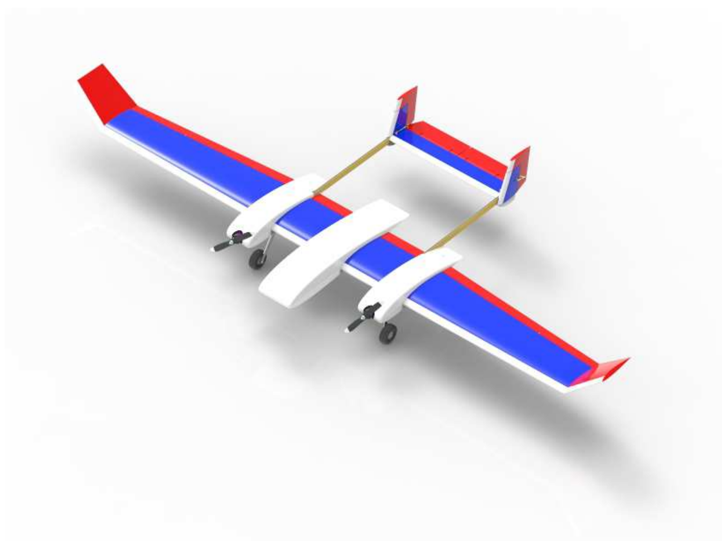
MTA SZTAKI
Hungarian Academy of Sciences
Institute for Computer Science and Control

Sindy UAV test platform assembly manual



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Chapter 1

Introduction

Figure 1.1. Take-off during a test flight

This practical assembly manual explains the reproduction of the UAV test platform designed by MTA SZTAKI, by providing comprehensive information and going into the detail of the assembly of each component.

The aircraft was designed with the aim to serve as a test platform for UAV on-board avionics system development. The mathematical model is identified, and is available on the project's webpage [1]. The main goal was to create an easily reproducible aircraft using accessible parts and simple technologies, which only require ordinary tools. This feature and the available mathematical model combined make this aircraft a good platform for control research purposes.

Since the integration of UAVs to common airspace requires safe aircraft [2], considerable effort is put in the development of safety critical UAVs. The twin boom configuration of the airframe offers duplicated control surfaces, even the elevator is split. This redundancy, in addition to the two electric motors enables this plane to serve as a test platform for various research purposes like reconfiguring control developments, sense and avoid collision avoidance system and many others.

Figure 1.2. Sindy (CAD model)

The fuselage is entirely reserved for the payload; it can carry up to 1-4 kilograms of avionics and test equipment. It has a modular structure: different set-ups can be installed to the frontal section in a few minutes, and the fuselage itself is also easily changeable.

The fact that easy reproduction was given as a priority over weight reduction is significantly constrained the possible shapes and the quality of the parts used. The base materials of the aircraft are polystyrene foam and plywood which made the easy modification possible.

The vast majority of the components are either laser cut plywood or hot-wire cut polystyrene. Such technologies provide the cheap and fast manufacturing of the components. In case of the few parts where the strength of plywood is not sufficient, printed circuit board core material (FR-4) is preferred and PCB milling is an accessible technology. Additional exceptions are the coverings of the nacelles and the fuselage, which are thermoformed in vacuum. The thermoforming process and the construction of an inexpensive mold is described in this manual.

The use of precut parts enables a fast assembly: a new aircraft can be built in about 180 man-hours. For three people, the assembly spans through 8 workdays, taking the curing times into account.

This manual focuses on the step by step process of the reproduction of the airframe, precise drawings and dimensions can be found in the CAD models. The used materials are listed in the appendix of this document. All necessary drawings, CAD models (see Fig. 1.2) and other useful resources necessary for the fabrication of the aircraft are provided on the website of MTA SZTAKI's Aerospace Guidance, Navigation and Control Group (`uav.sztaki.hu`).

Chapter 2

Wing spars and tail booms

2.1 Introduction

During the designing of the wing spars the main aim was to create a sufficiently strong, yet easily constructible spar, which can be built from accessible parts. The wingspan of the aircraft is ca. 3.5 meters, but since the most common length for carbon tubes is 1 meter, so the wingspar is divided into 3 parts: two outer, and a middle section. The tailbooms are exactly 1 meter long for the same reason. To connect the divided wing spar sections and the tailbooms, spar belts are used (see in subsection 3.3.1).

The spar itself is constructed of two square carbon tubes (see list of materials) fixed together by plywood slats as shown in the section view Fig. 2.1. Since the elasticity modulus of plywood is much less than that of carbon, most of the normal stress caused by the bending will act on the carbon rods, not on plywood, the main load of which is shear stress.

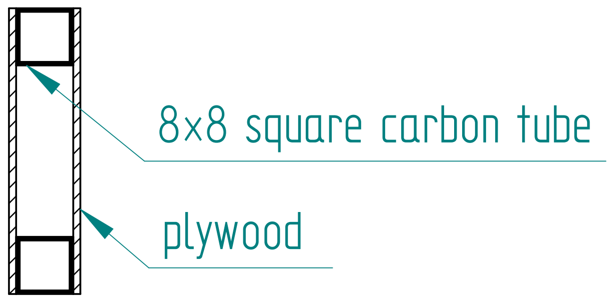


Figure 2.1. Section view of the wing spar

The plywood slats are also divided to smaller parts in order to fit on 500 mm long plywood sheets. The contact surface between plywood parts are orientated 45 degrees, in order to reduce shear stress along the contact surface. This solution is based on the approximation that the load of the plywood slat is only shearing. In this case on a 45 degree contact surface solely compression will occur.

The inner structures of the spars and tailbooms are shown in Fig. 2.2, Fig. 2.5 and Fig. 2.6. Inside the spars, 4-5 spacers are located perpendicularly to help the carbon tubes stay in the desired location during gluing. Longitudinally placed spacers are also used, in order to prevent the cracking of the plywood slats during the vacuum lamination process.

Carbon tubes are not entirely suitable to be stressed with high forces normal to their faces. However, in the section of the connecting belts, especially in case of high wing loads, surface pressure might be a problem. To make the spar strong enough at these locations, bearer parts are placed, and epoxy is inserted into the carbon tubes, thus forming plugs (see in Subsection 2.5).

2.2 Wing spars of the outer wing section

The spars consist of laser cut plywood parts and two $8 \times 8 \times 1000$ mm square carbon tubes. Since the wing is trapezoidal, the spar itself also has a wider and a narrower side. The surfaces of the carbon tubes where gluing takes place need to be slightly sanded, in order to make gluing effective. This is a critical step, one should take care about that the surface of the carbon rods where gluing takes place is free from any residue of release agent. Grinding can also be used to remove ash from laser cut edges of wooden parts, where gluing takes place.

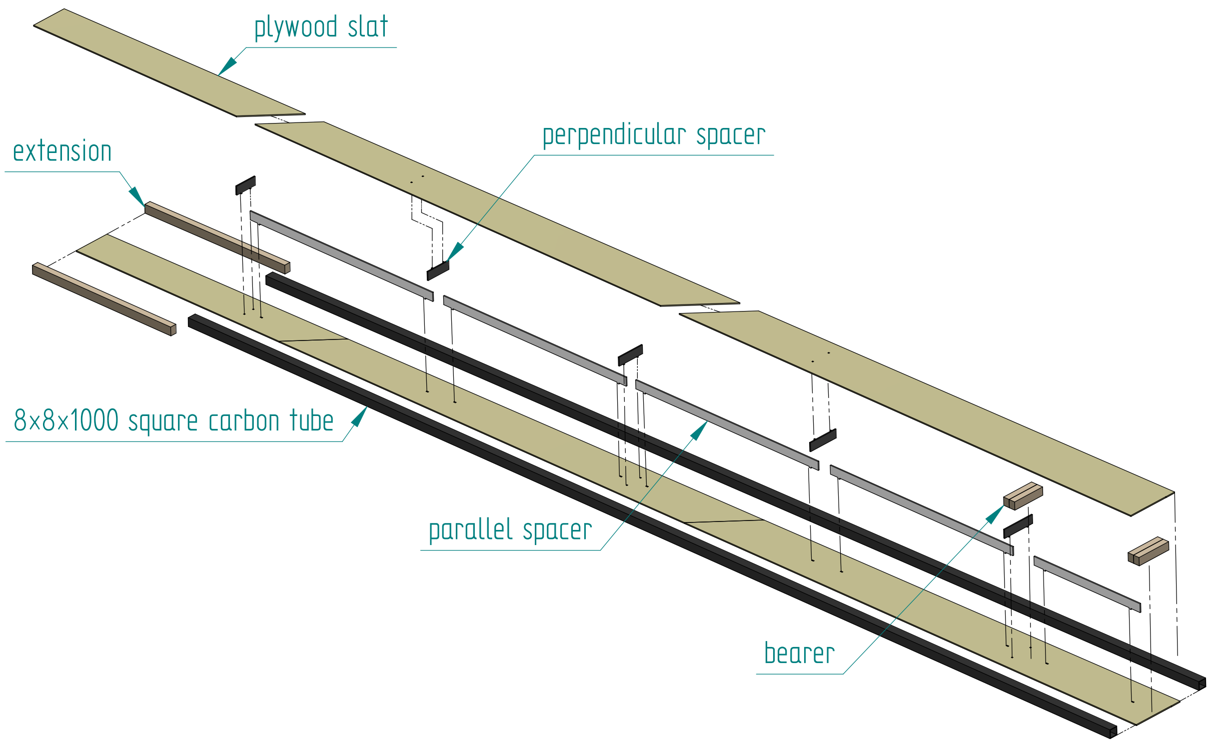


Figure 2.2. Exploded view of the outer wing's spar

First step of the assembly is the construction of the plywood slats. They can be glued with cyanoacrylate (CA) glue on the 45 degree contact surfaces. It is recommended that the glue should be applied on the outer surface, which is not connected with the carbon tubes. While parallel alignment of the parts can be ensured by a long, preferably steel, ruler (Fig. 2.4 left photo). The next step is gluing the inner parts (perpendicular and parallel spacers) in place with CA glue. However, two assembled slats are different; the longitudinal spacers are located only on one side, while the perpendicular spacers are located on both sides(Fig. 2.2). The perpendicular spacers are not interchangeable, because of the taper of the spar. There are precut holes for each spacers to make the fitting easier. Since the spar itself is longer than 1 meter, extension parts have to be placed behind the tubes, fixed with CA glue to one side.

The carbon tubes, the bearer parts, and the other side of carbon tube extensions are fixed with epoxy resin. EPOLAM2017 epoxy is used everywhere. It is best to have all the parts prepared and fittings checked before starting, so as to be able to finish the following steps before epoxy curing starts. If the slats are done and fitted with the spacers, you can apply some epoxy on the contact surfaces of the carbon tubes, and put them to their place, preferably on the spar which has the longitudinal spacers (Fig. 2.4 middle photo). Spanwise, the tubes are located on the edge of the inner side of the spar, while in the

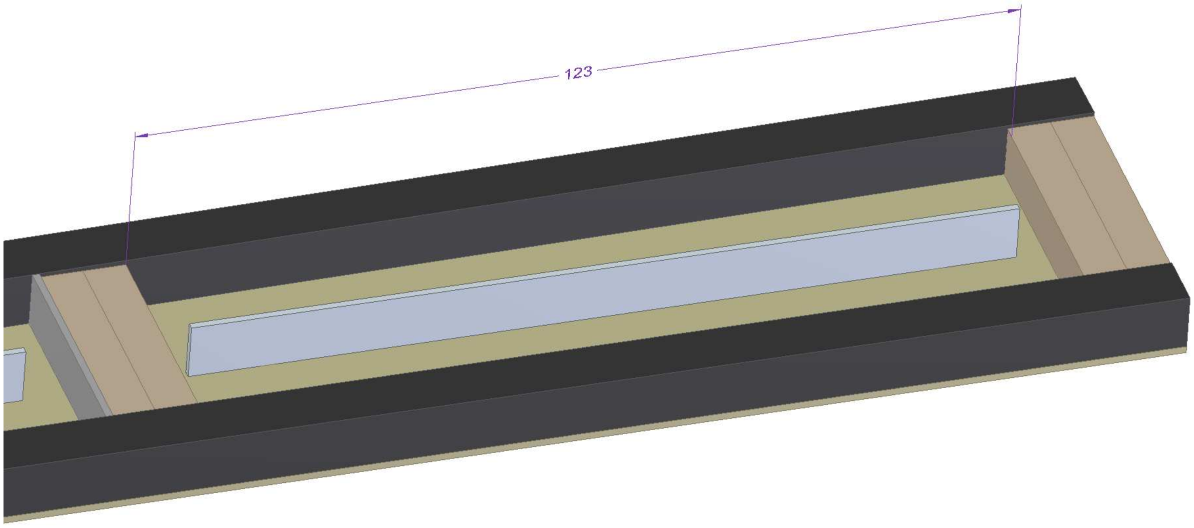


Figure 2.3. Placing of the bearer parts

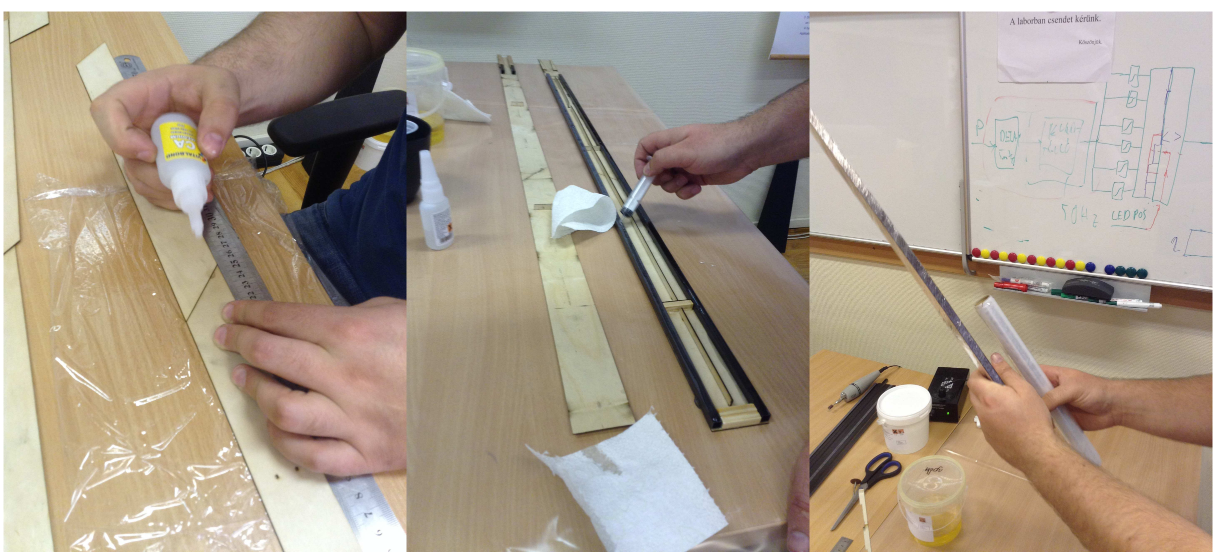


Figure 2.4. Steps of a spar assembly

other direction, perpendicular spacers keep the tubes in place. The bearer parts need to placed on the wider end of the spar. Two of these bearer parts should be placed directly on the edge, while the two inner ones are to be placed next to the spanwise innermost perpendicular spacer, as Fig. 2.3 shows. With correct placement the distance is exactly 123 mm between the bearers. After all of the above components are in place, the other plywood slat can be fitted. It is essential to ensure sufficient clamping during the curing. To achieve this, spars were wrapped tightly in multiple layers of cling film (Fig. 2.4 right photo).

2.3 Wing spar of the central wing section

The structure of the spar of central wing section is quite similar to the outer wing section's one see Fig. 2.5. One of the differences is that its length is only 1 meter, therefore there is no need for an extension. This wing section is not trapezoidal, so perpendicular spacers are interchangeable. Another difference is that this spar is attached to the spars of the outer wing sections, so bearer parts can be found on both sides. In this case the distance between bearers is 122 mm. The construction steps are identical to that of the outer wing section.

2.4 Tailboom assembly

The tailboom has a very similar structure as the wing spars described above. Cables are run through the tailboom to connect the servos, therefore, perpendicular spacers with openings are used see Fig. 2.6. Since tailbooms are not involved in vacuum laminating, there is no need to use longitudinal spacers. Distance between bearer parts is 48 mm.

2.5 Filling the carbon tubes

As described in the introduction, carbon tubes need to be strengthened at the section of connecting belts. By filling the critical section of carbon tubes with epoxy resin or polyurethane resin small plugs are formed (Axon System's F19 resin is used), These plugs provide additional strength at these specific sections (the bearer parts are used for the same reason). Approximately 1 cm^3 is needed for each plug. Wad should be placed into the carbon tubes to the specified depths (Fig. 2.7). These depths are 150 mm and 15 mm

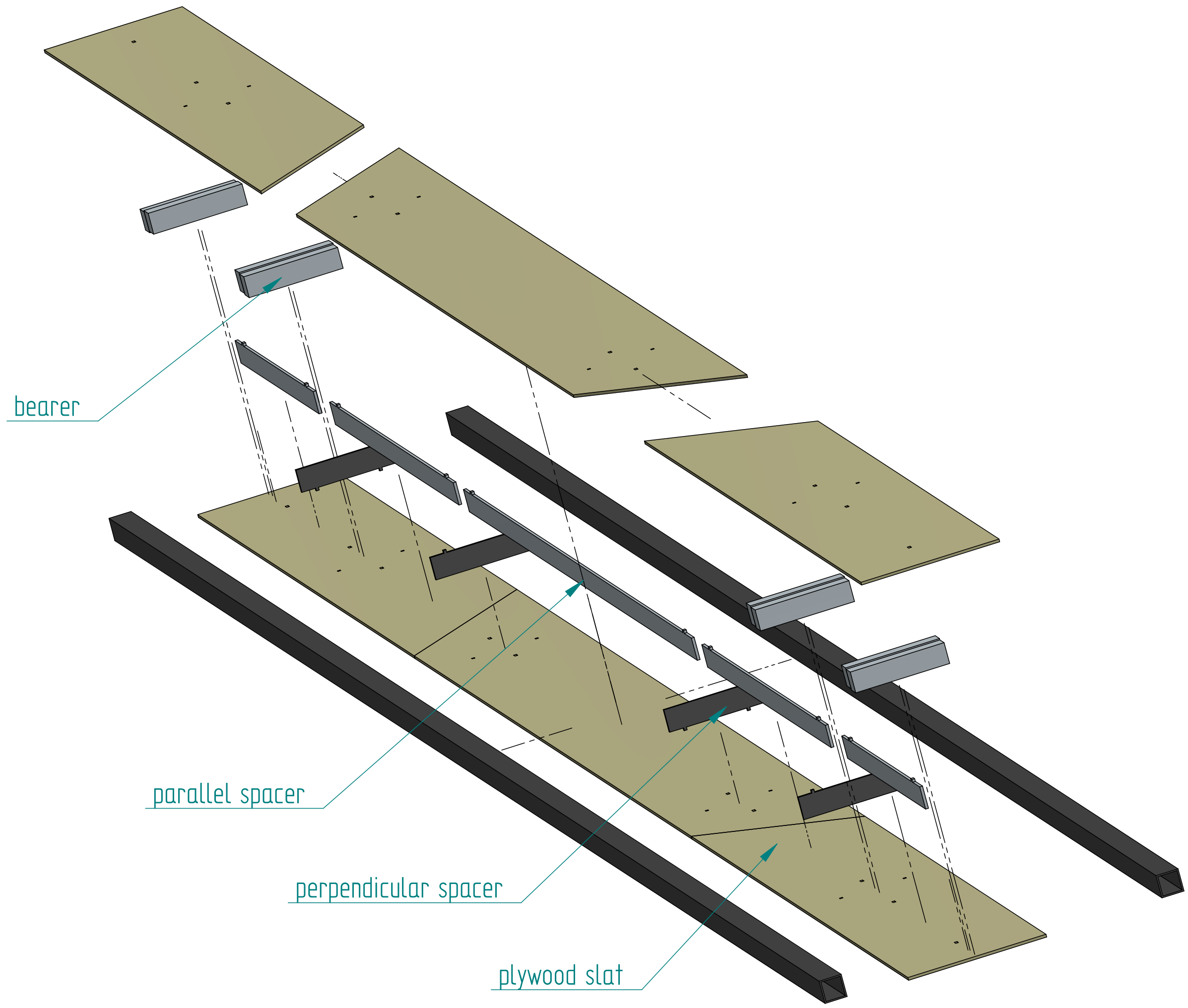


Figure 2.5. Exploded view of the central wing section's spar

in each carbon tube of the wing spars (outer and central sections as well), while at the tailbooms the depths are 65 mm and 15 mm. Thus, the epoxy forms two plugs in each carbon tube in the position of the wing belts. After the formation of the inner plugs, a check needs to be performed (again with a small rod); it is vital to verify if the plugs are formed correctly, or there had been a leakage.

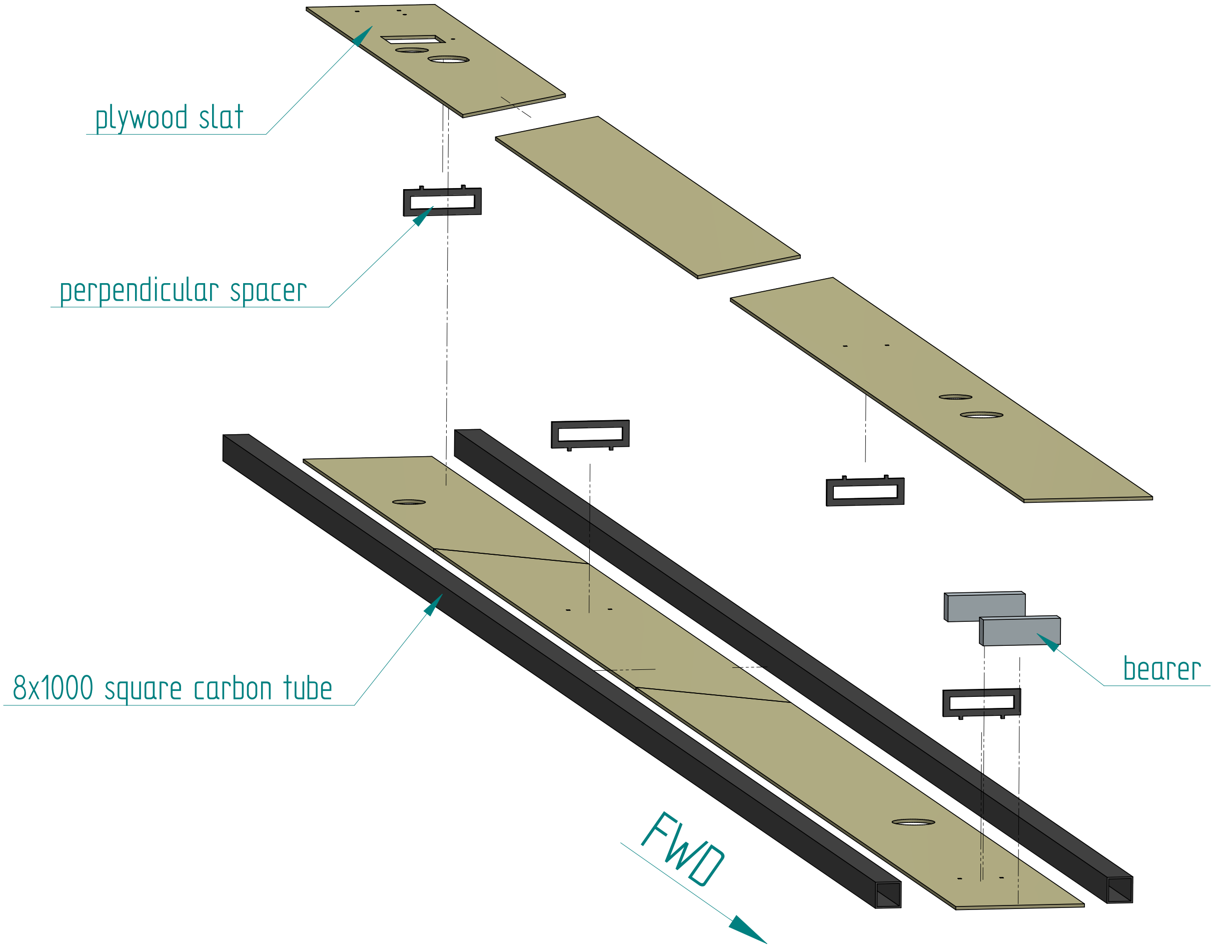


Figure 2.6. Exploded view of the tailboom

Figure 2.7. Forming the epoxy plugs

Chapter 3

Fuselage and nacelles

3.1 Introduction

The structure of the nacelles and of the fuselage is quite similar. However, while the fuselage is reserved for the payload, the nacelle has important structural roles as well: connecting the wing spars and and holding the tailboom, and the landing gears are also mounted on them.

