arises. The zone of the air inlet remains inaccessible so this zone cannot be joined by means of epoxy resin with fiberglass microballoons. To solve this problem the procedure used in the bottom skin is repeated in the zone of air inlet – see Figure 4.43.

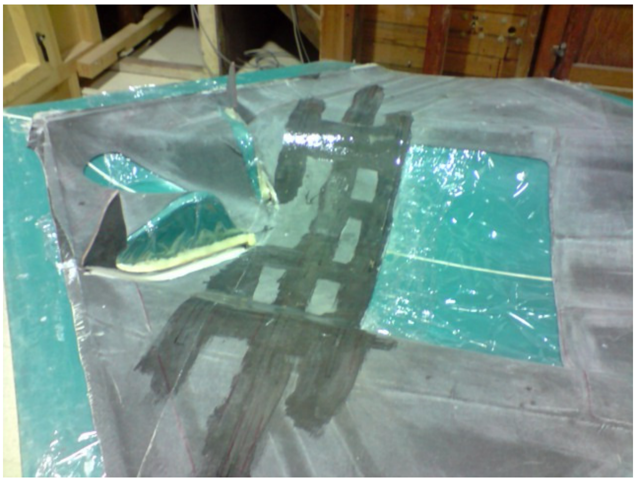


Figure 4.43: Preparation of the top skin joint.

Putting the sheets in the air inlet zone and doing an impregnation process, both the top and the bottom part of the structure (see Figure 4.44) are prepared to be joined to the skins.

Figure 4.44: Top part of the structure.

In spite of having all the components ready to be joined, at the conclusion of the thesis it has not been realized.

4.3 Rear Wing manufacture

The rear wings are produced using foam core and then this is used as a male tool to build the composite skin. In the Figure 4.45 one can see a cross section of the rear wing.

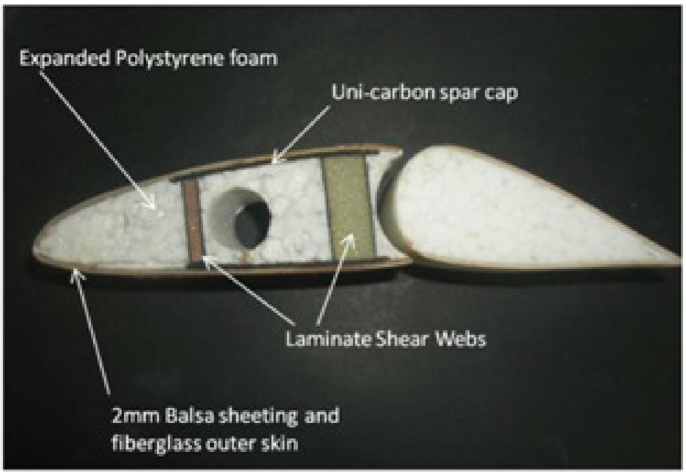


Figure 4.45: Rear wing cross section.

The main wing is cut in eight panels along the length of the wing in order to accurately capture the changing wing cross section along the span – see Figure 4.46.

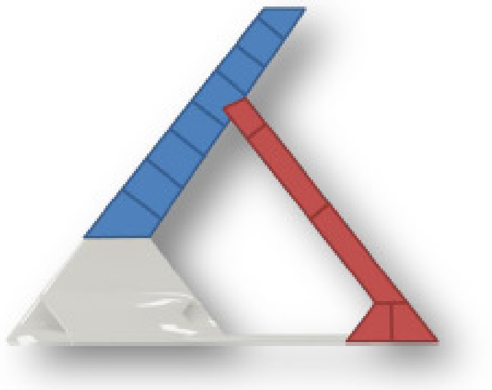


Figure 4.46: Wings segments.

The foam plug for the wings is produced using airfoils extracted from the supplied Catia geometry. It is cut from expanded polystyrene foam using a four axis CNC, hotwire foam cutter (Figure 4.47). Since the piece is too big for the CNC machine of the IST, the foam has been cut in a similar but bigger machine where if it the piece fits.

Figure 4.47: CNC hot cut wire.

The wings have a core of foam and the structural components as the shear webs and wing ribs, are constructed using sandwich composite. The accuracy of these parts is especially important in areas where the rear wing spars join into the main wing as they help to ensure the proper mating of the parts and ensure that the overall geometry is maintained. The Figure 4.48 below show an example of one of these parts. Inside the wing is left an annular conduit for passing servo wires and leads to other electronics such as accelerometers or strain gauges.

