# Manufacturing of a Joined Wing SensorCraft

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***Abstract***

Since the UAV's 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.

## 1 Introduction

This work is about an experimental relative to a non conventional and new type of aircraft configuration – the joined wing. The present document is a resume of the thesis [1] that one is invited to read for more detailed information. The work here presented, is divided into two different but connected parts: one is related to the manufacture of the moulds and the other is the manufacture of a 5m Joined Wing Sensorcraft future research tests.

### 1.1 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 1.1. The rear wing is both used for pitch control and as a structural support for the forward wing [2].

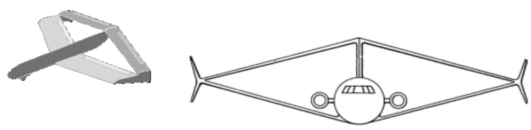


**Figure 1.1:** Joined Wing design.

Wolkovitch patented the first joined-wing design in 1976 [3], claiming that the aircraft would have a lighter yet stiffer structure when compared with a conventional wing-tail configuration.

This new configuration provides a versatile control capability as shown in Figure 1.2 below.

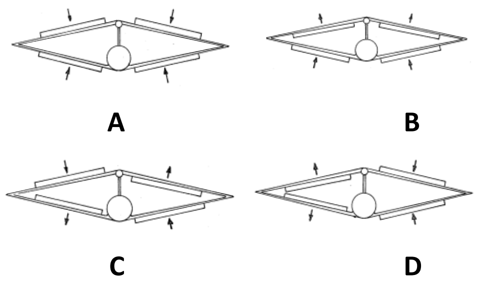



**Figure 1.2:** Joined Wing Control.
A - Pitch Control; B - Direct Lift Control; C - Roll Control; D - Direct Side Force Control

This configuration may also reduce the fuel consumption since the airplane has a higher wing area producing more lift. Another important characteristic of a non planar wings geometry airplane is the drag reduction achieved by an improved structural efficiency to accommodate larger spans without higher structural weight [4].

## 1.2 SensorCraft concept

Sensorcraft [5] 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.

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).

## 1.3 Boeing Joined Wing Sensorcraft

The design of the SensorCraft for the Remote Piloted Vehicle is a 1/9 scaled from the full aircraft. One can see a view of its design in Figure 1.3. Table 1.1 lists some of its geometric characteristics.

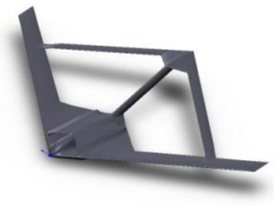


**Figure 1.3:** The Boeing Joined Wing SensorCraft.

| | Parameter | Value |
|---|---|---|
| | Wing Span | 5 m |
| | Length | 3.2 m |
| | Planar area | 3.3 $m^2$ |
| Front Wing | Root chord | 1.014 m |
| | Tip chord | 0.340 m |
| | Area | 0.973 $m^2$ |
| | Sweep Angle | 38º |
| | Dihedral Angle | 6º |
| | Root incident Angle | 3.2º |
| | Tip Incident Angle | -4.4º |
| | Twist Angle | 7.6º |
| Rear Wing | Chord | 0.222 m |
| | Area | 0.357 $m^2$ |
| | Sweep Angle | -38º |
| | Anhedral Angle | 8º |

**Table 1.1:** Sensorcraft's characteristics.

# 2 Composite sizing

To determine the composite sizing is done an stress analysis of the Aircraft using Ansys. To make the aircraft components is used plain weave carbon, uni-carbon and Divinicell foam core.

# 3 Manufacturing of the fuselage moulds

The fuselage consists on the main body and also includes a portion of the forward wing. The fuselage is manufacture from female moulds. These moulds have been built using CNC machinery due to their complex shape.

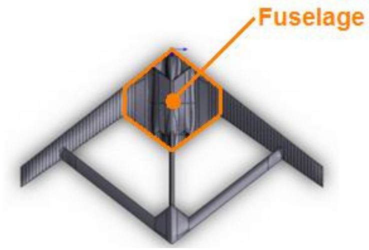



**Figure 3.1:** Fuselage.

The moulds (Figure 3.2) had already been built with low density polyurethane foam, because it is a very easy to machine.