3.2 Fuselage

3.2.1 Main parts

The assembly of the fuselage is quite simple; the laser-cut parts are fixed together with generously applied wood glue (main parts are shown in Fig. 3.1). It is essential to clamp during drying, using rubber bands, wires or clamps; but care should be taken to prevent deformation. Prior to gluing, the laser-cut surfaces need to be slightly sanded. By the removal of ash from these surfaces, the bonding is improved (in Fig. 3.2 the main steps are shown).

3.2.2 Spacers for the cover

The fuselage covers are supported on spacers (Fig. 3.3). The bottom side of the fuselage cover is fixed with screws, and it has 6 spacers, placed in each corner and in the middle of the fuselage (the two rear ones are shown on Fig. 3.3). Since the screws are driven in parallel with the layers of the plywood, 6 mm thickness might not be enough to prevent cracking between layers, that is why the spacers are constructed of two 6 mm thick plywood parts. The parts are fixed together and to the fuselage with wood glue. The upper covering is easily removable: when assembled it can be slid to the front direction. To enable this, its frontal section is fixed by wedges, while rear section is fixed with one screw and a sheet nut. The nut is put on a small stand (assembled with wood glue), which places the nut in correct position.

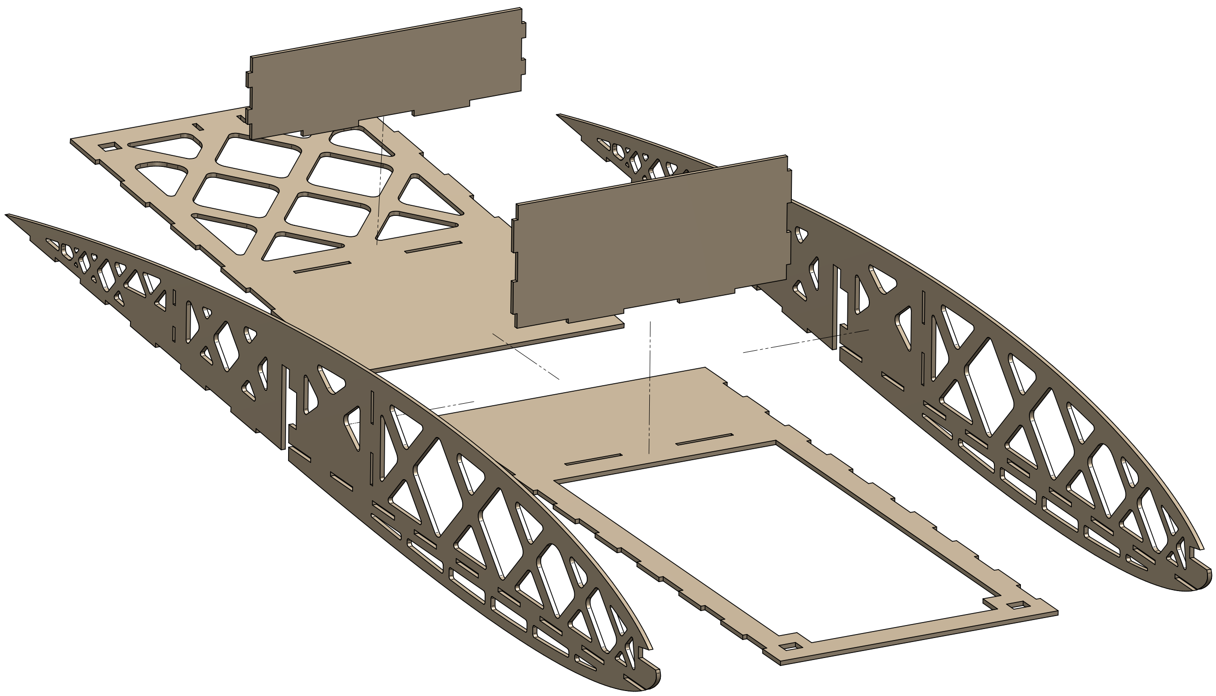


Figure 3.1. Exploded view of the fuselage's main elements

3.2.3 Diagonal reinforcement

A diagonal reinforcement is needed to provide sufficient torsional stiffness for the fuselage. Since it is located over a cargo bay, easy removal and installation on a daily basis is important. To enable this, the reinforcement part is fixed by T-nuts and screws instead of wood screws, which would wear the thread out after a few removals. The assembly and installation of the diagonal reinforcement is shown in Fig. 3.4. First the corners need to be made thicker, to provide enough area for the wood nuts, laser cut plywood parts of 3 mm thickness need to be glued in each corner of the diagonal reinforcement part. On the fuselage precut holes show the location for the fasteners. It is very important to ensure tight fitting in place, so the diagonal reinforcement is made slightly longer, and has to be

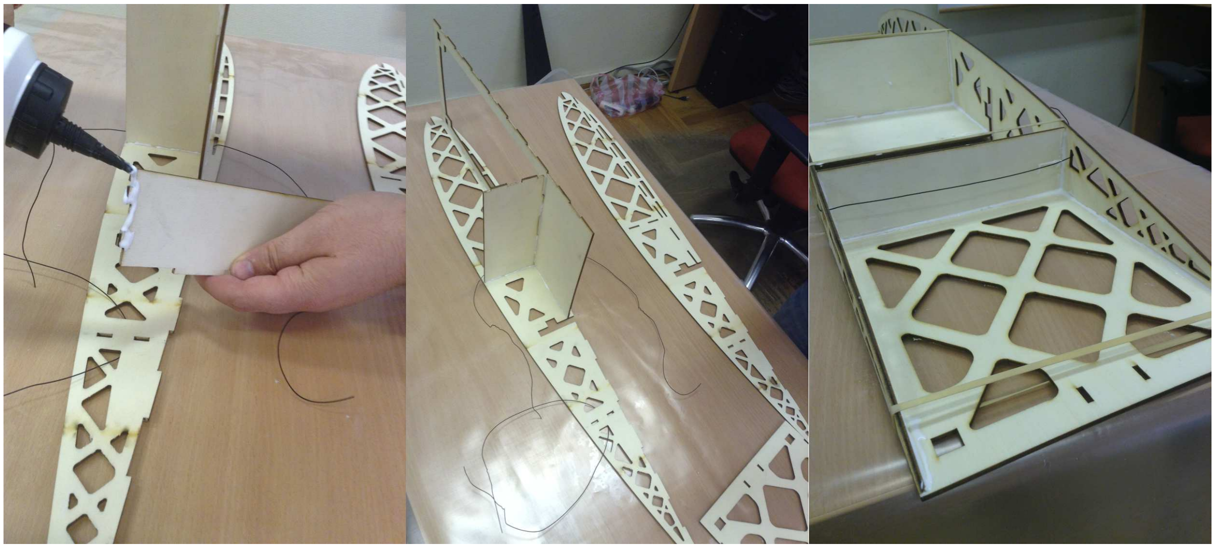


Figure 3.2. Steps of fuselage gluing

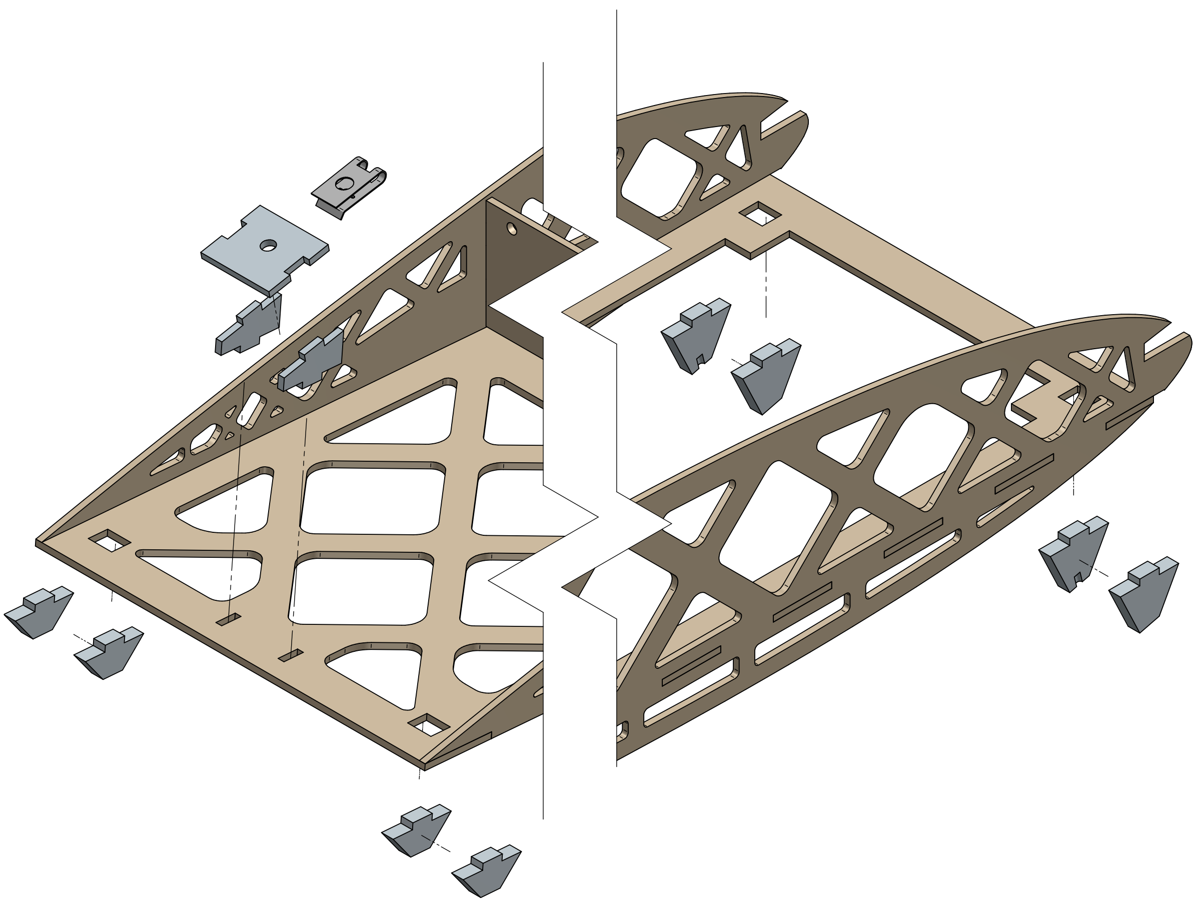


Figure 3.3. Retainer parts for the fuselage covering

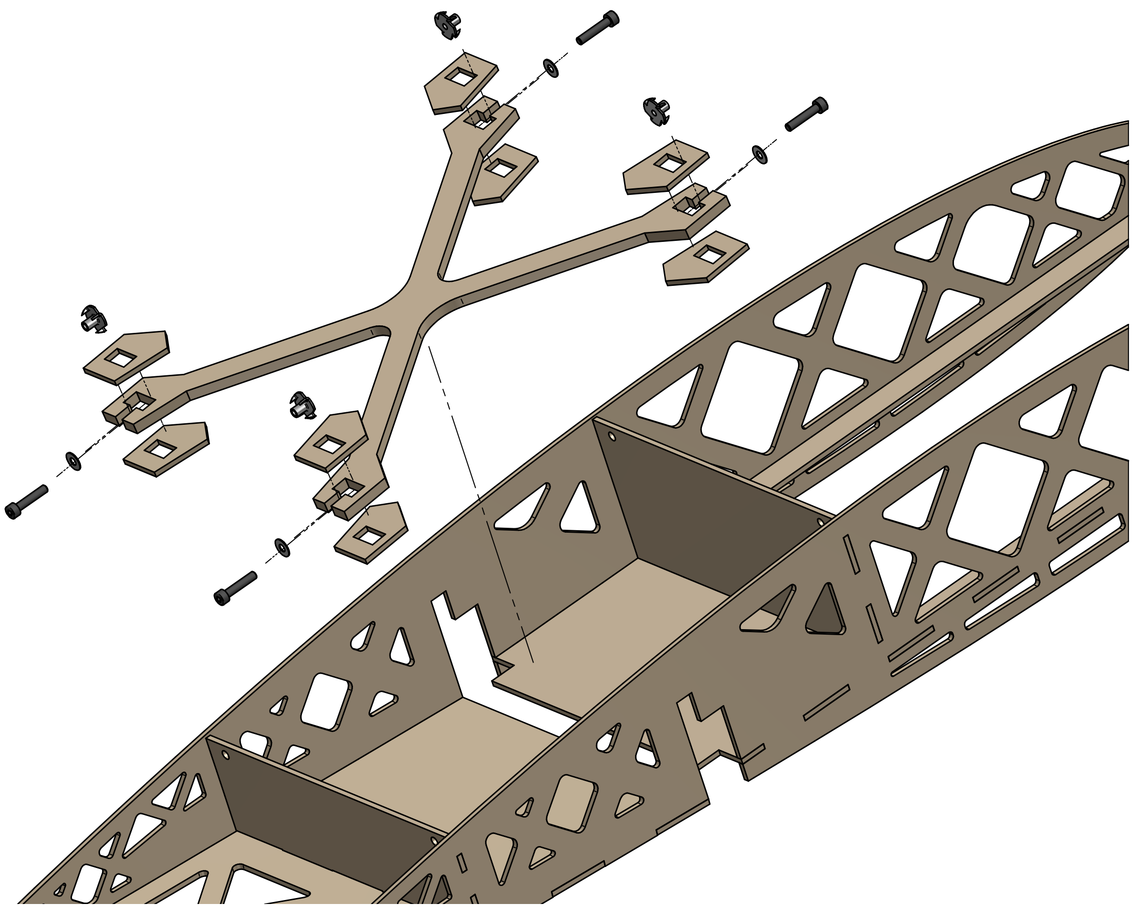


Figure 3.4. Diagonal reinforcement of the fuselage

grinded on the connecting surfaces to fit in. At the end of this sub-assembly the wood nuts are pulled into the wood by tightening the screws.

3.3 Nacelles

3.3.1 Spar belts

The spar belts are constructed form multiple layers of PCB core material (2 mm thick FR-4 material is used), which is easily accessible and get them cut to the correct shape, yet quite cheap and strong. These belts has a thickness of 10 mm, to reach this 5 layers is used. As it is shown in Fig. 3.5 in the aircraft two different shaped spar belts are used. The outer one is only for fixing wing spars together, while the inner one supports the landing gear and the tailboom as well. The belts are fixed to the side ribs of the nacelles, by the same method as it's layers together: by epoxy (see Fig. 3.6). Two screws in each belt helps to find the correct position, and keep the belt tight during the polymerisation. Before applying epoxy, the layers have to be sanded.

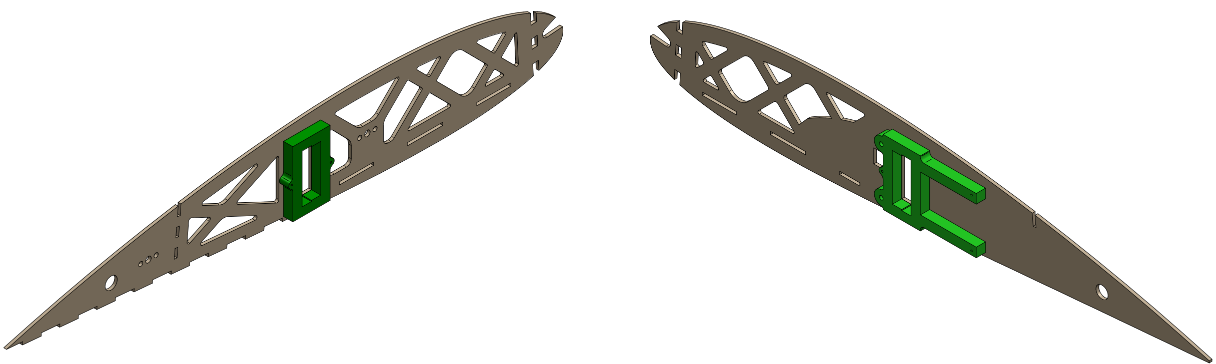


Figure 3.5. Outer and inner spar belts

The tailboom is enclosed between the inner nacelle rib and a side plate, and fixed with epoxy resin. The same screws are used for positioning again. The extending threads need to be cut later. The threads for the landing gear strut screws should be cut at this point, because later they will hardly accessible.

3.3.2 Inner structure of the vertical fin

Before continuing with further assembly of the nacelle, it is practical to build the vertical fins first. Each fin has 2 carbon spars, and 4 ribs in between. The upper and lower ones

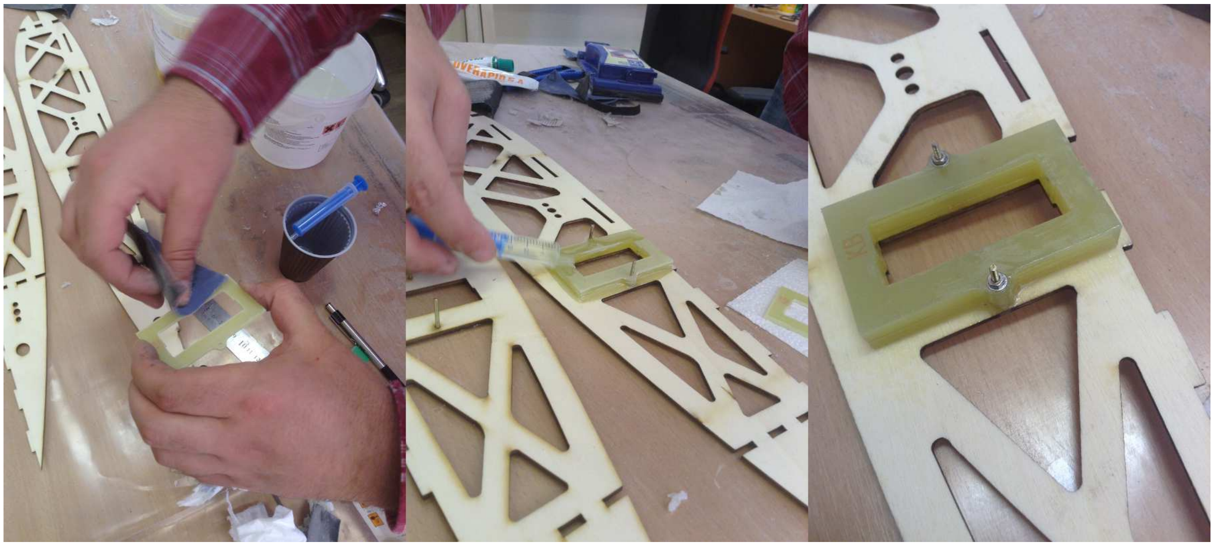


Figure 3.6. Assembling the spar belts from layers

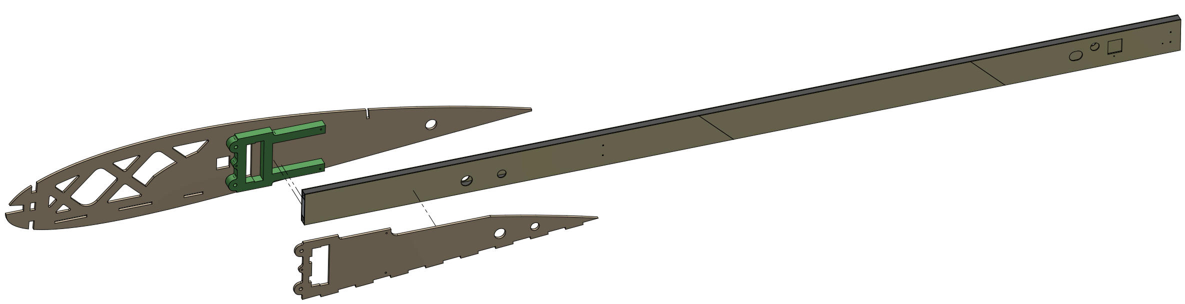


Figure 3.7. Tailboom assembly

are simple laser cut plywood parts, but to provide housing for two servos in the relatively small volume of the fin, servos are integrated to the middle rib, as shown in Fig. 3.9. As a first step the two carbon rods need to be cut. The next step is to fix the major parts together with a small amount of CA glue (Fig. 3.8 left photo). The servos need to be fixed together and to a plywood fork between them, with two bolts and 6 nuts. Fix the connecting elements with wood screws to the outer mountings of the servos, place between the carbon rods and move upwards, to find it's position, then fix with a small amount of CA glue (Fig. 3.8 middle photo). As a last step put filler mixed epoxy resin all around the joints. It is vital to apply the epoxy generously. Microballons are added to epoxy in a volume ratio of 2:1 (in favour of microballons).

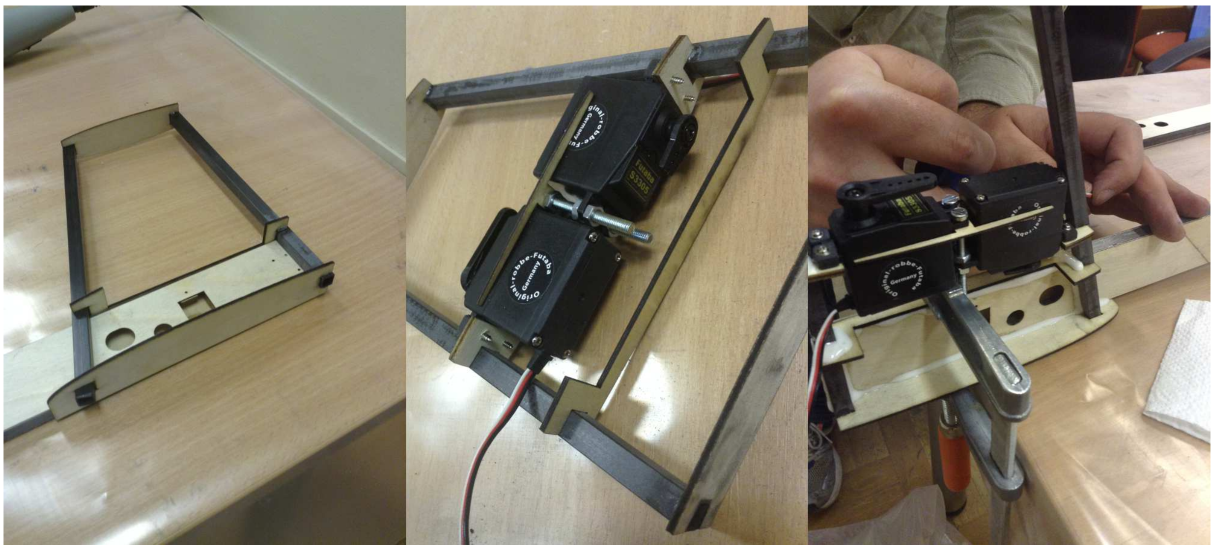


Figure 3.8. Vertical fin assembly steps

3.3.3 Gluing the main parts of the nacelle

Gluing the main parts of the nacelle is more or less the same process, as the gluing of the fuselage in subsection 3.2.1. The exploded view of the main components is shown in Fig. 3.10.