Figure 4.48: End of rear wing shear web.

Once the shear web is got in the foam core and is glued with epoxy resin, left it to dry during the night, it is possible to start covering the rear wing. In the space where the shear web is placed is put on two layers of bidirectional fibercarbon to reinforce the zone.

With balsa wood of 2mm. thickness the foam core is covered in four parts: two sheets of balsa wood in the top and two in the bottom. One can see the top part of the wing in Figure 4.49. To glue the balsa wood to the core there is used epoxy resin.

Figure 4.49: Gluing the balsawood.

When the four parts are glued, it is put both rear wings in a vacuum bag and it is applied a VARTM process during eight hours to assure the perfect glued between the balsa wood and the foam core. During the process the vacuumstator, the piece that controls the grade of the vacuum, is broken provoking the compression of the foam core due to the excess of vacuum. The rear wings are left useless – see Figure 4.50.

Figure 4.50: Useless rear wing.

When the wings have cured, the balsa sheeting is sanded to fair the surface and a final layer of fiberglass is applied to seal the surface for painting.

Since these wings are remained useless this last step could not be done and two new wings have been done. In the conclusion of this thesis these two new wings have not been constructed.

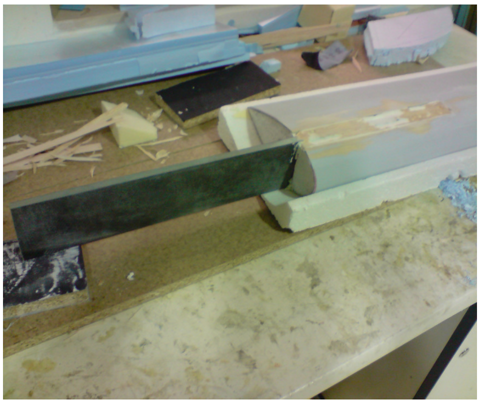
4.4 Tail boom manufacture

For the accomplishment of the tail boom the same procedure of the rear wings is followed: foam core redressed of balsa wood and later cover with fiberglass. This tail boom was realized out of the facilities of the IST and the constructors do not put the shear web on it.

The first step is cut the tail boom according on the measures specified in the Catia data – see Figure 4.51.

Figure 4.51: Cut of the tail-boom.

As said previously the tail boom do not incorporate shear web therefore it is necessary to put on a shear web in the top part of the tail boom and another on the bottom part in order to improve the resistance and also to use them as help in the assembly between the tail boom and the fuselage on the top side and the rear wings on the bottom side. One can see the shear webs at Figure 4.52.



(a)

(b)

Figure 4.52: Shear webs: (a) Bottom shear web; (b) Top shear web.

To put the shear webs, the foam core and the sandwich are cut; the sandwich are glued to the tail boom with epoxy resin with fiberglass microballoons and finally a layer of fiberglass is put on to reinforce the joint. This process is the same that the following in the shear webs of the rear wings.

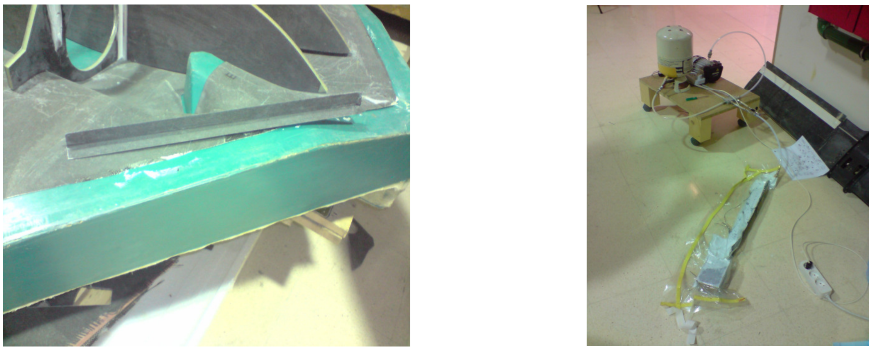
This is the final step for the tail boom manufacture.

4.5 Other parts

Besides the manufacture of the fuselage, the wings and the tail boom, other pieces of the Sensorcraft have been realized and designed.