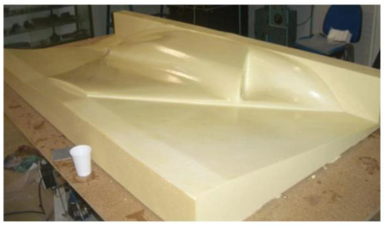


**Figure 3.2:** Female mould.

Since the moulds were constructed in two halves it became necessary to joint them and mount an adequate wood frame as chassis to build the fuselage (Figure 3.3).

**Figure 3.3:** Wood frame.

# 4 Manufacturing of the Joined Wing.

The construction of the aircraft starts with the fuselage, followed by the construction of the wings and the boom and finally the other parts.

## 4.1 Composites and methods

The materials choice fell on composites. Composite materials consist of strong fibers such as glass or carbon set in a matrix of plastic or epoxy resin, which is mechanically and chemically protective.

The fuselage skin is made with layers of glass and carbon fiber. The wings and the tail boom have a skin of fiberglass 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.

It has been used two methods of composites manufacture to build the fuselage: vacuum assisted resin transfer moulding (VARTM) in which 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 impregnation process. In this technique 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.

### 4.2.1 Fuselage skin

The fuselage skin consists of several layers of fibercarbon and fiberglass. In Figure 4.1 is shown the final piece of the bottom fuselage skin.

**Figure 4.1:** The bottom fuselage skin.

The inside of the aircraft has to accessible for different task of maintenance such as changing batteries or refueling. 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 center of the top fuselage. The center panel is reinforced to give it more stiffness. Figure 4.2 shows the access panels and the reinforcement of the center panel.

**Figure 4.2:** Access panels.

After this the top mould is painted with gel coat (see Figure 4.3) and then the fibers of glass and carbon are collocated above the top mould within a direction of 45º to the front.

**Figure 4.3:** Mould covered with gel coat.

Doing the same procedure as the bottom skin it is done the top skin (see Figure 4.4).

**Figure 4.4:** Top fuselage skin.

### 4.2.2 Bulkhead manufacture

The fuselage skins are not rigid enough to support all the loads in flight. Its interior requires a set of bulkheads (Figure 4.5) to provide the proper rigidity. These are made of PU foam with one layer of carbon fiber and fiber glass on both sides. They are after cut with a CNC machine.

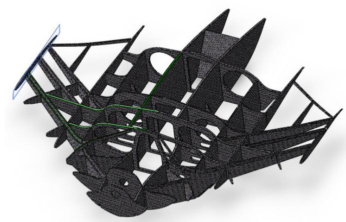
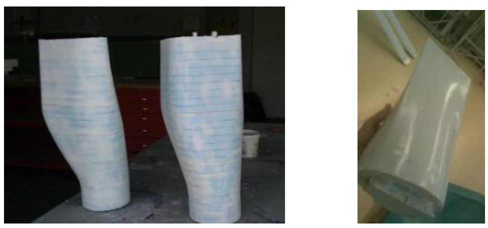


**Figure 4.5:** Bulkheads.

### 4.2.3 Air intake manufacture

Both the inlet and outlet require their own separate tooling (Figure 4.6).



(a) (b)

**Figure 4.6:** Intake and exhaust moulds: (a) intake moulds; (b) exhaust 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. The result is shown at Figure 4.7.

**Figure 4.7:** Exhausts.

### 4.2.4 Bulkhead assembly

Once all the pieces are available it is possible to start the structure assembly. Before start the assembling process it is needed to sand the pieces with a 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. The next step is to assembly it according to Catia® planes available. At this first step it is only developed the assembly of the fuselage central part (Figure 4.8). The central structure is divided in two separated longitudinally symmetrical parts, because the CNC machine where the bulkheads are developed was not able to make parts as large as the two transverse bulkheads, so it is decided to divide it in two parts.

**Figure 4.8:** Central bulkheads assembly.

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. The glue used to paste the pieces is epoxy resin with fiberglass microballoons and it is applied where two bulkheads are joined with a palette knife or with using the hands.

Once the resin is applied it needs to dry during a whole night, then the central structure is glued (see Figure 4.9).