The connections of the wingspars and the spar belts are critical points, tight fitting needed between these parts. The wingspar of the central wing section is also glued to a plywood panel of the nacelle. Wedges are inserted to the sparbelt slots, to apply pressure on this plywood panel while the nacelle is being glued (Fig. 3.11). Later grinding on the spar belts and plywood panel might also be needed, if overlapping encountered during

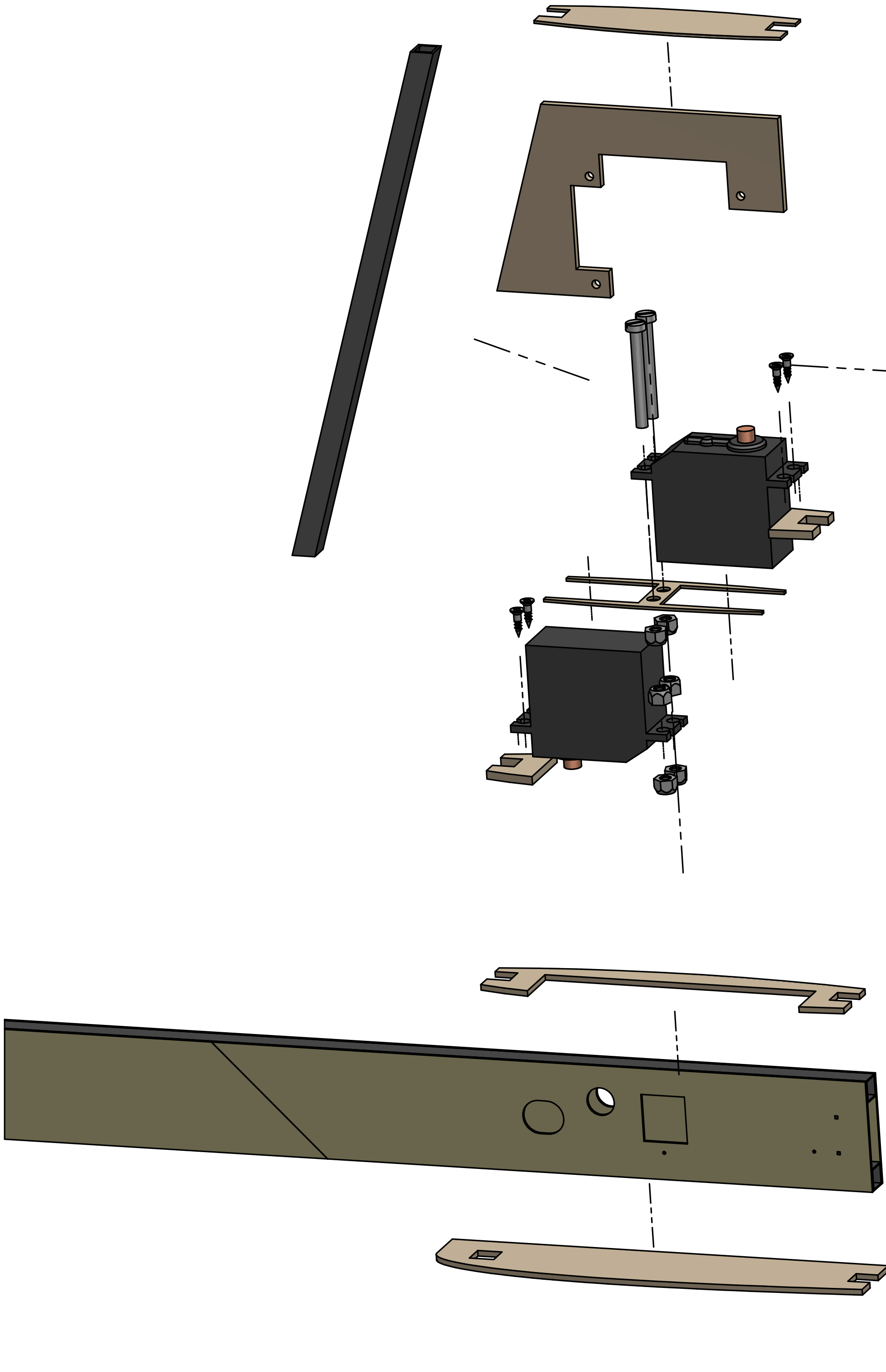


Figure 3.9. Exploded view of the vertical fin

the spar fitting.

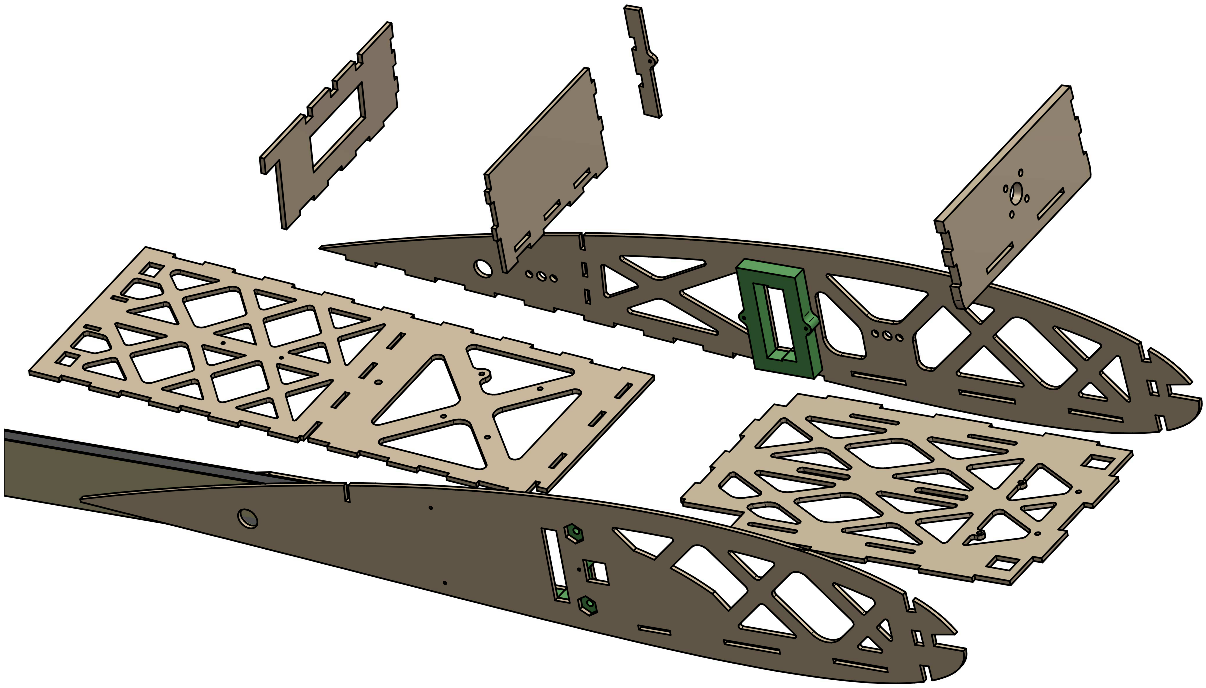


Figure 3.10. Exploded view of the main parts of the nacelle

Figure 3.11. Gluing of the nacelle

Chapter 4

Nacelle and fuselage covering

4.1 Introduction

The cover provides fairing for the fuselage and nacelles. The coverings are from low density PVC foam sheets, which are first bent and glued to an approximate shape, then put into a plaster mould, and vacuum formed to adopt it's final shape. An advantage of this material is, that compared to more expensive materials like glass or carbon fiber composites, holes or orifices could be more easily cut on it for instruments, connectors or for other equipment.

A simpler manufacturing process is described in section 4.8, where vacuum forming is not needed for the production of the coverings. In case of this choice the sections 4.2–4.5 can be skipped.

4.2 Flat patterns and folding

To create the shape of the fuselage and nacelles from a PVC foam sheet, the temperature dependent elasticity of this type of sheets are not high enough. Therefore a flat pattern need to be cut, which close enough to the original shape, when it is bent, thus creating a raw part. The drawing of the patterns is shown in Fig. 4.1 and Table 4.1 contains the dimensions of the four types of parts. Notice, that the bottom part of the nacelle has different pattern. Dimension 'J' on the bottom of the figure refers just to the nacelle bottom, and dimension 'I' does not apply to this part.

When the patterns are ready, the next step is folding up the sides (steps of folding are shown in Fig. 4.2, and photo of the process can be found in Fig. 4.3). The sheet needs

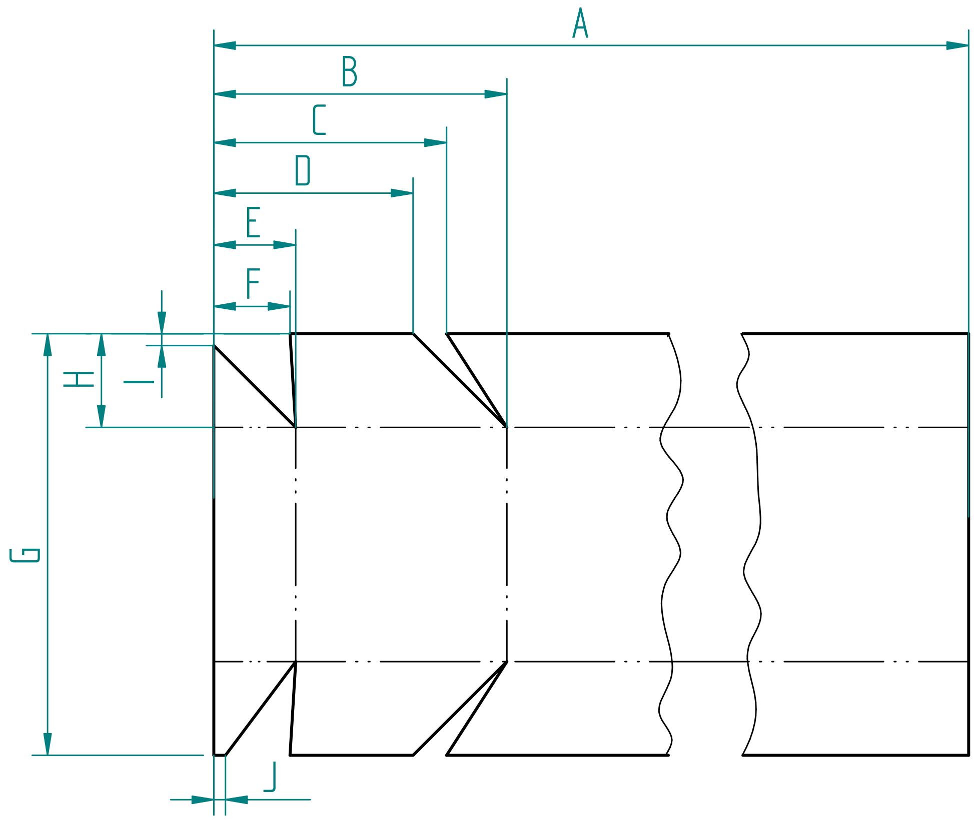


Figure 4.1. Dimensions of the sheets

	Fuselage bottom	**Fuselage top**	**Nacelle bottom**	**Nacelle top**
A	1076	1106	793	813
B	250	414	207	333
C	199	354	154	284
D	170	304	127	233
E	70	85	90	90
F	65	77	88	87
G	360	420	310	350
H	80	110	80	100
I	10	25	-	10
J	-	-	10	-

Table 4.1. Dimensions of the covering sheets

to be heated up along the folding line, for this hand held electric heat gun is used. The non-folding parts of the sheet are fixed with wood laths and clamps. A spacer halfway between the clamps is placed, to provide sufficient squeezing force in the middle region as well. Try to heat up the sheet evenly along the folding line, and the projecting parts will start to fold down. Sustain heating until the bend reaches nearly 90 degrees, then immediately press with another lath to ensure the perpendicular position. The cutted and glued side have to be covered with a wood slat, otherwise the connections could melt.

When the two sides are bent, the next step is to glue the edges of the cut outs, to create the bent shape of the coverings. For this gluing CA glue is used with activator spray. As a last step cut the exceeding corners (with a segmented blade knife), which would not fit into the plaster mould (Fig. 4.7). Now the part is ready for vacuum forming.

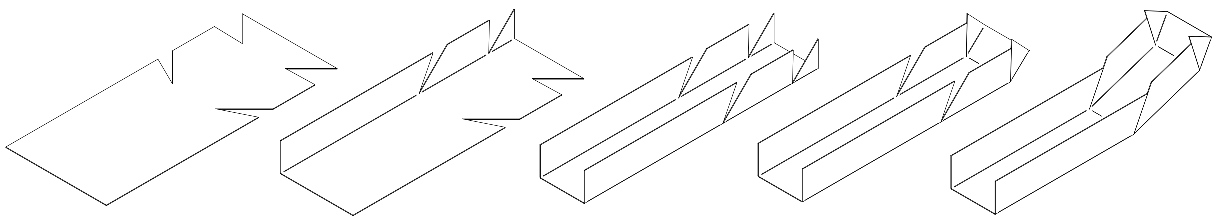


Figure 4.2. Folding steps

4.3 Plaster mould

The moulds for the vacuum forming process are made of plaster. A negative shape is needed to be created for the fuselage and nacelle coverings. As a first step, one needs to create the contour of the covering elements, the corner radius is shaped later.

There are different laser cut plywood containers for each covering element, each contains the specific outer contour of the part. The assembling of these containers is fairly easy, just some connecting parts are needed to be placed between the two sides. The front, rear and bottom of the mould is closed with plywood walls. Insulation material is placed on the bottom of the mould.

The container is then filled up with plaster (gypsum plaster is used) (Fig. 4.4). It is recommend to start with more dense plaster to prevent leakage, and for the final steps, to smoothen the contour, use thinner material. The final step is the key for an accurate mould, so sanding is needed, and maybe another layer of skin coat plaster as well.

As the contour surface is finished, the next step is to shape the 30 mm corner radius. Two sideplates can be fitted on the walls of the container (Fig. 4.5). A tool with spherical form and 30 mm diameter is needed. Put some plaster to the corners, and create the

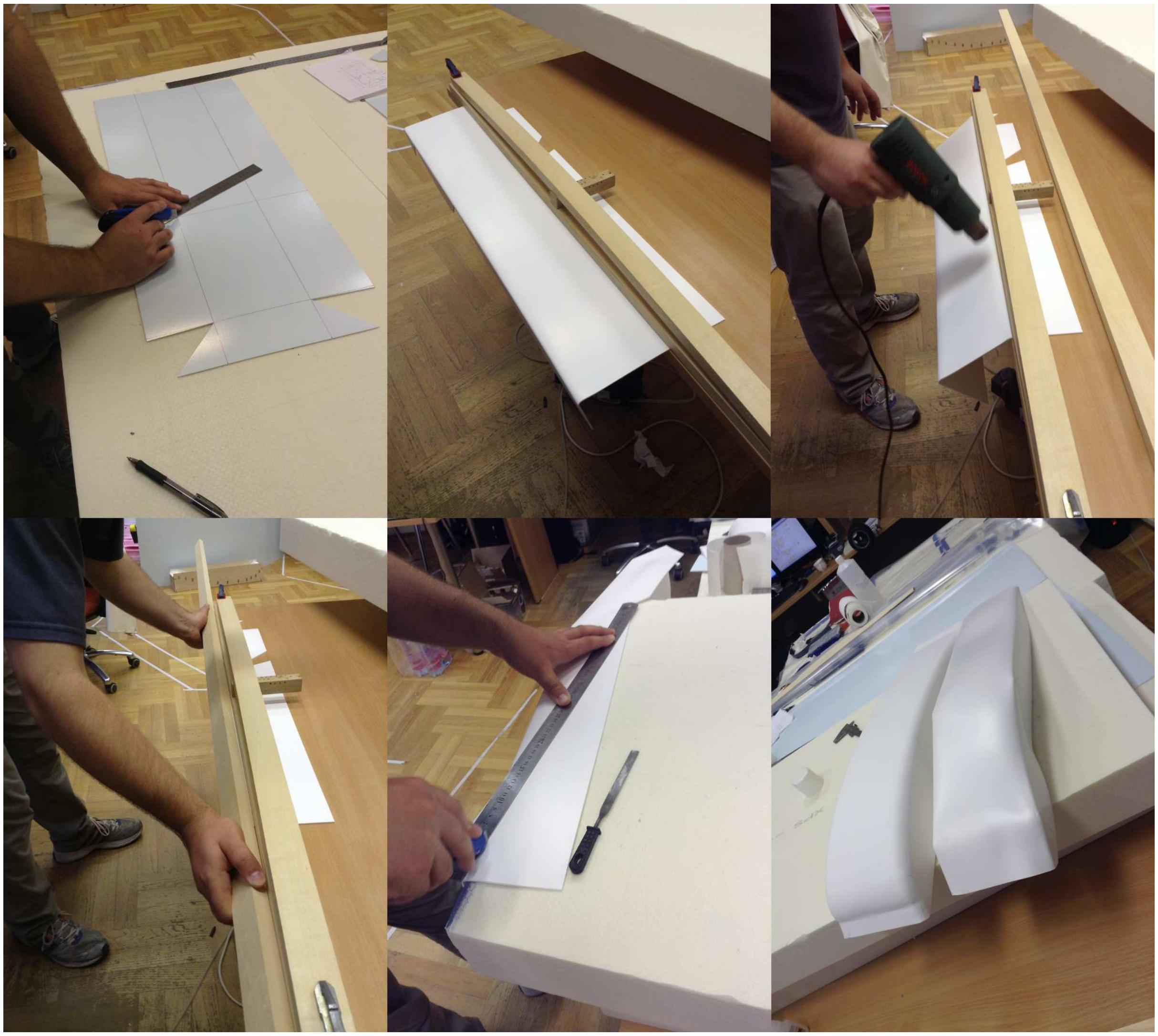


Figure 4.3. Creating the approximate shape

shape with the spherical tool, remove the excessing material, and after drying sand it with a sandpaper to create smooth transition between elements (Fig. 4.6).

4.4 Vacuum forming

A suitable vacuum bag need to be created for the forming process, but unlike vacuum bags used during lamination, in this case a more heat resistant bag is needed, that is the reason why bag created from rubber sheets is used. These rubber sheets are used as bed-sheets in hospitals. These sheets are usually covered with powder, to prevent sticking. For the effective gluing, this powder need to be washed out from the region of the edges. One should wash the edges several time to get rid of the powder, acetone is an effective

Figure 4.4. Filling the plaster into the container

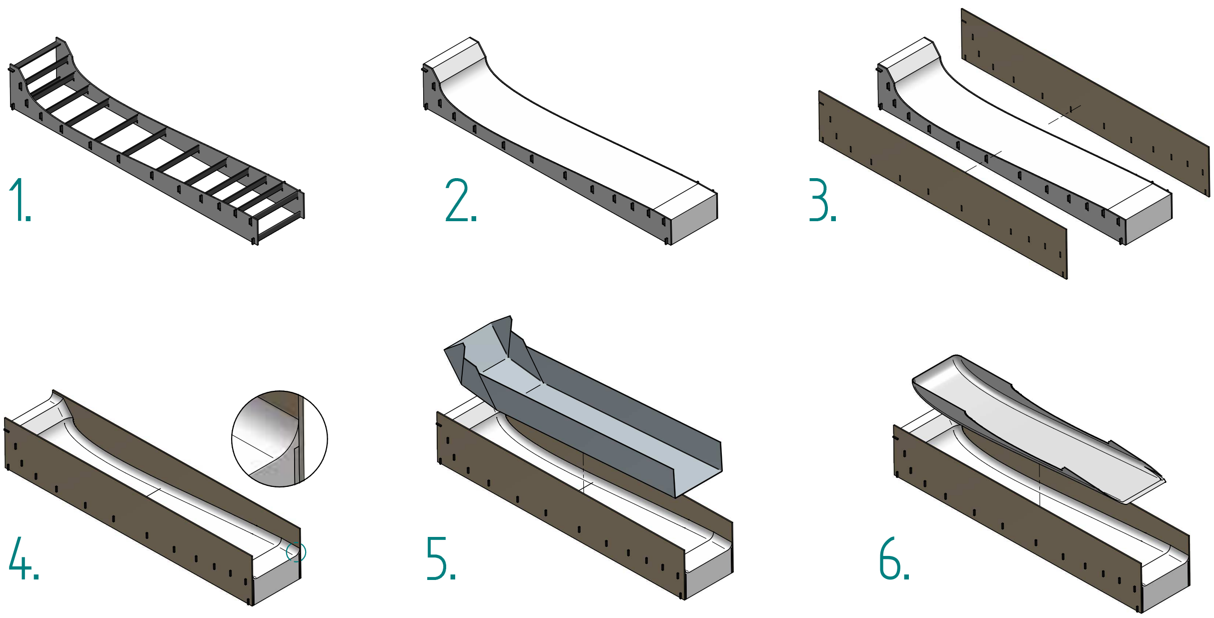


Figure 4.5. Constructing the plaster moulds

material for washing. The two longer edges and one short edge are glued by CA glue. Since sufficient insulation is critical, he glue is applied in multiple lines, and even some perpendicular lines are made, thus creating smaller chambers, to prevent leakage.

When the vacuum bag is ready, the plaster mould and the approximate shape part can be put into it (Fig. 4.8 left photo). The placement of the bent plastic part in the plaster mould is shown in Fig. 4.7. The open end is glued and a valve is fixed with using a hot glue gun. This end can be opened easily later, but be prepared to put some more

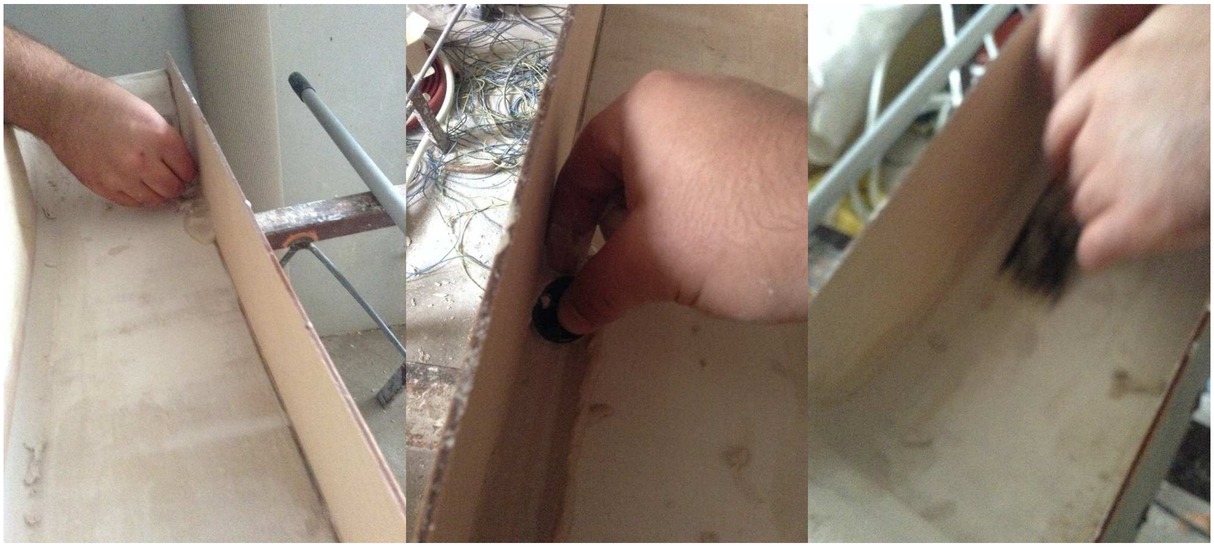


Figure 4.6. Rounding the corners

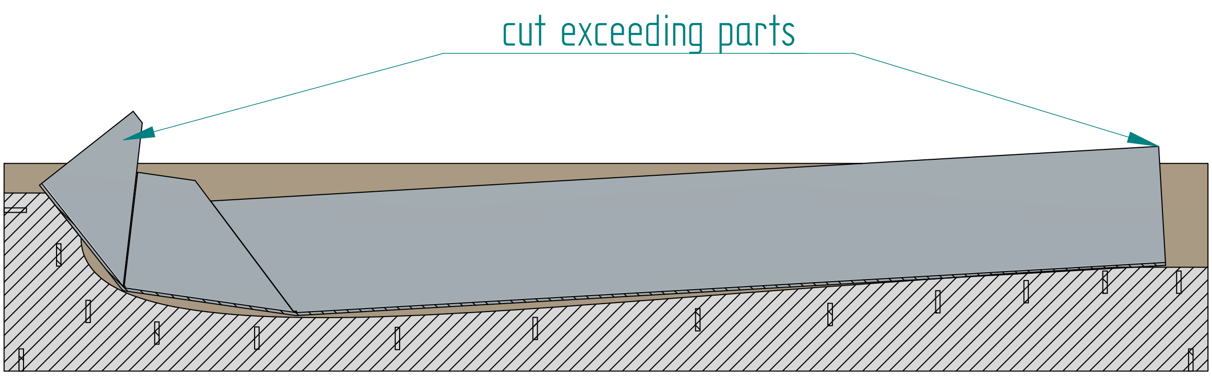


Figure 4.7. Vacuum forming

glue there during the vacuuming, if leakage occurs. It is recommended to cover the sharp edges of the plaster mould by sponge (or similar material) to save rubber sheets from ripping.