4.5.1 Creation the support of the reservoir

It has been realized an L shape pieces with three layers of fibercarbon with a orientation of 45º following a VARTM process to be used as support of the reservoir on the central structure. This L pieces will serve as support to the reservoir and prevent these ones from resting on the skin and cause some hurts. One can see in the Figure 4.53 the VARTM process and the final piece. Once realized they will be joined to the structure by epoxy resin and some screw.



(a) (b)

Figure 4.53: Support of the reservoir creation: (a) Final piece; (b) VARTM process.

4.5.2 Design of the front landing gear

The landing gear was not designed in the initial Project. The idea is done a double front landing gear and the same for the rear landing gear with four wheels each, where to assure the stability of the aircraft is provided with two small wheels joined with one small tube of metal to each of the tops of the forewings.

The front landing gear would be retractable to reduce the drag, though the major difficulty is that the available space in the central structure to protect the landing gear is limited. In the Figure 4.54 is shown the initial design for the front landing gear realized by Catia. One can be seen that it consist of four wheels, arranged two to two and joined with a dulling system to a fixed part by means of a joint that would permit that the landing gear was retractable.

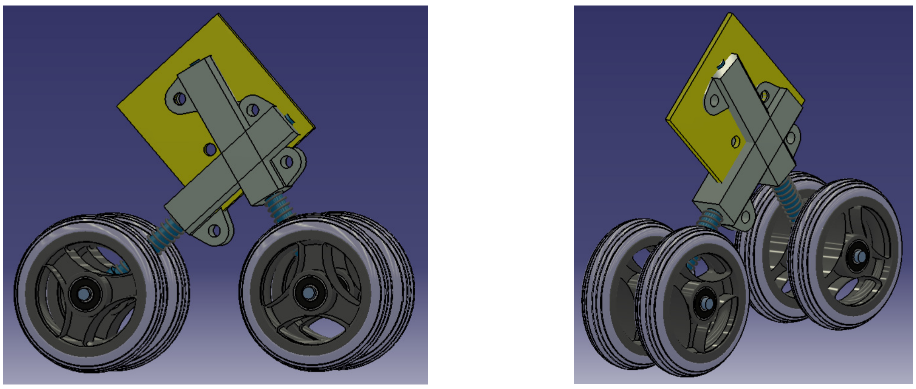


Figure 4.54: Front landing gear.

The rear landing gear and the wheels of the wings has not been designed at the end of this thesis. This work is left to a future work.

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Chapter 5

Future work and conclusions

5.1 Future work

The work realized in this thesis, the construction of the Joined Wing is not concluded, so the remaining work will be done in future projects or thesis. In relation to the manufacture of the fuselage the last task that remains is the joint between the bulkheads and the skin. Once the entire fuselage is done, the rear wings and the forewings will be finished as well the joints between them and between the forewings and the fuselage. Regards to the tail boom, it is necessary to design and realize the assemblies with the fuselage and the rear wings.

To conclude the structural part of the Joined Wing it is necessary to finish of designing and constructing the landing gear of the aircraft. Once ended the structure of the aircraft, the non-structural part is realized, it includes the choice of the engine, the servos to move the aileron and the vertical stabilizer, studied in other thesis, as well the retractable landing gear and the electronics such as the automatic pilot.

When everything is ended, all the systems will be tested and verified to assure the correct functioning. If it was necessary the aircraft will be sanded and painted. Once tested all the systems, the last tasks is to realize the flight tests to observe the behaviour of the aircraft and to compare the data with the studies realized in other thesis.

These tasks will be realized in the next months, now the work is stopped because the Canadian government retains the automatic pilot in its customs.

5.2 Conclusions

The principal aim of the Project was the construction of the Joined Wing, has been expired up to a certain point. During the whole thesis there have been arising not wished and not foreseen problems that have been late the project and it will not be finished. In spite of not having finishing the Joined Wing, it has been realized an extensive and laborious work for eight months in which it has been advanced in the construction of the UAV. There have been some mistakes because of the little experience in UAV's construction, overhead in the joint of the bulkheads that have provoked that the work has had to be repeated.

Thanks to these mistakes it has been learned how the work should be done, so if other one had to be done from zero, the time of the construction would be minor. In this project, it has been learned about composites and about methods of joint like the epoxy resin with fibreglass microballoons. Also it has learned about Catia in order to realize the landing gear and to open and to manage the files of the Joined Wing.

It could be said that the most part of the project is done, the rest of tasks rest for later projects.

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