**Figure 4.9:** 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 air inlet is pasted into the central structure and the two symmetrical parts are joined (Figure 4.10).

**Figure 4.10:** Joint of the two halves and air inlet glued.

When the central structure is finished, is done the exterior part of the fuselage. The bulkheads of the exterior part are reinforced by plywood's sheet lined by a fibercarbon layer by the fact that this part is the one that resists the forces and moments from the wing. The principal bulkheads are glued to the structure with resin epoxy with fiberglass microballoons and later sanded. Since it is a zone that receives big efforts, the joints of the main bulkheads of the exterior part with the central structure are reinforced with two layers of fiberglass following the impregnation process.

For the assembly between the fuselage and the forewing, since the bulkhead with the plywood is not too resistant, it has been done six plates of carbon, using twenty layers of fibercarbon and using the impregnation process to reinforce them. Also is realized both in the carbon plate and in the bulkheads holes to introduce some bolts to have a better fixation between the bulkhead and the carbon plate.

To finish the exterior part of the fuselage (see Figure 4.11) the bulkheads are cut according with the measures for the correct assembly between the forewing and the fuselage and are placed the pieces that do not support any effort.

**Figure 4.11:** Exterior part.

### 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 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.

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.

When the sheets are cured, they are joined at the structure with epoxy resin with fiberglass microballoons, see Figure 4.12.

**Figure 4.12:** Sheets glued to the structure.

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. 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 4.13.

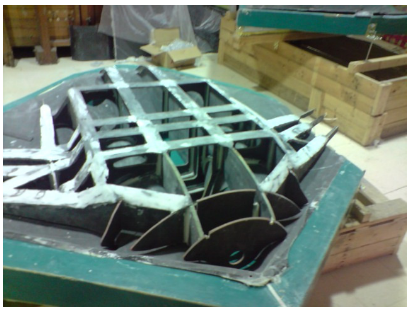


**Figure 4.13:** Filling the emptiness.

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.

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 4.14) are prepared to be joined to the skins.

**Figure 4.14:** Top part of the structure.

## 3.3 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 4.15 one can see a cross section of the rear wing.

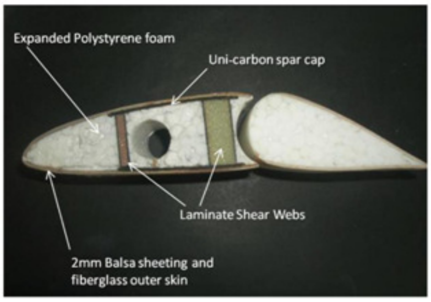



**Figure 4.15:** Rear wing cross section.

The wings have a core of foam and the structural components as the shear webs and wing ribs, are constructed using sandwich composite. 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. Finally with balsa wood the foam core is covered, see Figure 4.16.

**Figure 4.16:** 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.

## 4.4 Tail boom manufacture

The tail boom is done following the same procedure of the rear wings: foam core redressed of balsa wood and later cover with fiberglass. 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.

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.

The final tail boom can be seen at Figure 4.17.

**Figure 4.17:** Tail boom.

## 3.5 Other parts

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

### 3.5.1 Support of the reservoir

It has been realized an L shape pieces (see Figure 4.18) with three layers of fibercarbon with an 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.

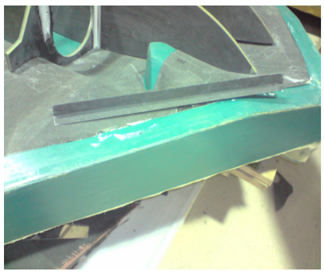


**Figure 4.18:** L piece.

### 4.5.1 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 4.19 is shown the initial design for the front landing gear realized by Catia®.

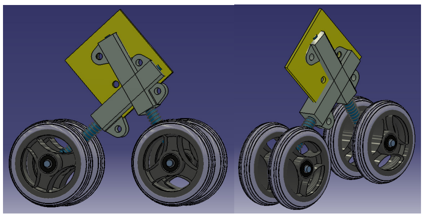


**Figure 4.19:** Design of the front landing gear.

# 5 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 Summary 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.

## 6 Acknowledgements

I am especially grateful to Hannibal Motta, for his insightful ideas and suggestions, principally for his help in this project and his support during all the time.

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