Start to remove the air with a vacuum pump, and heat up the plastic with a hand-held electric heat gun, especially along the edges. Try to apply the heat uniformly, otherwise the rubber bag might be damaged. The adaptation to it's final form is a longer process, it is ready when the corners can not be pushed further down, because the surface is already touching the plaster mould.

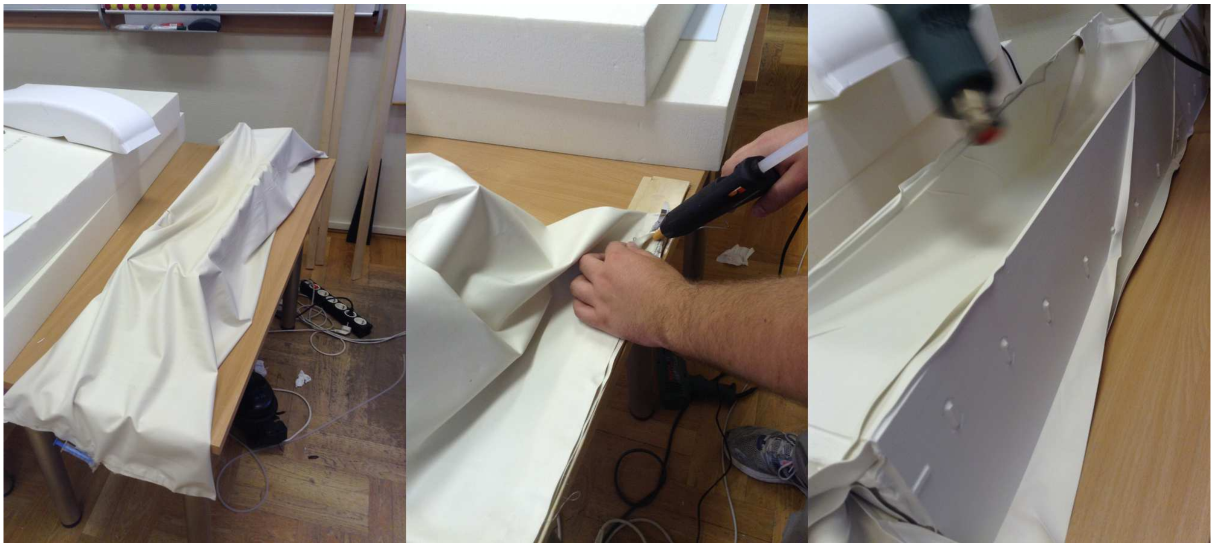


Figure 4.8. Vacuum forming

4.5 Trimming the connecting edges

The sideplates have marking slots along the connecting edges of the covering, as it is shown in Fig. 4.9 with green contour. During the vacuum forming these slots leave marks on the surface of the covering, to help cutting the edges accurately. In the region of the rounding (red edges on Fig. 4.9) the slots can not be used, as the sideplate and the covering are not in connection. On the front there is an edge on the plaster mould, what marks the connecting edge (see Fig. 4.5 last photo, the vacuum formed covering on the left). For cutting the aft connecting edge, some trial fitting and adjusting is needed, to achieve a tight connection between coverings. But it is generally advisable, to take extra care and make some trial fittings before cutting.

4.6 Orifice for the electric motor and cut outs for the tailboom

The electric motors need an orifice on the covering of the nacelles (Fig. 4.10). This opening is concentric with the motor as seen from the front. Patterns are enclosed in five different diameter (60, 65, 70, 75 and 80 mm), to suit different sized motors and they are provided in the Appendix. Too tight fitting is not advised, at least 5 mm clearance is needed, since the orifice also supplies fresh air into the nacelle, to cool the BLDC motor controller and other equipment exposed to overheating. Place the shape on the covering and make the

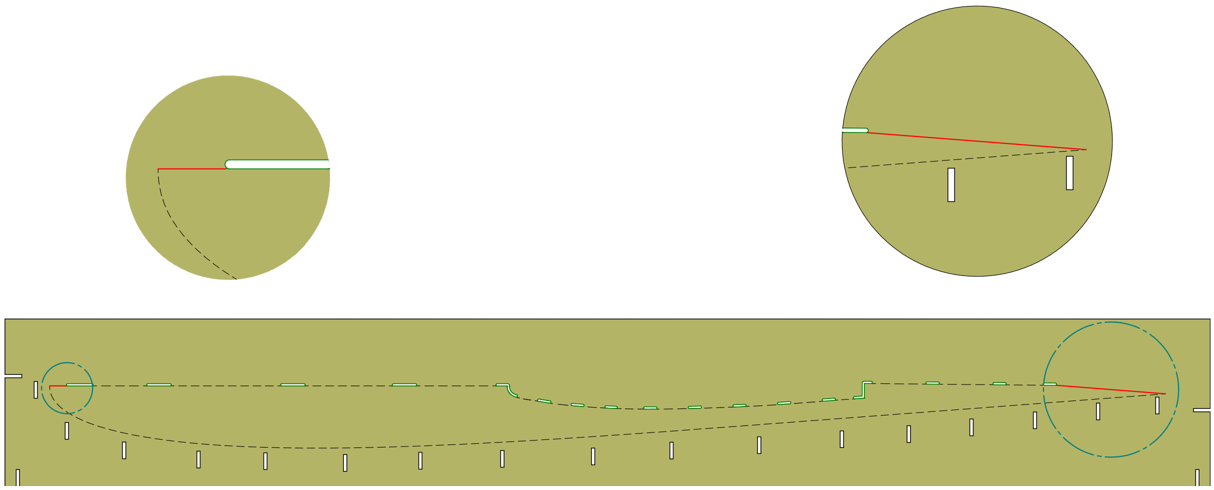


Figure 4.9. Marking slots

horizontal line collinear with the front connecting edge, while the vertical line have to be on the symmetry plane.

To fit the coverings in place, cut outs for the tailboom are also have to be made. Dimensions are shown in Fig. 4.11.

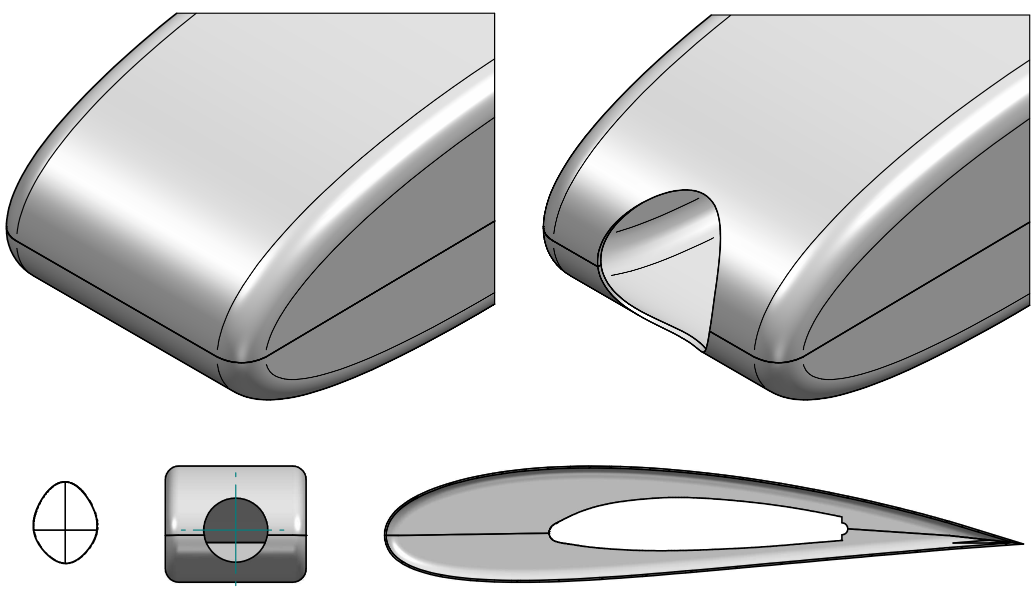


Figure 4.10. Orifice for the engine

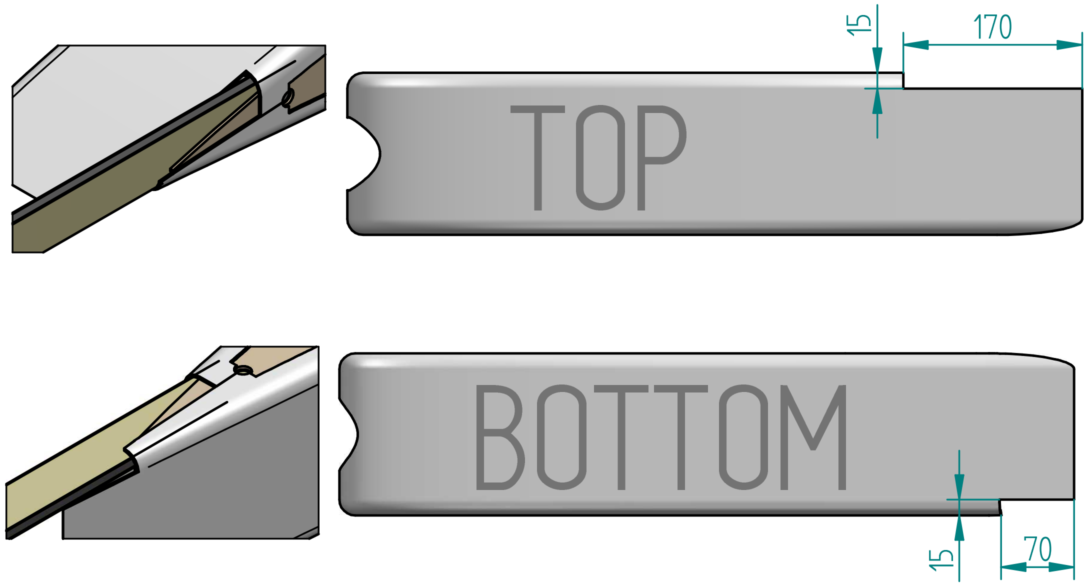


Figure 4.11. Cut outs for the tailboom

4.7 Placing the covering on the nacelles and on the fuselage

The two halves are fixed differently, because the top coverings need to be removable regularly, while the bottom part can stay in place for most of the time.

The frontal section of the top covering is fixed with wedges, and a single screw is fixing the aft section. As it is shown in Fig. 4.12 the cover can be slid on the fuselage/nacelle in a tilt path, and then it is just fixed with a single screw, this enables fast removals. The wedges are fixed with CA glue. Position the top covering (while the bottom part is not in place), and you can make some marks on the covering, or fix the wedges directly (Fig. 4.14). For the aft section, a laser cut plywood slat needs to be glued to the screw's hole (Fig. 4.15).

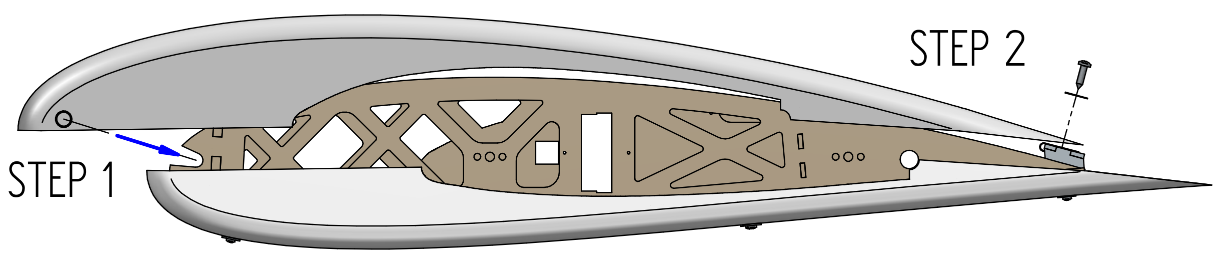


Figure 4.12. Sliding the top covering

The bottom coverings are fixed to the retainer parts (described in Subsection 3.2.2,

Fig. 3.3) with six wood screws (Fig. 4.13), after careful placing. The spacers are glued in, and the coverings are positioned on their final position.

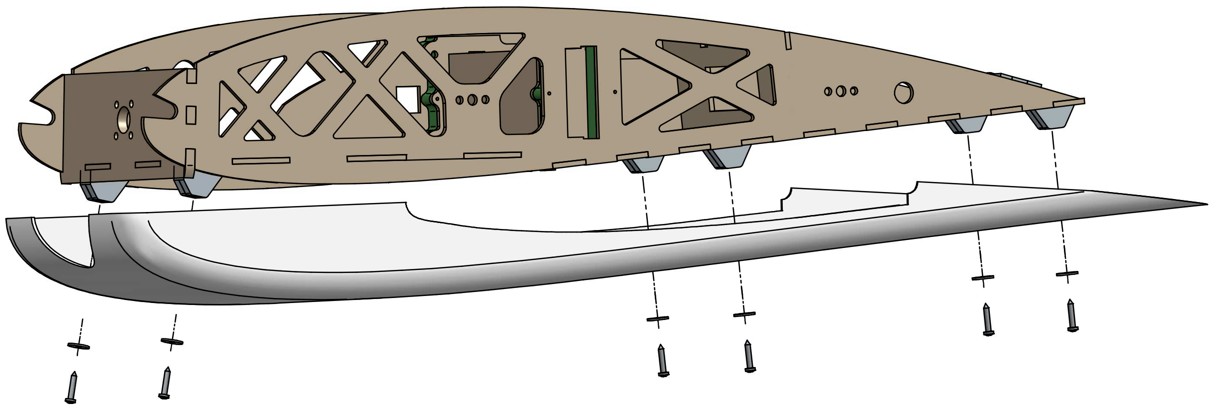


Figure 4.13. Fixing the bottom covering with wood screws

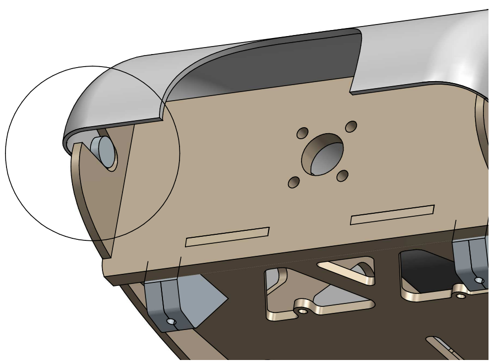


Figure 4.14. Covering fixing disc

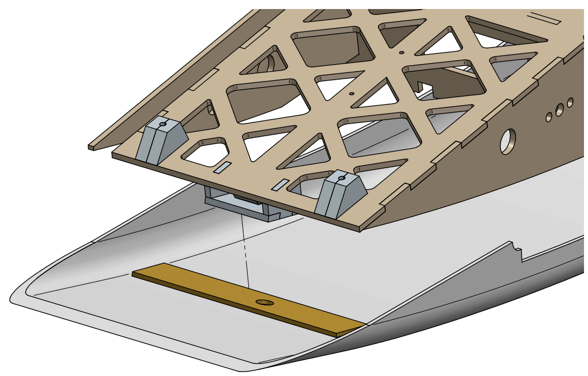


Figure 4.15. Covering fixing plate

4.8 Alternative coverings

The following alternative method for the manufacturing of nacelle and fuselage coverings is significantly less complicated and time consuming than the thermoforming of the plastic coverings described in the previous sections, although it also has some disadvantages, including the larger drag due to the sharp edges on the corners and the increased mass of the coverings due to the plywood corner elements. These plywood parts are needed to provide sufficient stiffness and a large gluing surface to join the thin plastic sheets of the coevring to each other.

The flat pattern of the top and bottom parts of the coverings is shown in Fig. 4.16. The

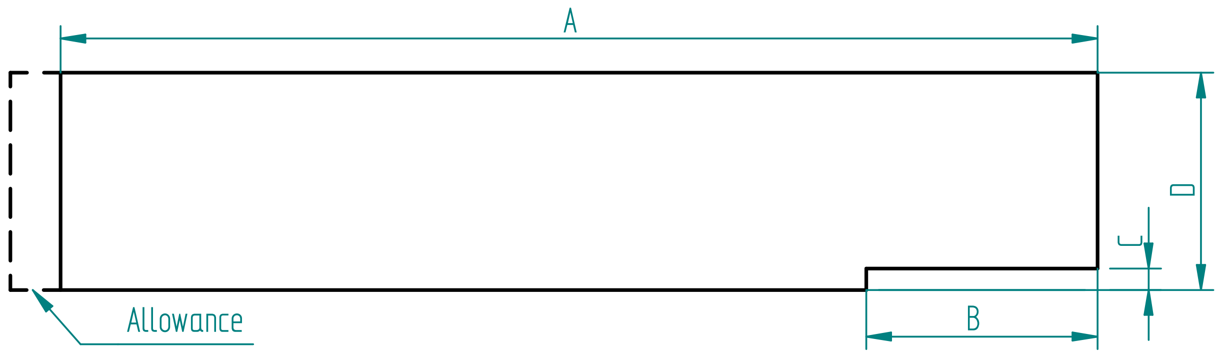


Figure 4.16. Boxy covering dimensions

Table 4.2. Alternative covering dimensions

	Fuselage bottom	**Fuselage top**	**Nacelle bottom**	**Nacelle top**
A	1018	1030	716	726
B	-	-	15	15
C	-	-	68	162
D	202	202	152	152

main dimensions for the top and bottom sheets are provided in Tab. 4.2. The side parts of the coverings could be easily cut out using the corner plywood parts as a pattern. The assembly steps of the coverings are shown in Fig. 4.17. The plywood corner stiffeners are glued together with wood glue (*step 1*). After the corner elements are glued together, their cambered side should be slightly grinded, to remove the thin coaly layer from the plywood. 12 mm wide paper strips are glued to the plastic sheets with CA glue (*step 2*). The corner parts are glued to the paper strips with epoxy. The paper strips are necessary, because the polyvynil chloride (PVC) plastic parts adhere poorly to epoxy, however cyanoacrylate glue can not fill up adequately the clearence between the plastic and the uneven surface of the laser-cut faces of plywood parts. The side plastic parts and the corners are glued with cyanoacrylate glue, because this face of the plywood parts is fairly smooth to adhere correctly (*step 3*). The cut outs of the electric motor orifices, tailbooms and landing gear struts are made with the same technics as in the case of vacuum formed coverings and their fixing to the nacelle and fuselage frame is also identical. It is recommended to cut out the openings for the landing gear struts after the assembly of the coverings.

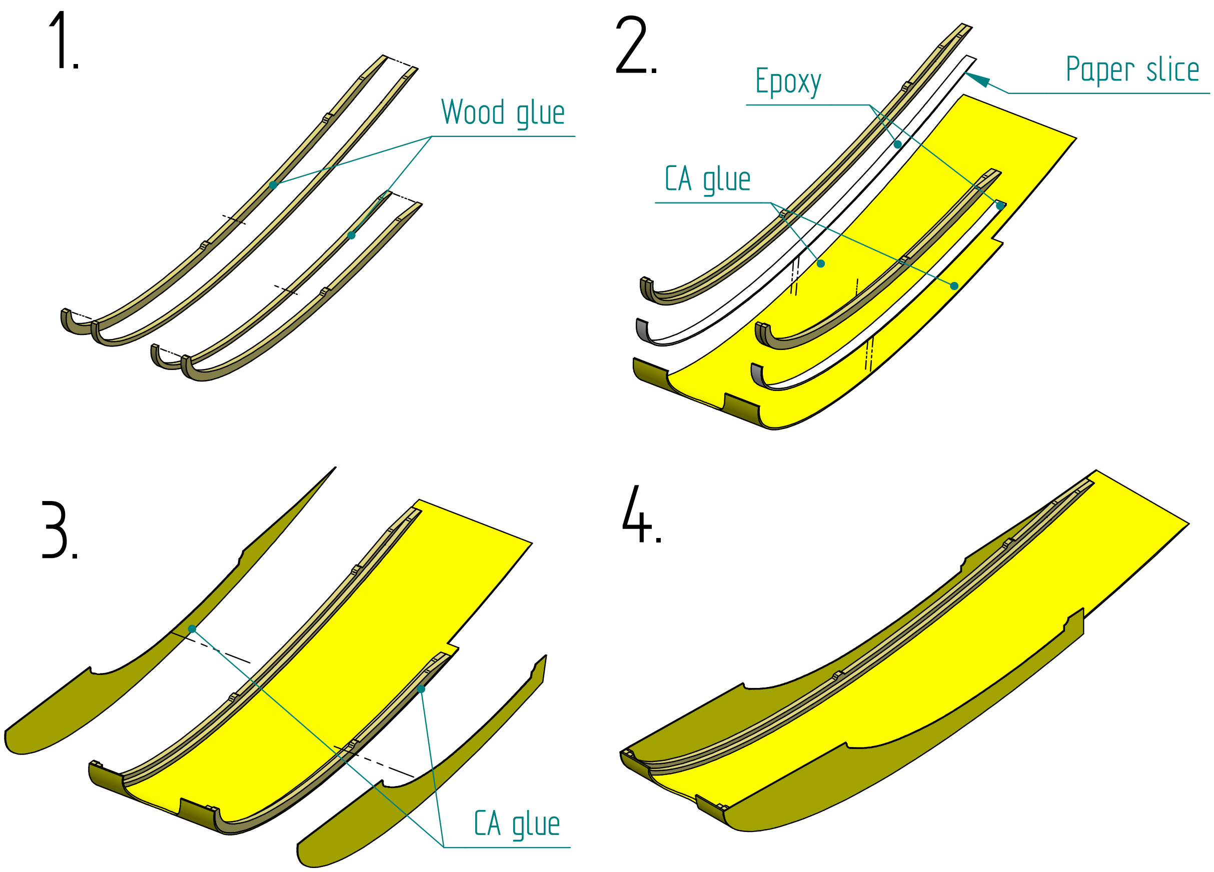


Figure 4.17. Alternative covering assembly steps

Chapter 5

Foam parts

5.1 Introduction

Minimizing labour need during the construction was one of the top priorities during the design of the aircraft, so using foam parts was an obvious solution to create the wings and the control and stabilizing surfaces. Hot wire NC foam cutting is an easy, fast and accurate way to create these parts, while the sufficient strength can be achieved by using spars when needed, and laminating the surfaces with glass fibre fabric.

5.2 Cutting the foam parts

5.2.1 Hot wire CNC foam cutting

The foam parts are cut with hot wire CNC cutting machine. To create an accurate foam cut part, it is very important to set a precise kerf. The hot wire cuts the foam by melting it. The kerf is influenced by many factors, in our case only the voltage of the hot wire was adjustable, so predetermining the voltage would have been too troublesome.

For tapered parts this uncertainty can be eliminated by cutting longer parts than the nominal. If the kerf varies, the same part still can be cut with using a proper offset (see Fig. 5.1). This correction can be used for the vertical control surfaces and for the winglets, but not for the wings, even though they have tapered shape, as the spar slot is straight and parallel with the leading edge.

Another solution is calibrating the kerf, setting it to a pre-determined value. For the calibration special pattern is used. In Fig. 5.2 the A-A line is collinear with the B edge. The A-A line is not influenced by kerf, while the B edge is strongly dependent. The offset

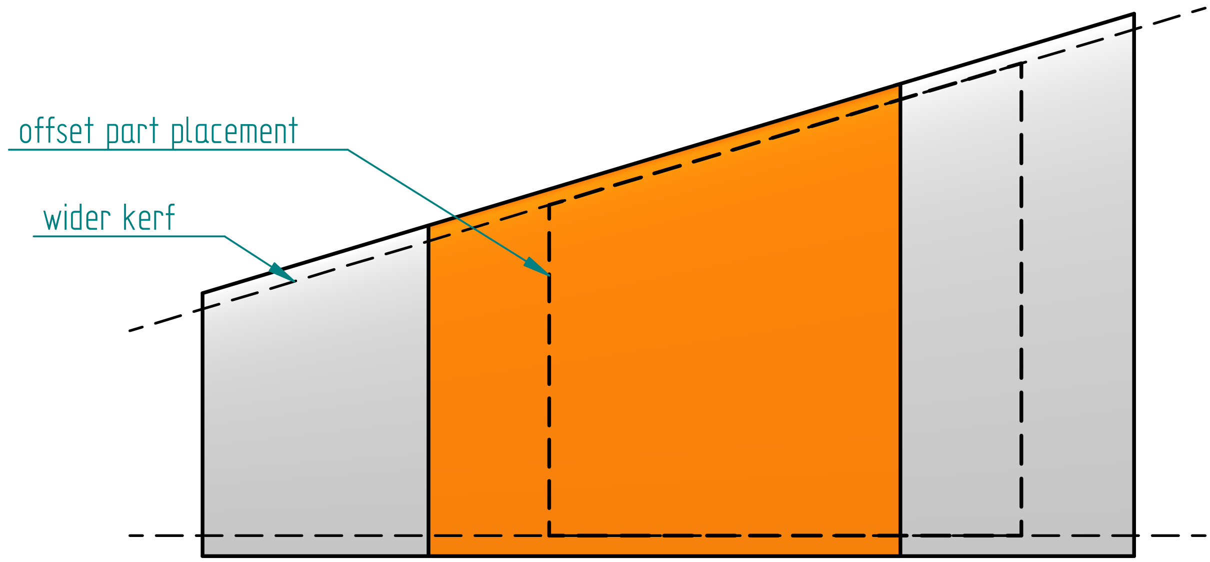


Figure 5.1. Kerf size compensation

of the B edge should be exactly the half of the planned kerf. In this case if the kerf is properly set, the outer edge of the kerf is exactly collinear with the A-A line.

A calibration process is illustrated in Fig. 5.3. The kerf is too wide on the first pattern, so before the next pattern it is being adjusted. On the second pattern the kerf is too narrow, and with a final adjustment it is correctly set. Fig. 5.4 shows a calibration in practice.

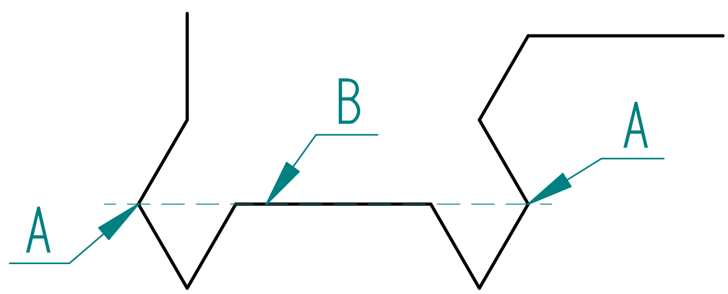


Figure 5.2. Calibration

5.2.2 Making additional cuts

In some cases further cuts might be needed in addition to hot wire cuttings. Cutting the foam is quite easy, but it is still difficult to perform an accurate cut. Besides obvious methods (saw, or segmented blade knife for smaller cuts), accurate cuts can be performed by using fishing line. When the line is forced against the foam and alternated, the friction

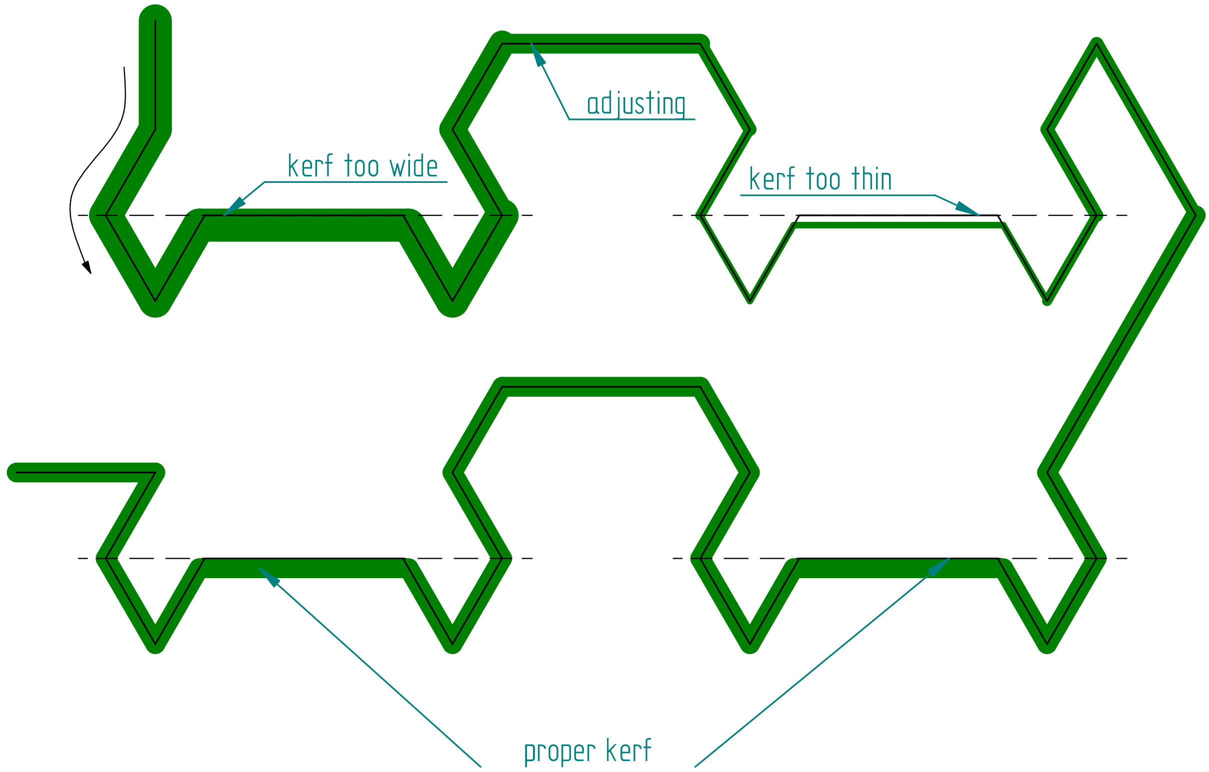


Figure 5.3. Kerf calibration

Figure 5.4. Kerf calibration in practice

produces enough heat to melt the foam. The fishing line have to be strung between some mean of guidance, and the precision of the cut is dependent on the placing of the foam part and the guidances. Of course the friction induced heat weaken the fishing line too, and makes the line tear quite soon, but since fishing line is inexpensive, it is not a serious problem. Some sanding is needed on the resulting surfaces. During fishing line cutting the airfoils are placed back into the same foam panels they were cut off from with the hot-wire CNC machine. The wooden guidances are placed on these panels. This way the panels are protecting the airfoils from damages and are providing a flat surface for guidances during cutting with the fishing line.

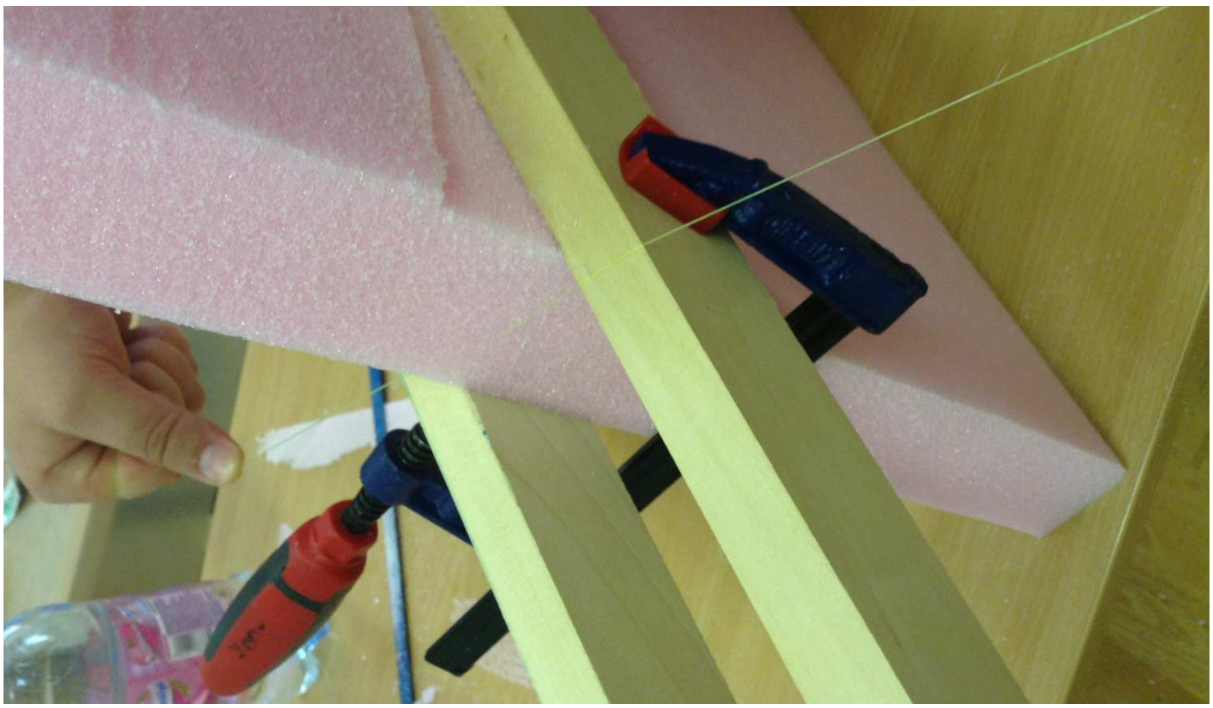


Figure 5.5. Cutting foam using a fishing line

5.3 Outer wing section

The outer wing section has the most complicated foam parts: this wing section is tapered, while the spar goes straight, and it has an aileron (possibly a flap as well), while a servo and it's control for the aileron is housed inside the wing.

5.3.1 Before laminating

The wing is cut as one part, with ailerons, which have to be removed (step 2 in Fig. 5.6). The wing itself also need to be cut into two parts along the spar slot, to allow easy spar installation. The hot wire creates small radii in the sharp corners during cutting, as it is shown in Fig. 5.8. In the corners of the spar slot these radii have to be removed, otherwise the spar would not fit in correctly (after the splitting of the wing it can be easily done with a segmented blade knife).

In Fig. 5.9 the steps of the spar gluing are shown. The spar has to be placed as to extend 150 mm from the root of the foam parts. For the gluing filler mixed epoxy was used (microballons). Squeezing was provided by rubber bands, and to protect the leading edge pieces from the original foam sheet is put on , and the corners of the trailing edge were protected with a plywood slat. The gaps on the upper and bottom surfaces are needed to be filled (as it is shown in the case of the horizontal tail, in Fig. 5.16).

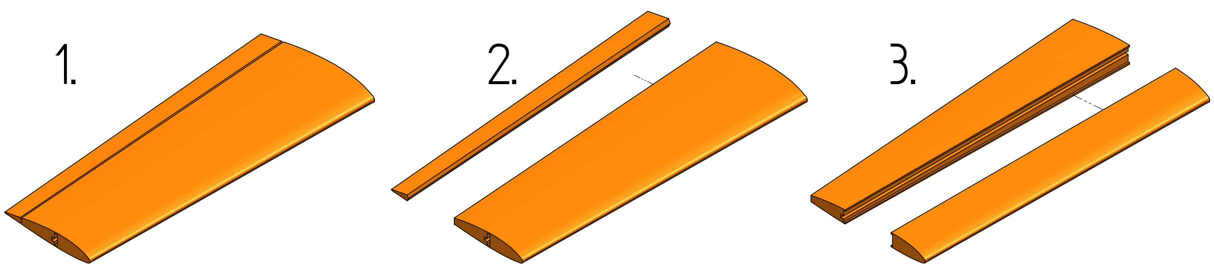


Figure 5.6. Cutting the aileron and dividing the wing along the spar

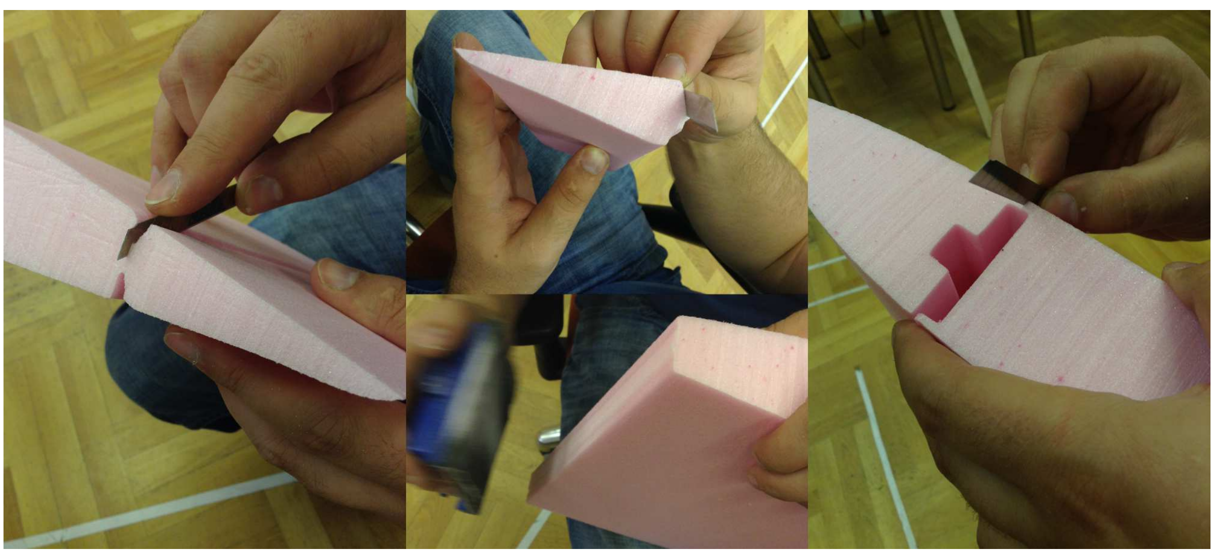


Figure 5.7. Performing cuts on the foam part of the wing

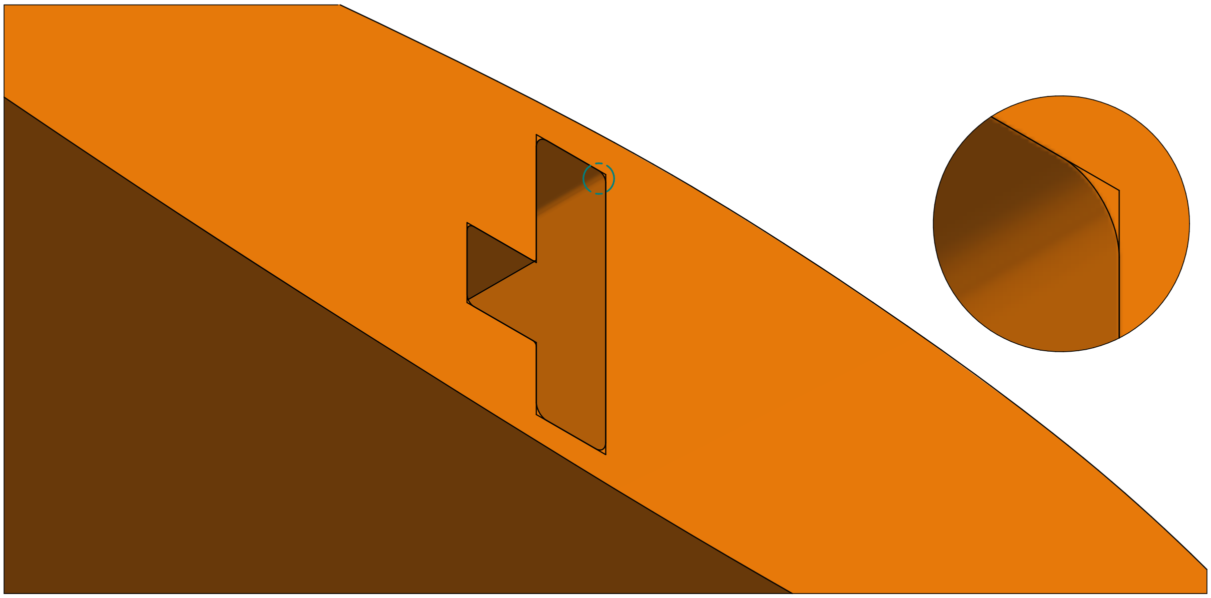


Figure 5.8. Corner radii in the spar slot

Figure 5.9. Gluing in the spar

5.4 Central wing section

The foam part of the central wing section is quite similar to the outer wing section, but the main difference is that this part of the wing is not tapered. It is also cut with flaps on, which have to be removed, and for easier spar installation, the part is cut into halves along the spar slot (*step 1* and *step 2* in Fig. 5.10). On the nacelle side, the cable channel has to be broaden, to provide adequate routing to the nacelle bypassing the sparbelt, which supports the tailboom and the landing gear (*step 3* in Fig. 5.10).

The central wing section connects to the fuselage with wood screws. To provide sufficient wood thickness for the screws, plywood parts are installed to the root. Since the threads wear out after a few removals, this plywood parts provide enough surface for multiple insertions. Foam has to be carved for fitting these plywood parts (*step 4* on Fig. 5.10).

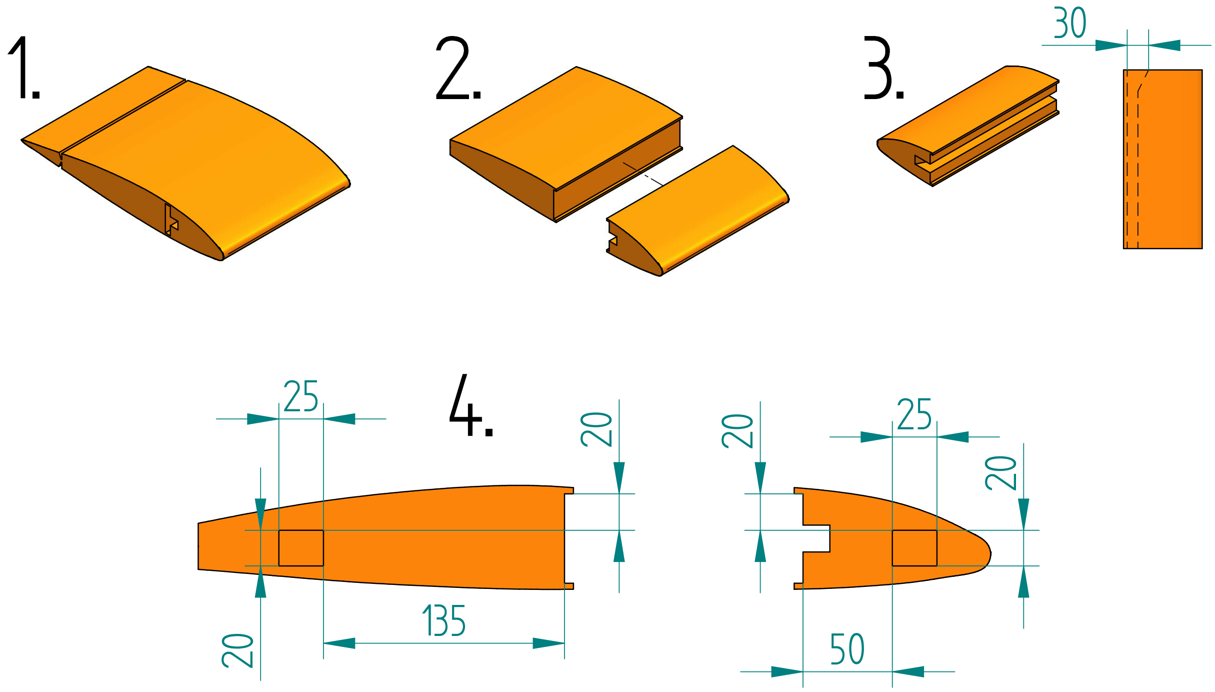


Figure 5.10. Steps steps of the central wing section's foam parts

Steps of the spar gluing can be seen in Fig. 5.13. The process is very similar to the gluing of the outer wing sections' spars, filler mixed epoxy is used here also (the mixing ratio is also 2 parts of microballons to 1 part of epoxy by volume). The main difference is that the root ribs have to be placed in this stage (see Fig. 5.11). The placement of the parts is shown in Fig. 5.12.

After the laminating a cut has to be performed on the nacelle side of the central wing section (Fig. 5.14) to provide space for the flap moving shaft (a similar assembly can be seen in Fig. 5.28.

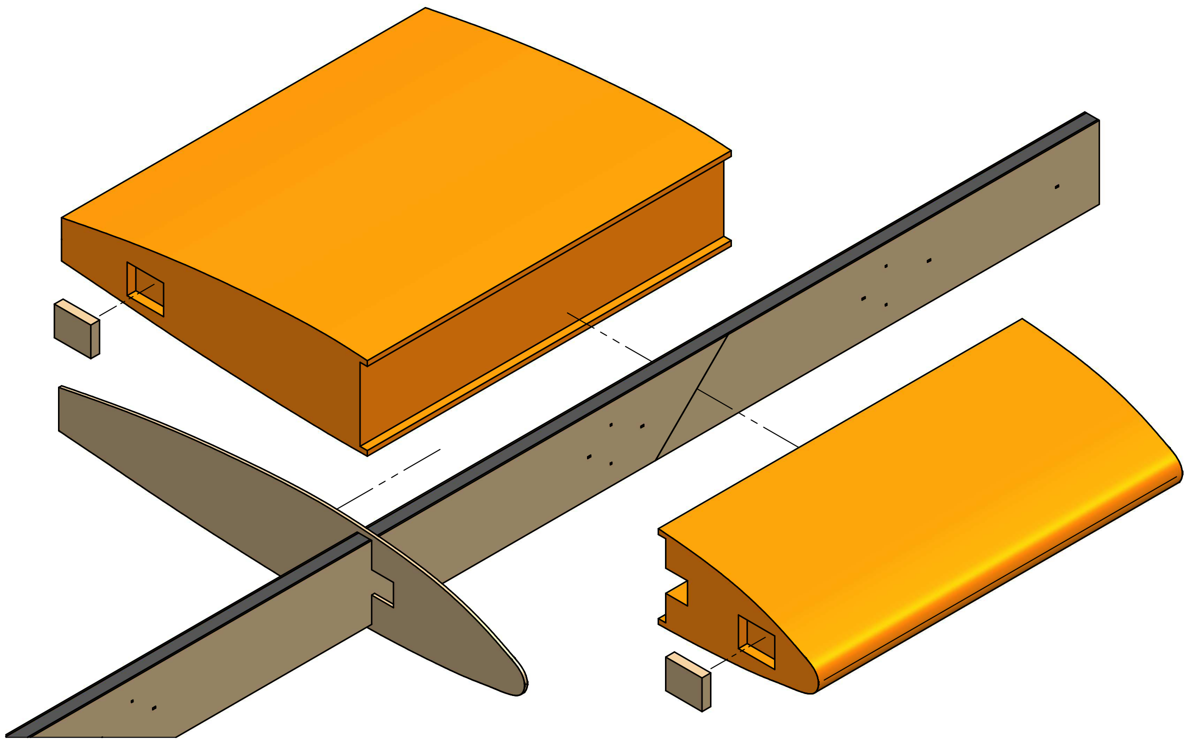


Figure 5.11. Assembly of the foam parts and root ribs of the central wing section

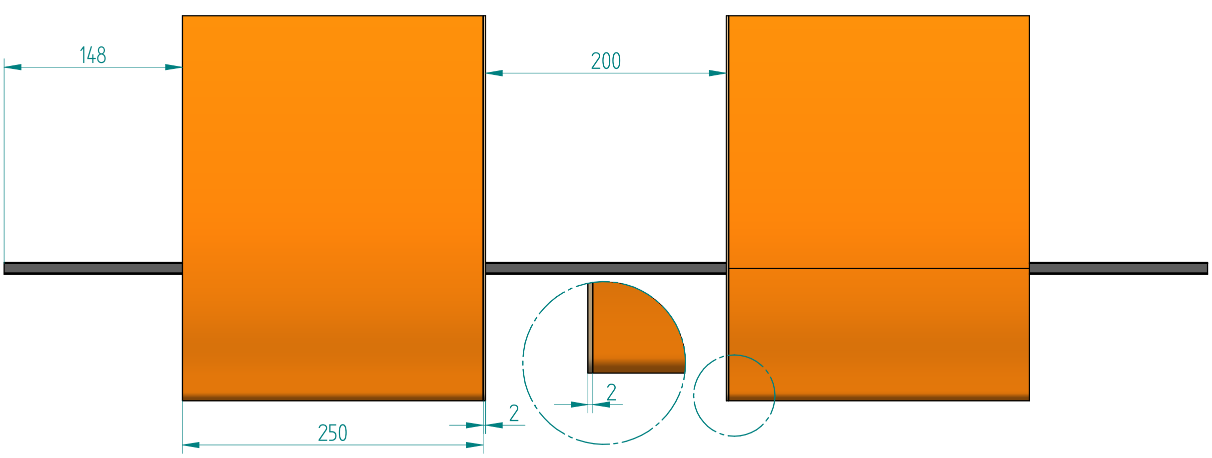


Figure 5.12. Placement of the root ribs and foam parts of the central wing section

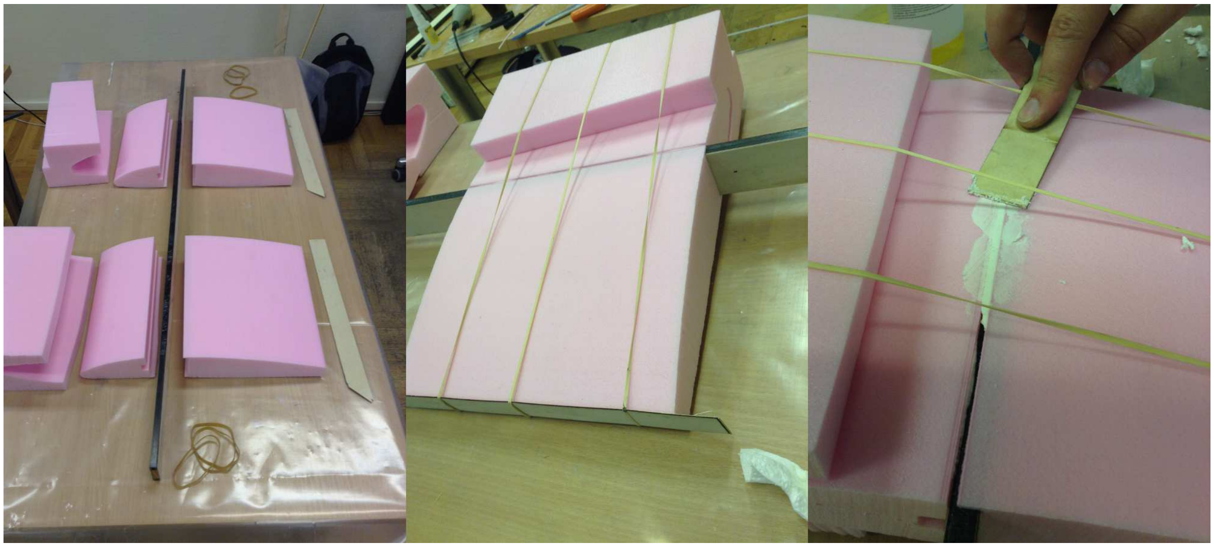


Figure 5.13. Gluing the spar and filling the gaps

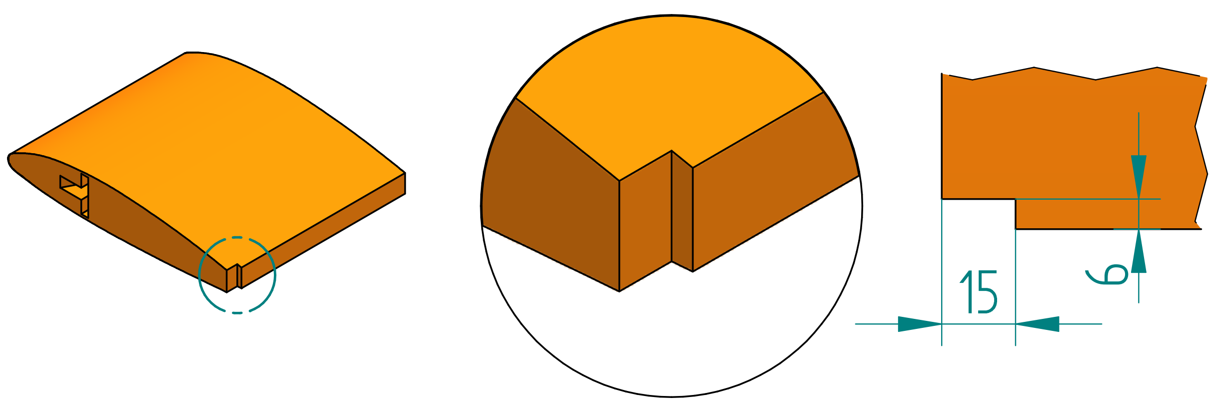


Figure 5.14. Cutout for the flap moving shaft

5.5 Winglet

The winglets include two plywood slats, which give them stiffness and the slats are connecting the wingets with the wing spars. The grooves of the plywood slats are cut out with a sharp blade. The slats are glued in with epoxy, the surface around the slats is filled and smoothed with a sandpaper.

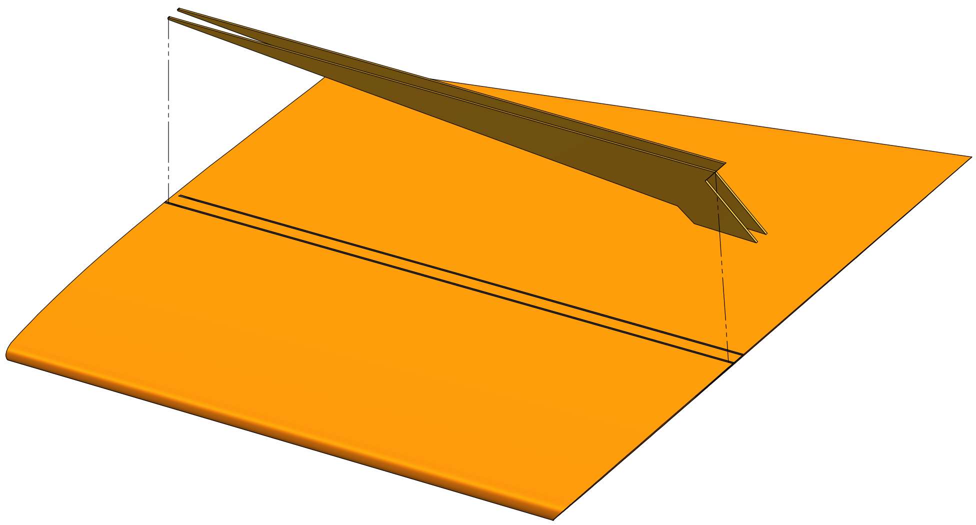


Figure 5.15. Winglet assembly

5.6 Horizontal tail

The aircraft can be built with two different versions of the horizontal tail. Both configurations have their advantages. The all-movable tailplane (stabilator) is easier to manufacture, and the aircraft balance could be changed within wide limits. The conventional split horizontal tail is more favourable regarding to structural considerations. The aft section of the aircraft is stiffer, then with a stabilator, therefore the chance of jamming is minimal. If one decide to build the all-moving tailplane, then it is advisable to build in diagonal stiffeners. The detailed manufacturing process of the two version is presented next.

5.6.1 Stabilator

Since the aircraft was designed to be a safety critical test platform, the horizontal tail is consisted of two, independently moving foam parts, and it is an all-moving tailplane. A single spar is built in fixed between the tailbooms at 20% of the chord. The horizontal tail surfaces are connecting with ball bearings to enable rotation around the spar.

A gap is cut on the lower surface of the horizontal tail when the space for the spar is being cut with the hot wire (it has to go there somehow). It needs to be filled, using filler mixed epoxy resin prior laminating (see Fig. 5.16 and Fig. 5.17). It is important to keep the spar slot clean from spilling epoxy, as it would not let the bearings and the spar to fit in. A rod is used (which diameter was adjusted with masking tape to match the diameter of the spar slot) to remove excessing material.

After the laminating, some modifying have to be done. The rudder requires more clearance when it is deflected, so a triangular section need to be cut out (2nd step in Fig. 5.18). A slot for the control horn also need to be cut ((3rd step in Fig. 5.18), which goes through the whole part. The control horn then glued in using epoxy. Make sure there is enough epoxy to wet the whole surface. By moving the piece in and out a few times, it can be spread evenly.

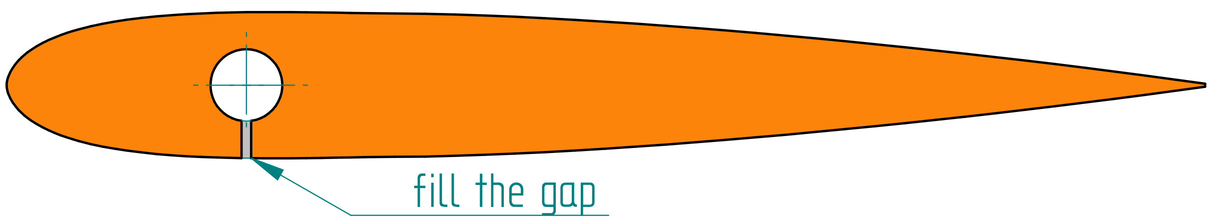


Figure 5.16. Filling the gap

Figure 5.17. Filling the gap with filler mixed epoxy

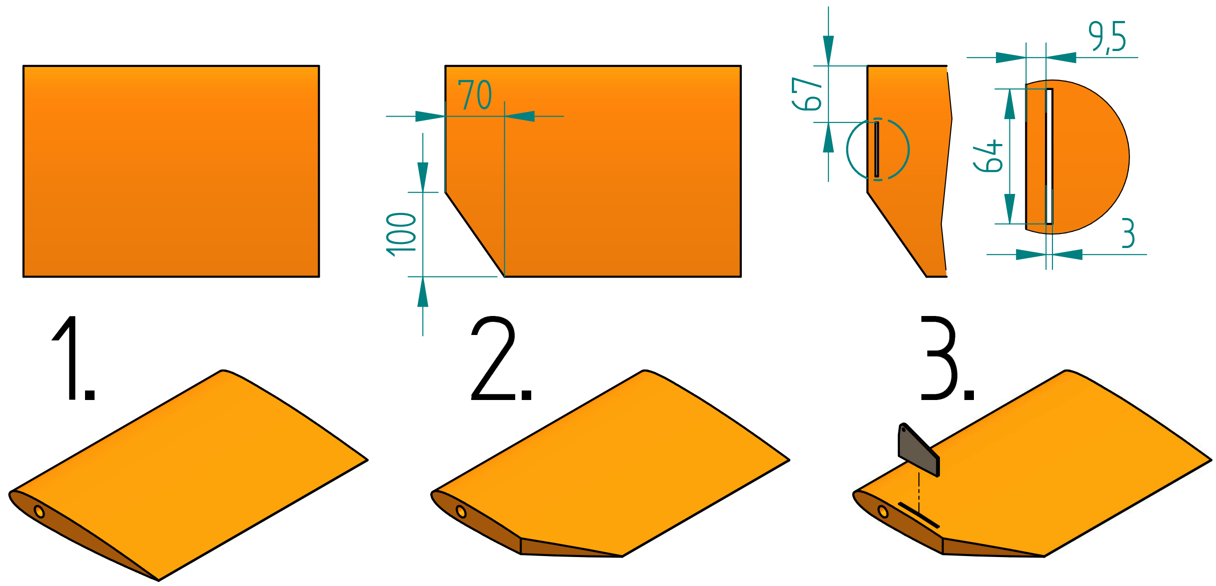


Figure 5.18. Steps of the stabilizer construction

5.6.2 Split horizontal tail

Besides using an all-moving tailplane, it is also possible to build a more conventional horizontal tail with separated control surfaces. It's advantage is that it provides a lot more stiff structure, what makes diagonal wires unnecessary. The tailplane consists of a stabilizer and two independently movable elevators. The stabilizer is stiffened with four carbon rods, which are glued in with epoxy. The spars have different lengths, the proper assembly is shown in Fig. 5.19. Each elevator connects to the stabilizer with two hinges (Fig. 5.20). The installation of the control horns is very similar, as described in the previous section.

5.7 Other control surfaces

The ailerons, rudders and flaps are fixed with nylon hinges. First paper to the surface of the hinges is glued with CA glue, because epoxy does not stick to nylon. Slots for the hinges were made on the foam with a segmented blade knife. To fill the slots, epoxy with a syringe and needle was injected. To disperse, and ensure the whole surface of the hinge is covered with epoxy, move the hinge in and out a few times (Fig. 5.21).

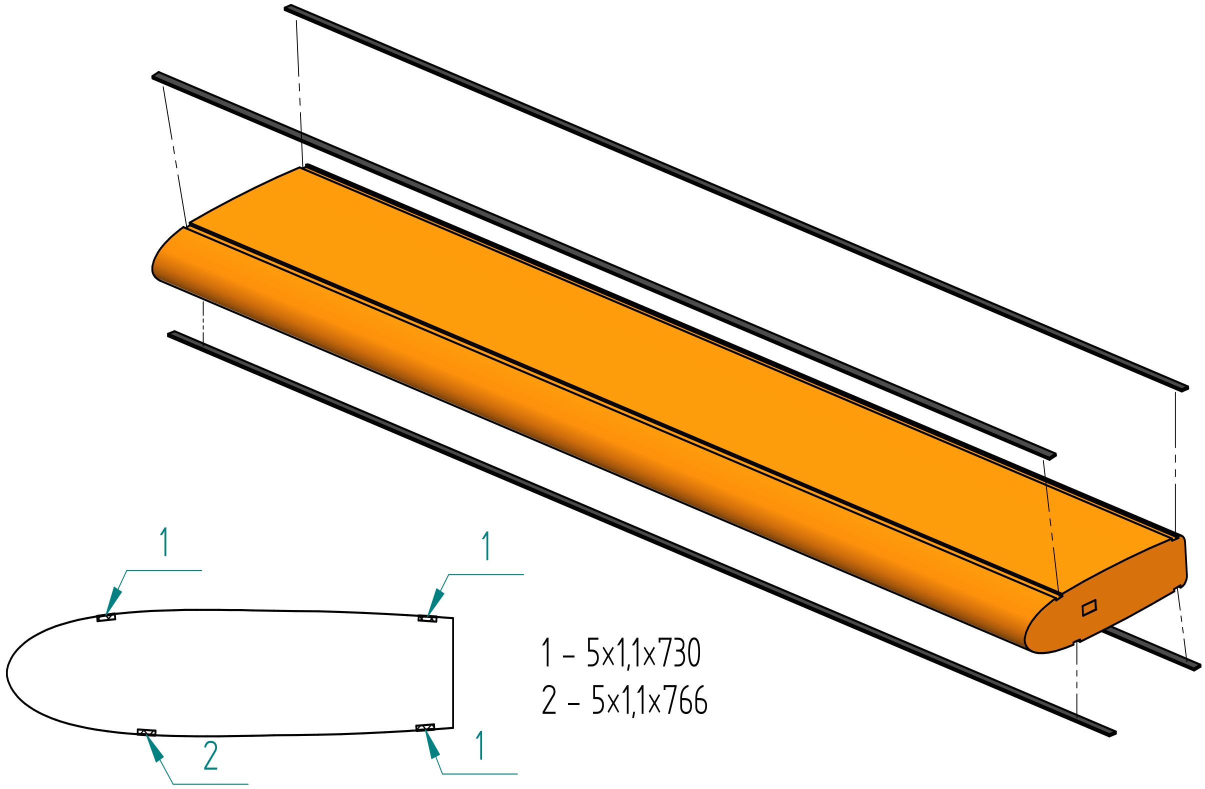


Figure 5.19. Gluing the carbon rods

5.7.1 Rudders

The vertical tail is a tapered part, the leading edge is swept back, while the trailing edge is straight. Kerf uncertainties can be eliminated by cutting a larger part (see Subsection 5.2.1 and Fig. 5.1)

After the lamination, rudders are shaped by cutting out foam (to make space for the vertical fin) (*step 2* in Fig. 5.22 and the left photo in Fig. 5.23), saw blade is used for this cut. The edges need to be chamfered to 45 degrees (*step 4*, and in the middle photo a chamfered and an unchamfered part can be seen), in order to enable control surface deflections. This cut was made with segmented blade, and then sanded. Since the aircraft has a taildragger configuration, another section has to be cut out to prevent tailstrike (*step 3*).

The rudder is fixed to the vertical fin with 3 hinges, and actuated with a control horn. To enable fast and easy installation, control horn is designed which is made of PCB core material, and it is fixed to the control surface with a circular segment shaped plate (assembly and installation is illustrated in Fig. 5.24). The plate itself is made of 3 laser cut plywood layer, fixed together with glue (holes help the setting). The base layer has a

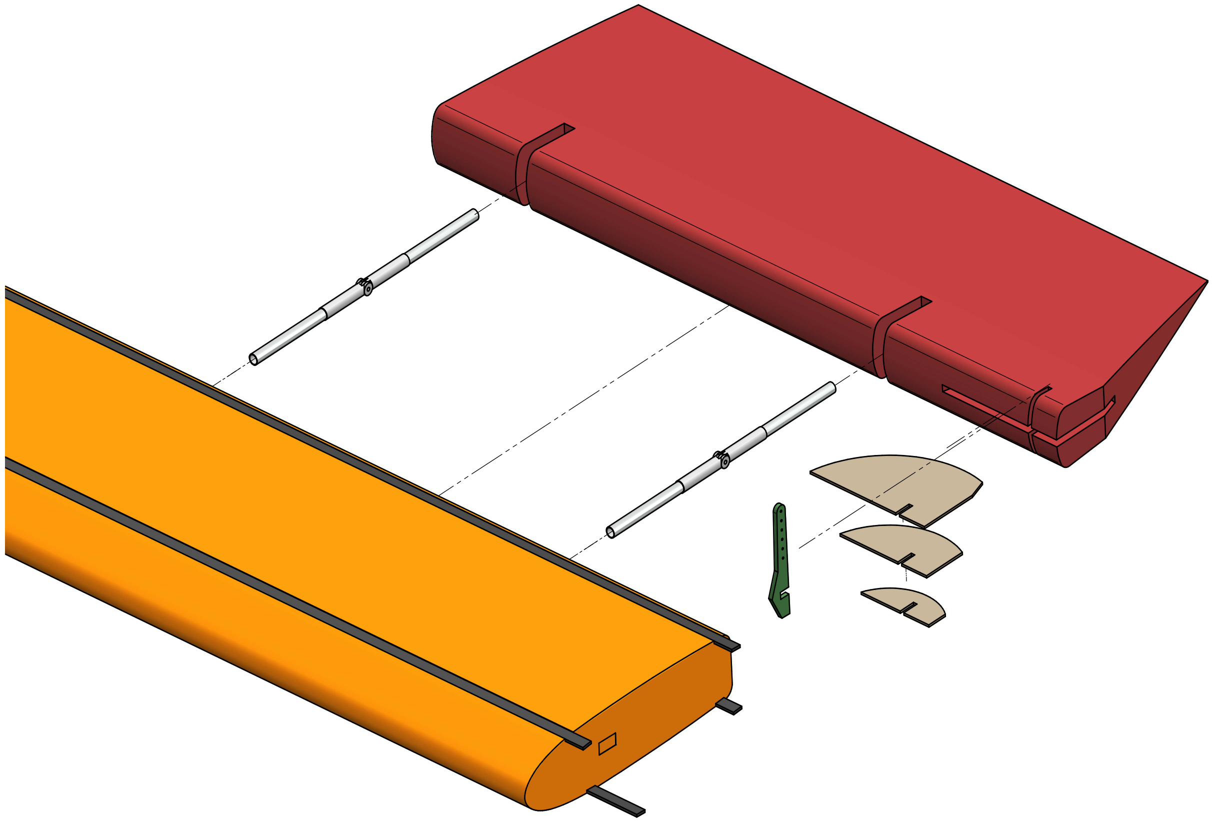


Figure 5.20. Assembly of the hinges

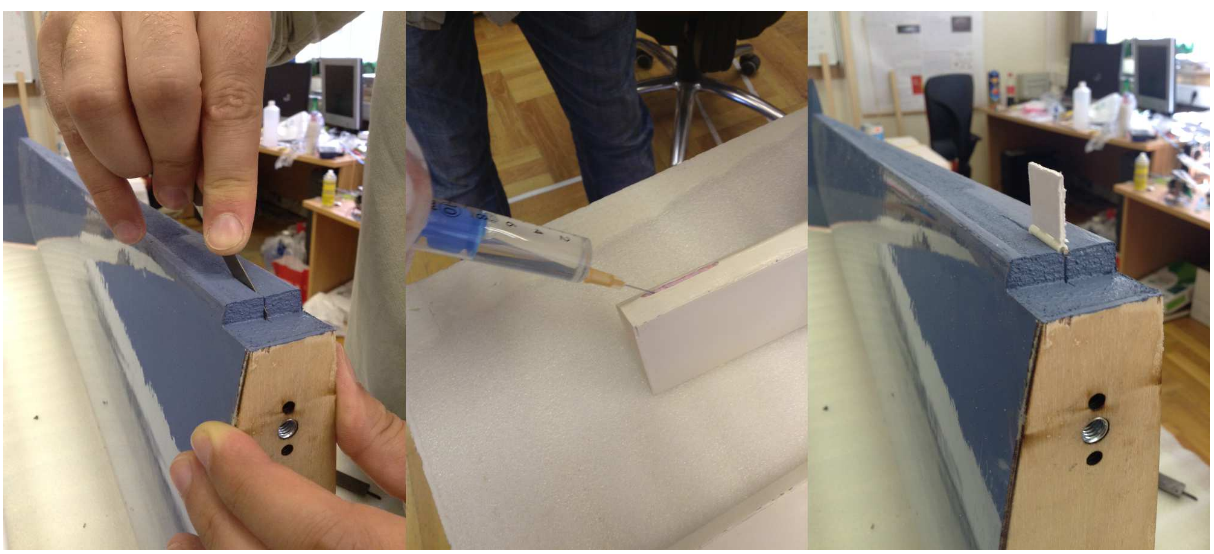


Figure 5.21. Gluing in the hinges

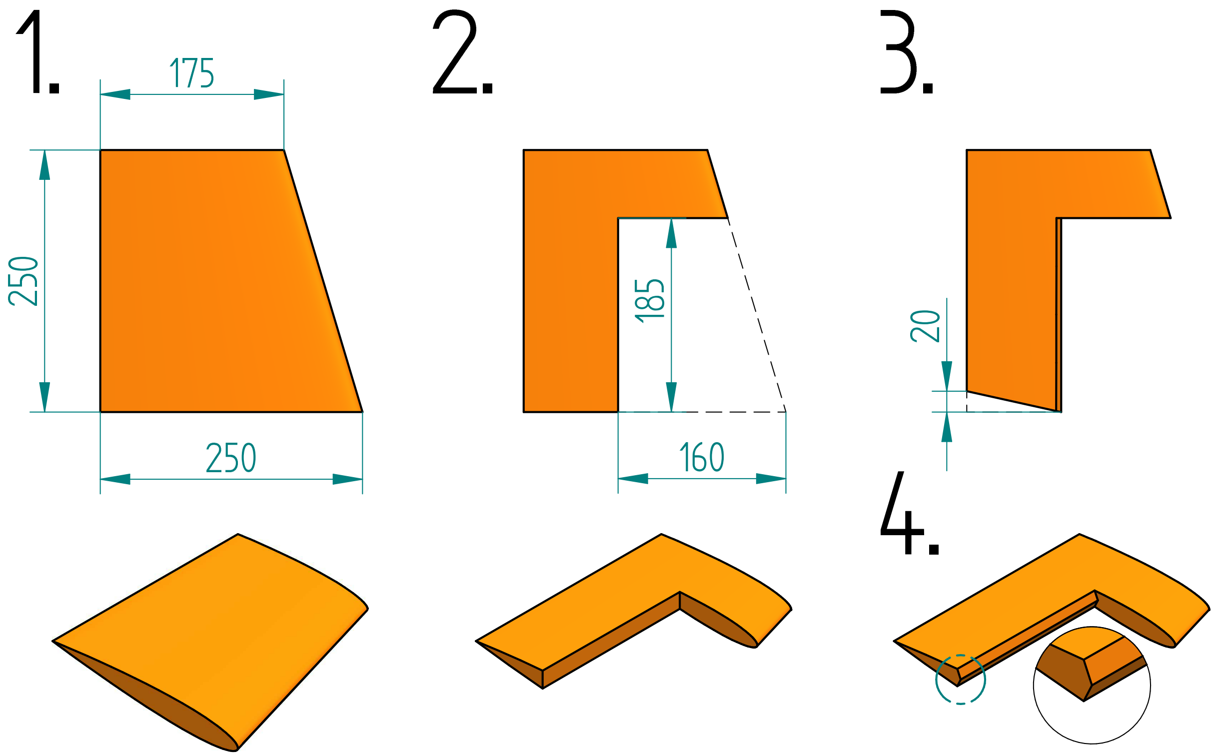


Figure 5.22. Vertical control surface construction steps

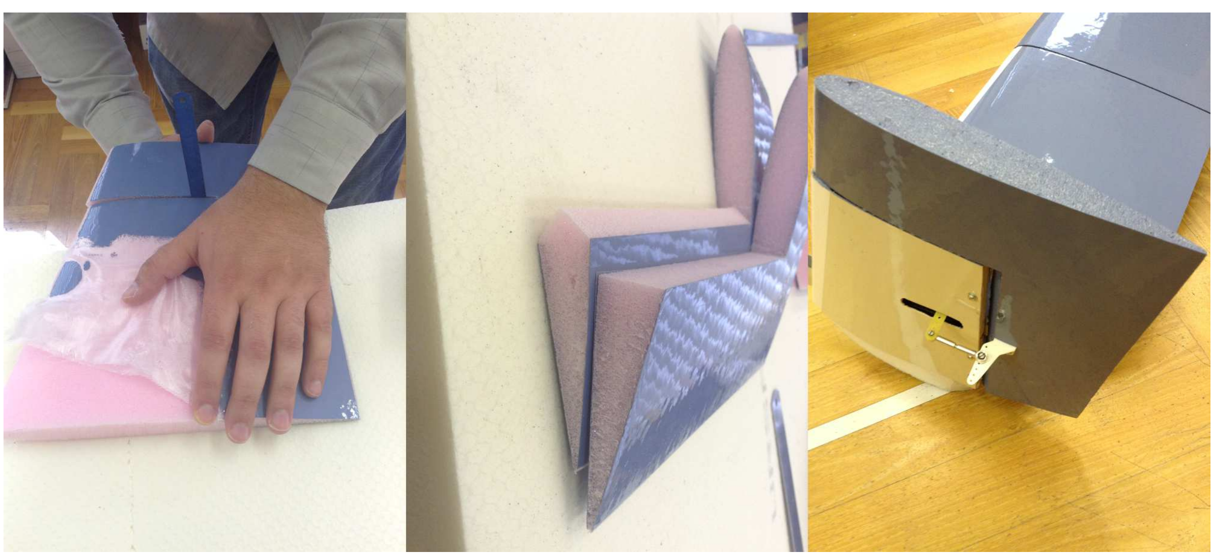


Figure 5.23. Rudder construction photos

cut out, to house a hinge as close to the control horn as possible. Two additional hinges are needed for the rudder.

Circular segment shape makes slot cutting for the plate easy and fast, it can be cut with a cutting disc, which contains the same section. The disc is made of laser cut plywood layers, glued together, and driven with a drill. This simple cutting tool is depicted on Fig. 5.26. Another perpendicular slot is needed for the control horn. Dimensions for the slots and control horn placement are in Fig. 5.25.

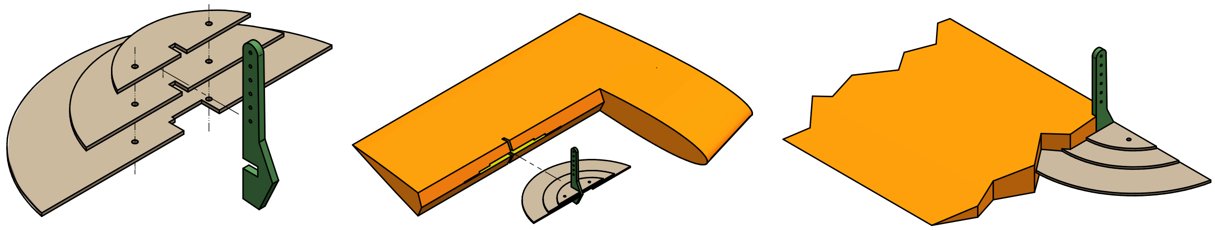


Figure 5.24. Assembly of the control horn and it's plate

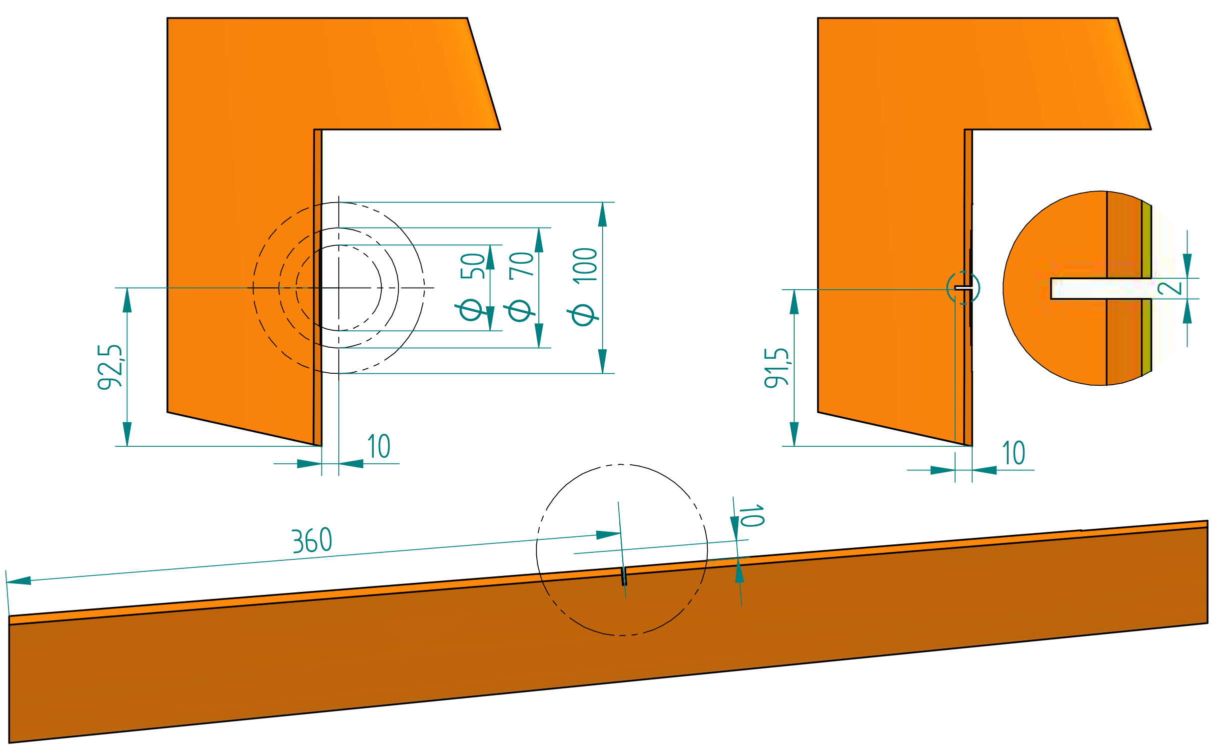


Figure 5.25. Control horn placement

The assembly of the vertical tail covering is described in Section 7.6. The covering is partly made of foam, but the the main material is balsa, which is laminated with the same process as described in Chapter 6.

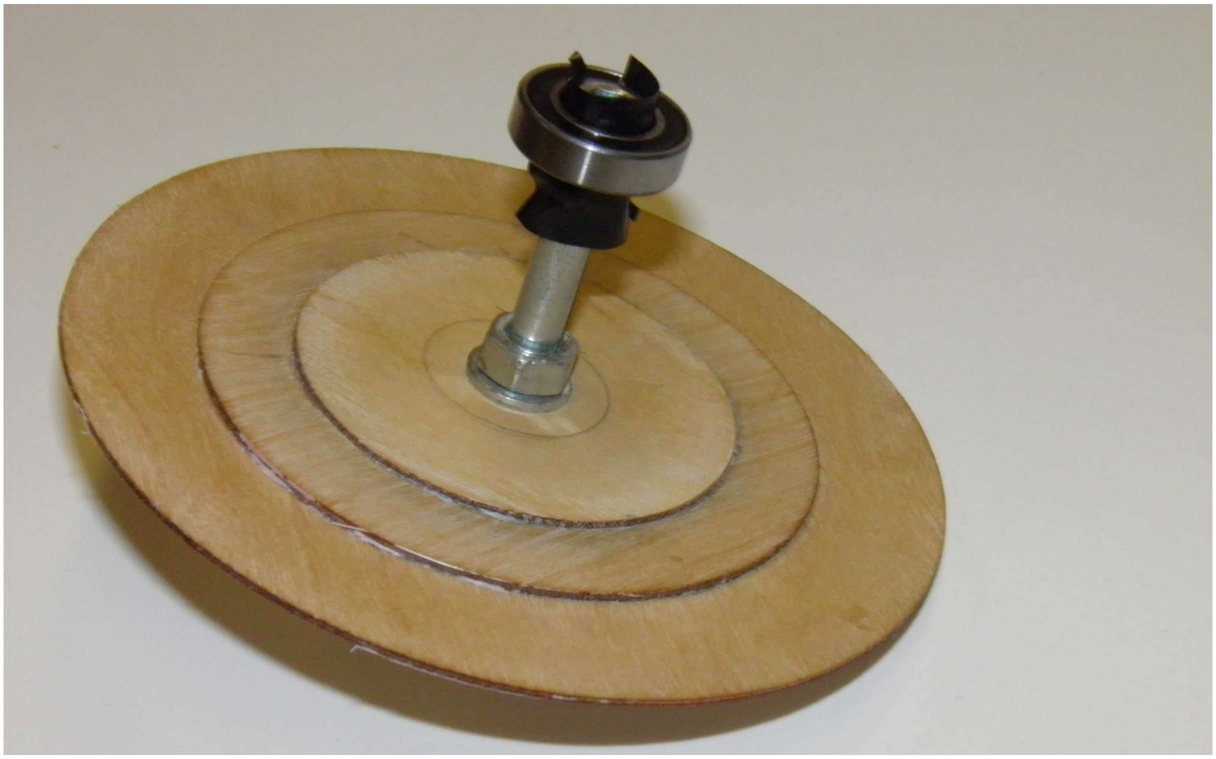


Figure 5.26. Servo horn hole cutting tool

5.7.2 Ailerons and flaps

The outer wing section has an aileron, and a flap as well. However, if the foam part is not divided, it can function as one bigger aileron. This division can be made after the whole part is fitted on the wing. Red dashed line shows the place of the division, and the position of hinges are also marked in Fig. 5.27.

The aileron has a control horn, which is similar to the rudder's control horn. The placement is shown at Fig. 5.27.

The flap are actuated a bit differently. It also uses a circular segment shaped plate, but it is located at the root side of the surface, next to the nacelle (see Fig. 5.28). The flap is actuated by a shaft, which extends from the nacelle, where the flaps' servos are housed. Another cutout have to be performed, to bare a bigger segment of the plate (see Fig. 5.29). The plate can be secured to the shaft, by drilling a hole and fixing a screw in it.

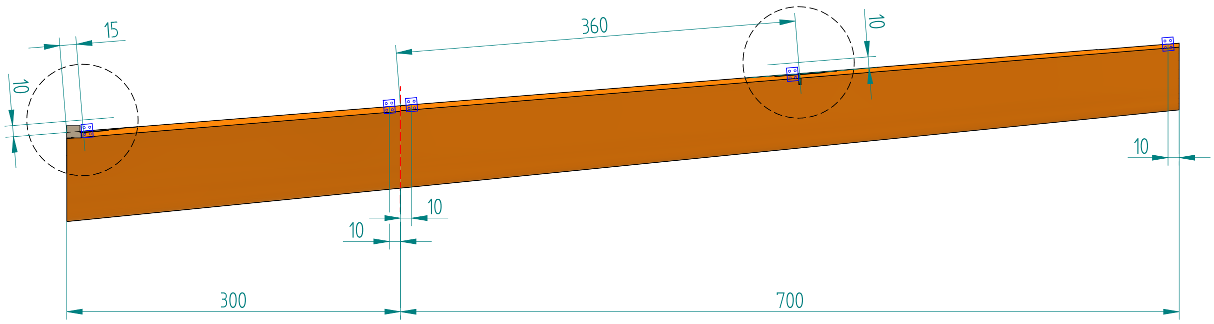


Figure 5.27. Division of the aileron and flap, and hinge placements

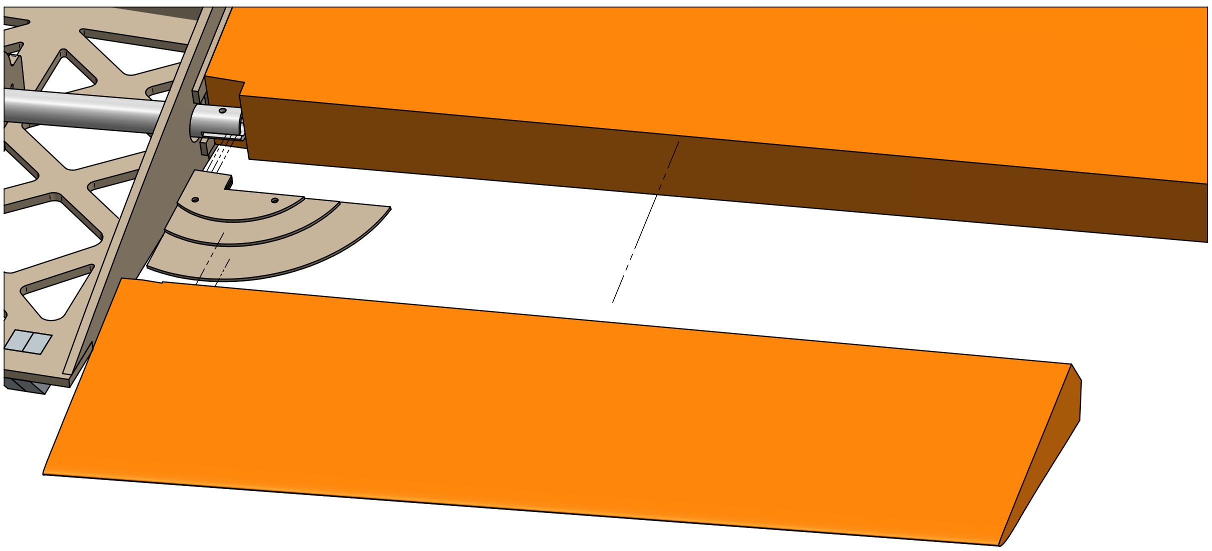


Figure 5.28. The flap and it's actuation

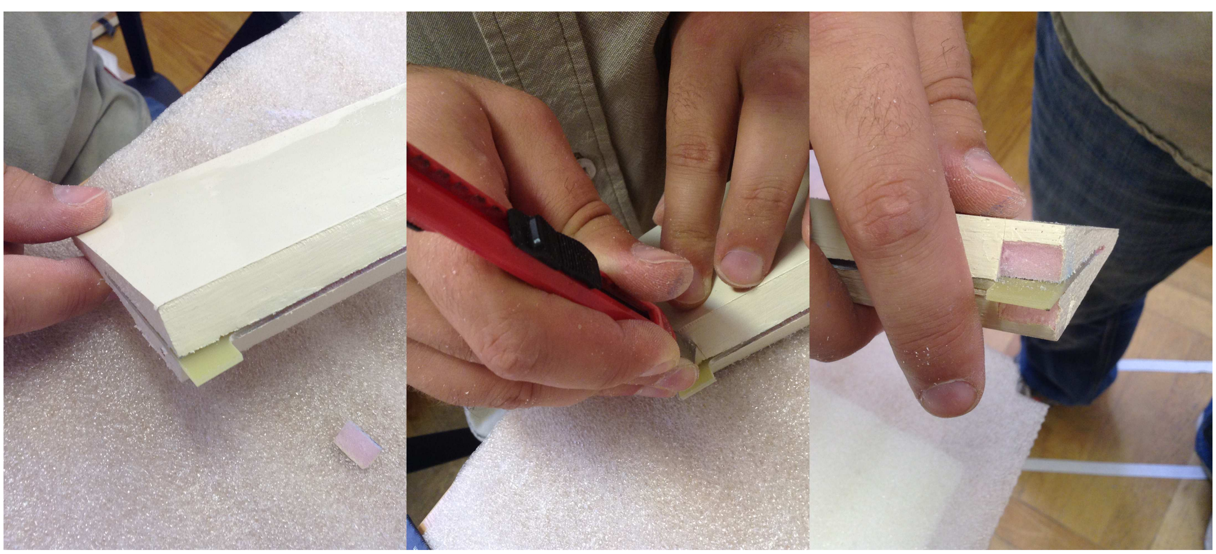


Figure 5.29. Cutout on the flap

Chapter 6

Vacuum bag laminating the foam parts

6.1 Introduction

To improve the stiffness and strength of the foam parts, the surfaces are laminated with fiber glass fabric, using epoxy resin as a matrix material. Wet layup method was used. Instead of vacuum bag laminating, which is described in the following sections, hand laminating can be used as an alternative method (section 6.5).

The following vacuum bag laminating method is an inexpensive and relatively simple technique. This method was developed to provide an alternative to professional laminating methods by substituting the tools and materials with cheaper and easily accessible alternatives. With professional laminating tools better results are achievable, and their use is recommended if the technical conditions allow it.

6.2 Painting

The foam parts are painted with transfer printing method. A PVC sheet is used as a transfer substrate and the paint is applied on that. The glassfieber fabric and the epoxy resin is applied on the top of the paint then it is folded to the foam core. Vacuum press is applied during the curing of the epoxy resin. When the curing process is finished the transfer foils can be easily separated from the surface.

Appropriate shapes have to be cut from plastic sheets, which match the surface, that is about to be painted (0.3 mm thick plastic sheets were used). These sheets can be cut with laser. Apply the paint in multiple layers, but first a layer of release agent has to be applied, to help the separation of the plastic sheet from the finished, painted surface. Care has to be taken to keep the base layer clean. Otherwise the paint might separate from the surface of the painted part. Five layers of water based acrylic paint were applied. Some acrylic paints react with the epoxy and are degrading over a short period of time. If other combination of paint and epoxy are used than recommended in the Appendix, the compatibility of the used materials have to be tested. Alkyd resin based paints in combination with the laminate can degrade in a long period of time (couple of moth) so it is recommended to test these paints befor applying it.

After all layers were applied, the spilling paint can easily be removed from the edges with a segmented blade knife, thus creating a more distinct edge for the layers, what helps the separation from the foil after the lamination (Fig. 6.1 middle photo).

As a cheap breather material we used paper towel. A breather material helps air from all around the part to be drawn. Glue the paper towel to the foil side, and remove the overhang to prevent it sticking to the foam part by the spilling epoxy (Fig. 6.1 right photo).

This painting method results in a smooth and shiny surface, when the foil is removed after the lamination.

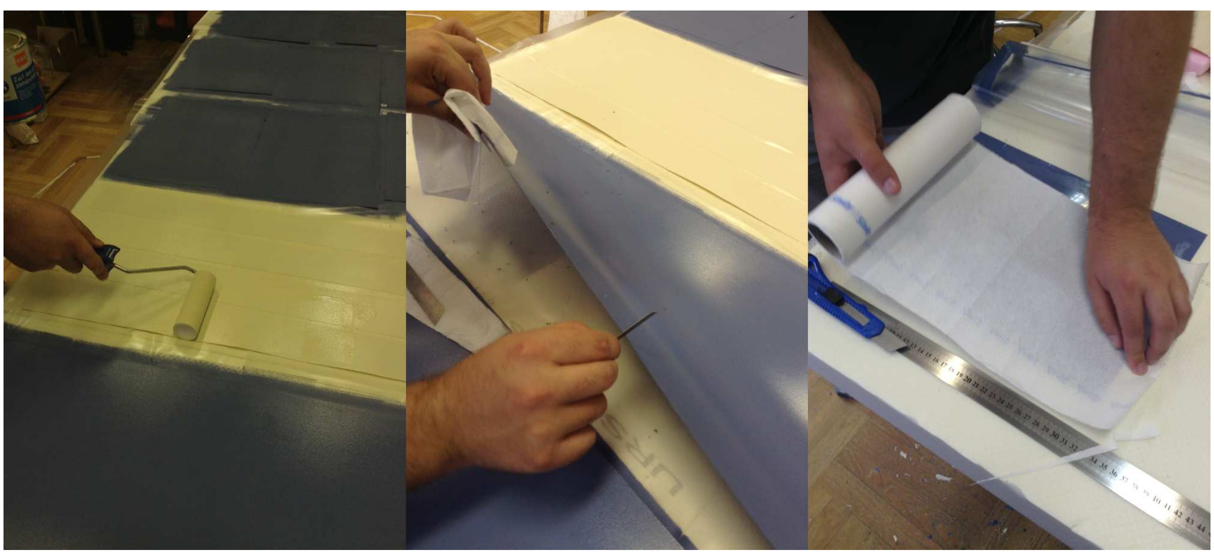


Figure 6.1. Painting the transfer sheets, removing paint from the edges and application of breather material

6.3 Preparing for the vacuum bag lamination

6.3.1 Preparing the foam surfaces

The hot wire cuts the foam by melting it, that results in a harder and smoother surface than the original foam. For laminating, it is better to remove this layer, to help the epoxy penetrate the surface. Therefore the foam surfaces need to be slightly sanded before lamination.

6.3.2 Laminates for the foam parts

Layers of laminates for the foam parts and their approximate filament directions are shown in Fig. 6.5. Most of the parts has one layer of glass fibre fabrics on its surfaces, and two layers in the region of leading edges. However, some parts has additional layers:

- two layers on the horizontal tail (in the region of the spar)
- control horns of the rudder
- central wing section (the whole surface)
- flaps and ailerons (the whole surface)

All the laminates are cut from 24 g/m^2 fibre glass fabric. Allow a few centimetres overhang around the edges, as it make the placement easier, and can easily be removed after lamination.

6.3.3 Laminating leading edges

As the above mentioned painting method is suitable for surfaces with limited curvature, the leading edges are laminated separately. Steps of the leading edge lamination are illustrated in Fig. 6.2. Leading edges on all parts has two layers of laminate. These laminates are 4-6 cm longer than the leading edge, and their perpendicular dimension is about 6-8 cm (this provides enough overlap, with the vacuum bag laminated surfaces).

Before the application of the layers, wet the surfaces with epoxy (Fig. 6.2 first photo). When it is done, put the fabric on the leading edge (second photo), and gently press with a brush (soaked with epoxy) (third photo), thus impregnating the layers. After the curing, cutting overhang is easy (fourth photo).

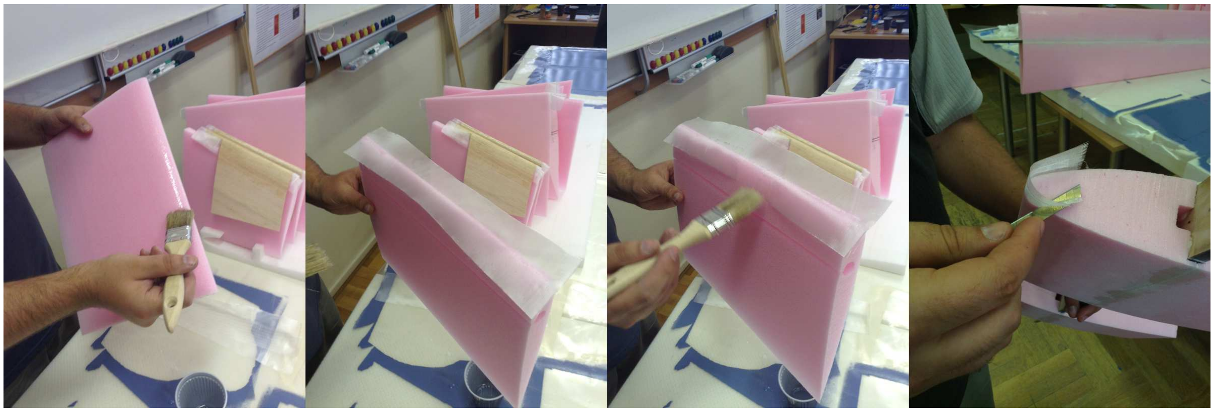


Figure 6.2. Laminating the leading edges

6.3.4 Vacuum bag

The vacuum bag forms an airtight envelope around the laminate. Film which is used as the material of walk-in plastic tunnels was chosen. This experimental solution worked well during the assembly, but if it is possible, the use of professional vacuum bags is recommended.

The vacuum bag should always be larger than the mold.Hot glue gun is used to seal the edges, and to provide sealing around the manifold. A chamber is included inside the bag to help maintain satisfactory vacuum pressure: by adding extra volume (40-120 ml), the pressure rise would be smaller in case of a leakage. This chamber is made of two syringe tubes, glued together (marked with 1. on Fig. 6.3).

For the central wing sections, the large volume between the foam parts would result in bending forces. To eliminate this, foam parts are placed to fill this volume (2. in Fig. 6.3). The foam parts of the winglet also need protection during the vacuum lamination. The connecting edge on the lower surface is acute angled, which is easily damaged by the clamping force during the lamination.

The sharp edges and corners (for example spar endings, or the chamber) need to be covered, otherwise the vacuum bag might be torn on them.

6.3.5 Vacuum port

As an experiment a self-made vacuum port is used, made of syringe components(see Fig. 6.4). An additional part has to be attached to the plunger, otherwise during the closing of the port, leakage would occur as the piston passes the opening on the tube (air could pass around the piston). To ensure the axial orientation of the additional piston,

Figure 6.3. Vacuum bag for the central wing sections

connect these parts inside a syringe tube. As it is not easy to glue this material, the parts are fixed together with welding, and sealing is done with a hot glue gun.

6.3.6 Straightening the ailerons

As the ailerons are long and thin parts, they are subject to warping, caused by the residual stress from the foam manufacturing. Therefore the ailerons have to be hold straight during the lamination. After the leading edge lamination is done, the ailerons were fasten to a lath with small amount of CA glue. After the curing, the laminates hold the part in this straight shape.

6.4 Lamination

For laminating the foam parts wet layup technology is used.

1. put the outermost laminate on the painted foils, and impregnate with epoxy
2. put on the additional layers, and impregnate as well
3. place the laminates on the surfaces of the foam
4. put the part, auxiliary foam parts (described in Subsection 6.3.4) and the chamber to the vacuum bag

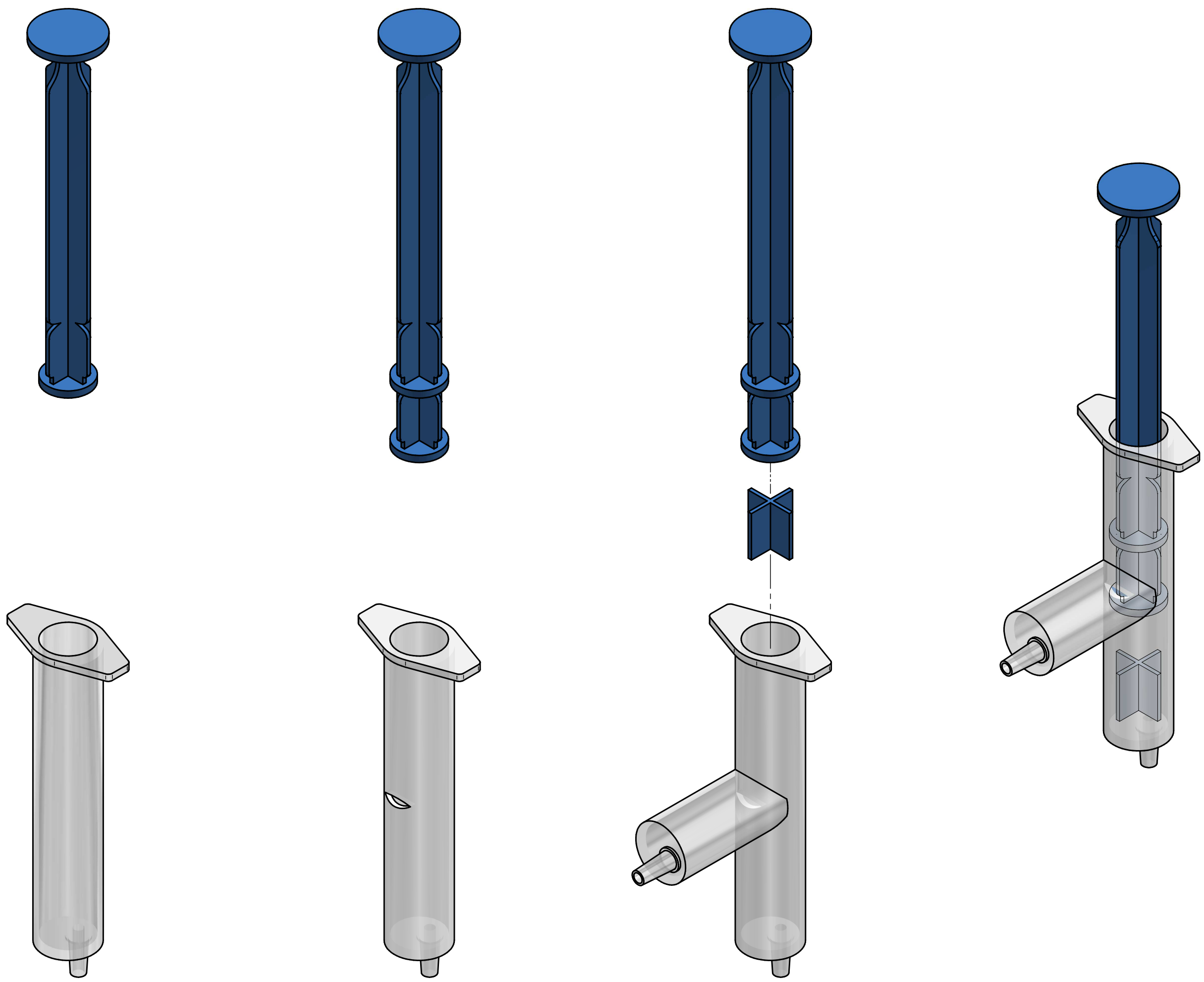


Figure 6.4. Vacuum port assembly

Figure 6.5. Laminates for the foam parts

5. lay breather material on the part, and around the vacuum port
6. seal the open edges and the point where vacuum port enters the bag
7. evacuate the air from the vacuum bag

To ensure correct surfaces, the vacuum has to be applied before curing starts.
Laminated parts are the following (See Fig. 6.6):

A. Wings
B. Winglets
C. Servo covers (plywood part)
D. Ailerons
E. Central wing section
F. Vertical stabilizer
G. Rudder
H. One-piece elevator (optional)
I. Elevator (optional)
J. Horizontal stabilizer (optional)

6.5 Hand laminating

The aircraft can be built without using vacuum lamination. Hand laminating is an easy manufacturing method, when layers are placed on the surface manually. The resin is applied on the foam parts and the glass fiber layers are placed on the foams. The advantage of this technique is the reduced preparation time and cost. However, the quality of the laminate in this case highly depends on the skill of the builders, and the thickness tolerances are larger. After the first layer of paint the surface must be sanded and repainted to obtain a sufficiently smooth surface. In conclusion, vacuum bag laminating is a better solution if quality is more important than short assembly time.

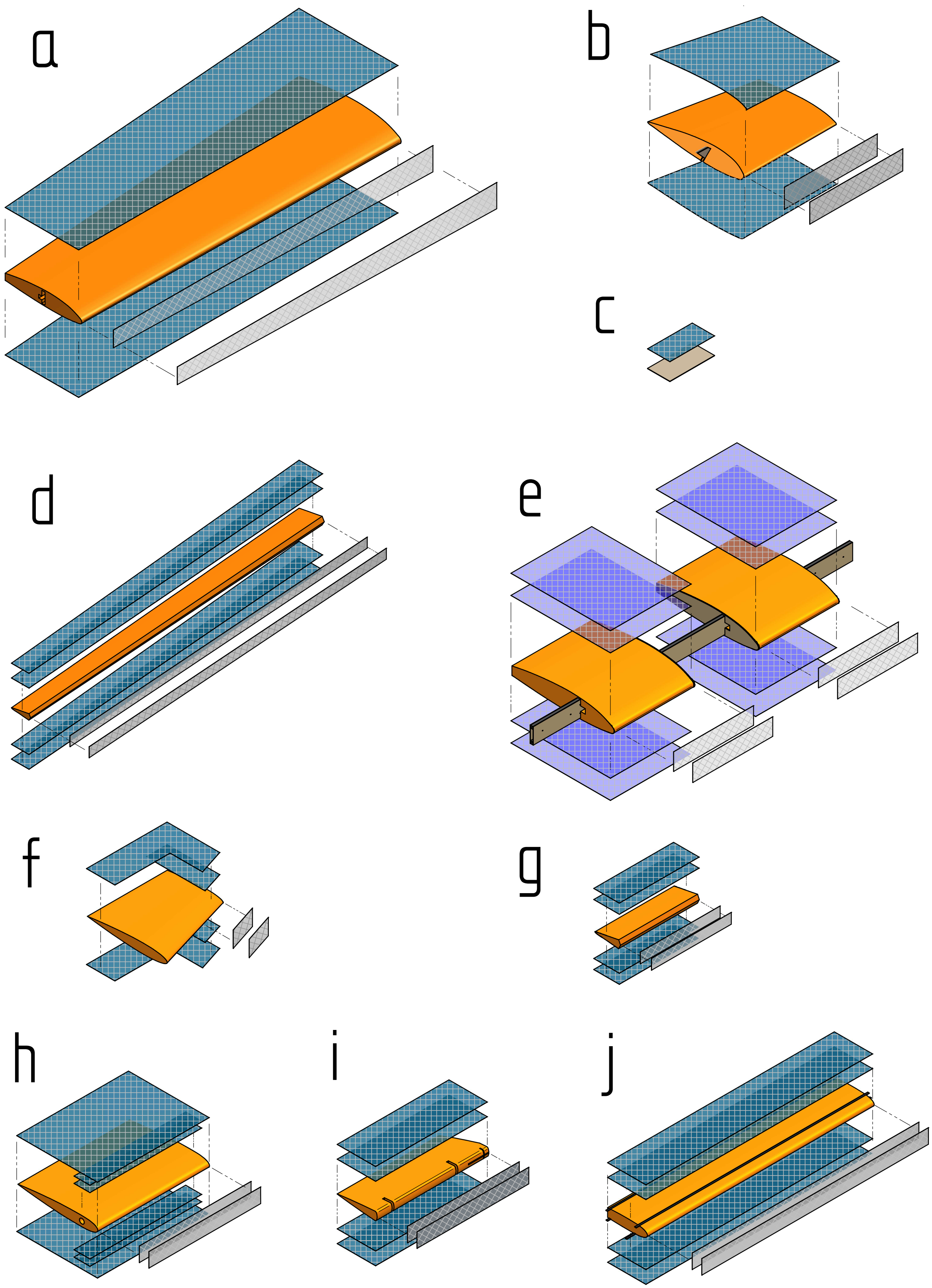


Figure 6.6. Laminates for the foam parts

Chapter 7

Final assembly

7.1 Gluing the central wing sections and nacelles together

The central wing section connects to the nacelle with the wing spar and on the side of the central foam parts. Photos of applying epoxy on the connecting surfaces are shown in Fig. 7.2. The foam on the connecting face is covered with thick filler mixed epoxy, which provides contact and adhesion on the whole surface (in the first picture – note the masked surfaces to protect the paint). The connecting side of the spar's extending part, and the top and bottom in the region of the sparbelts is covered with thin epoxy. Epoxy was also applied on the connecting surfaces of the nacelle: on the surface of the plywood board next to the spar, and on connecting surfaces of the sparbelts.

Squeezing force to keep parts in position during epoxy curing was provided with wires, strung between the nacelles.

7.2 Landing Gear

The struts of the landing gear are cut out from 5 mm thick aluminium sheet. The flat pattern of the strut is shown in Fig 7.4 *(a)*. The next step is the drilling of the holes for the landing gear fixing screws and for the wheels axle. After this the strut is bent at two places. The struts are placed in the nacelles, and the screws are installed. The screws should be strained very carefully to avoid shearing of the thread in the holes Fig 7.4 *(b)*. The axle of the plastic wheel is a long socket-screw. Each axle is fastened to the aluminum rods with a hex nut and with a self-locking nut Fig 7.4 *(c)*. The wheels are commercially

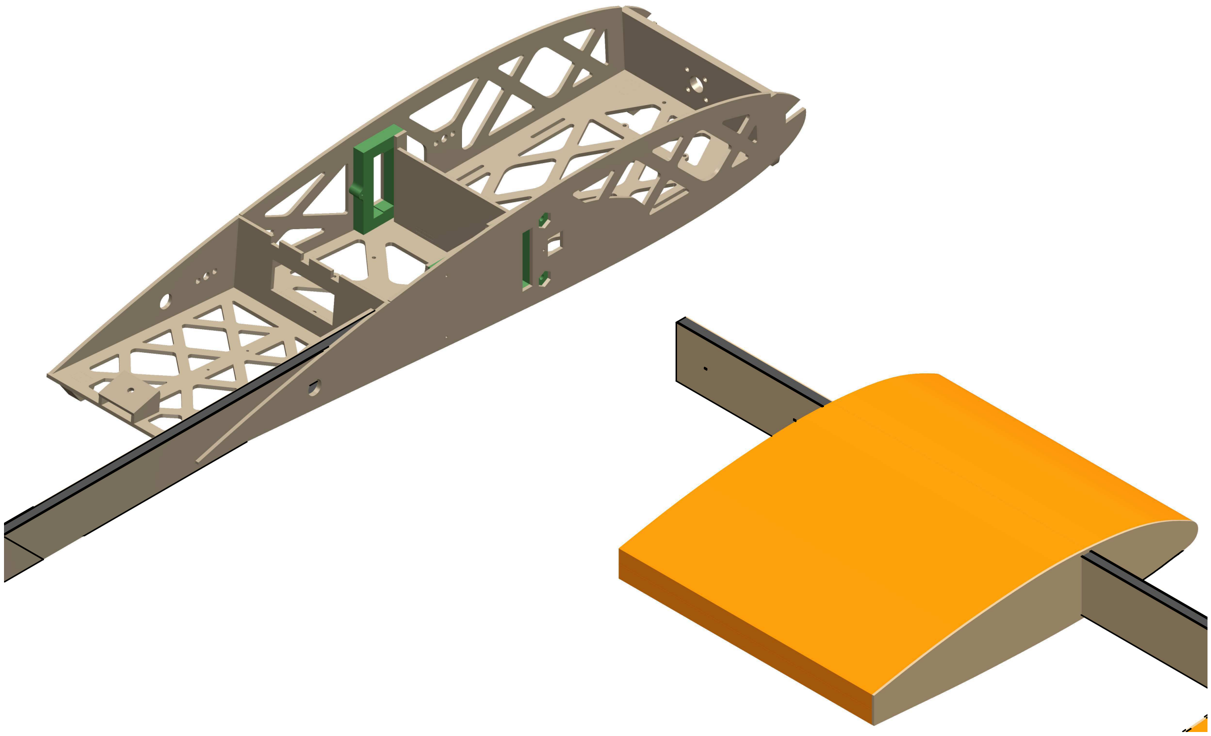


Figure 7.1. Gluing the central wing sections and nacelles together

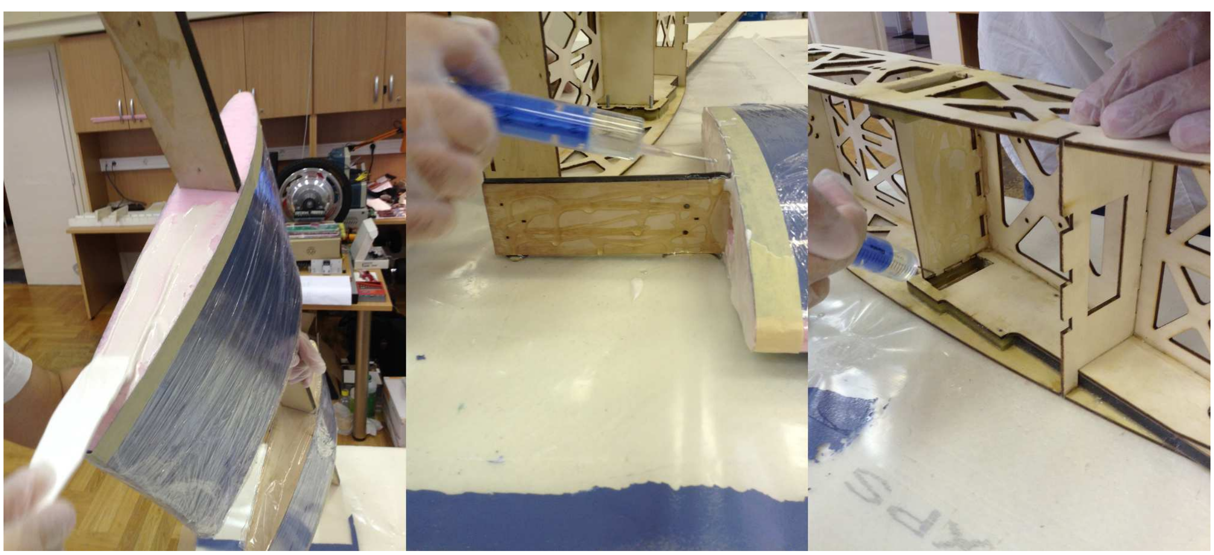


Figure 7.2. Applying epoxy on the connecting surfaces of the central wing sections and the nacelle

Figure 7.3. Squeezing nacelles during epoxy curing

available foam wheels made for RC airplanes. Wheels with 110 mm diameter were used.

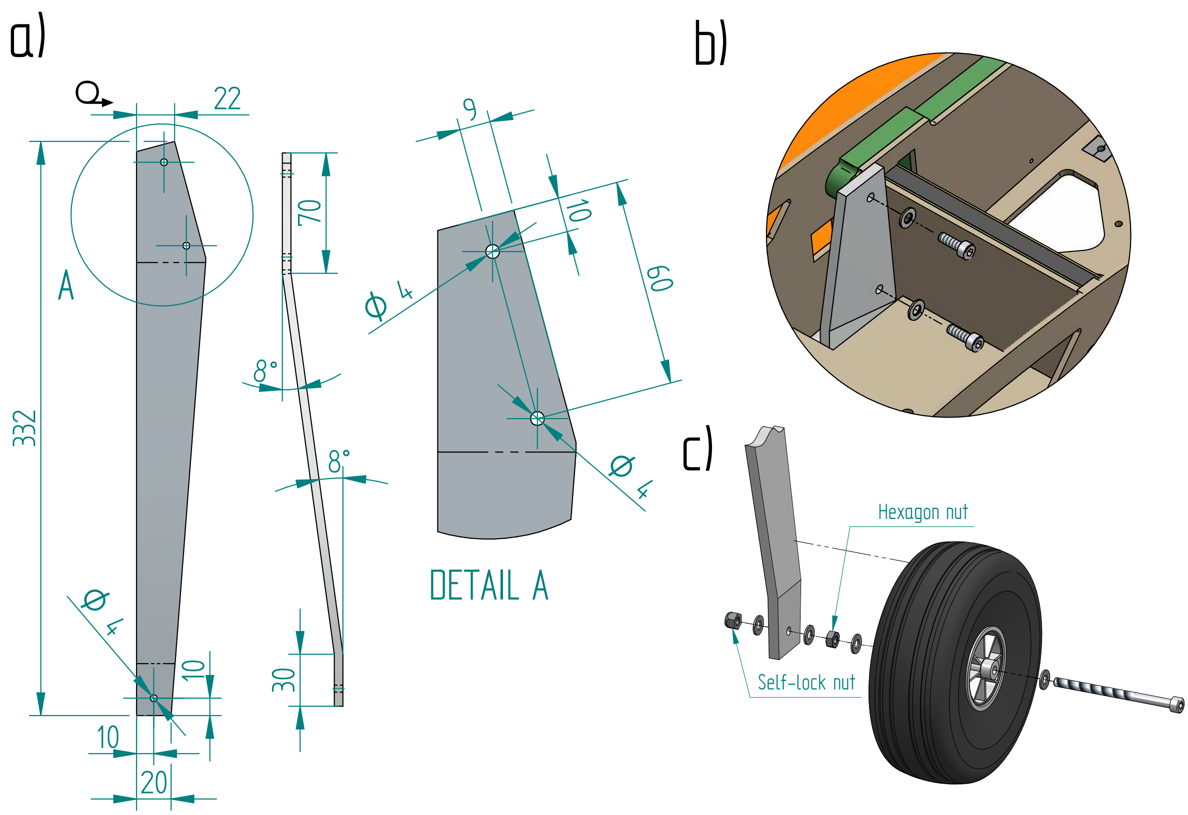


Figure 7.4. Landing gear

7.3 Fuselage installation

The fuselage is connected to the central wing section by wood bolts, which enables the removal and the use of various fuselages on the same airframe for different payloads. The steps of the fuselage installation are shown in Fig. 7.5. First, the fuselage is placed in the centroplane (*step 1*). Secondly, the fuselage fixing plate is slid between the front and rear floor plate (*step 2*) and fixed with screws. The wood bolts are driven into the thicker area of the root ribs (see Fig. 5.12) of the central wing section and the fuselage is fixed to the wing root rib with two screws on each side (*step 3*) , and finally the bolts are fixed with self-lock nuts from the bottom side (*step 4*).

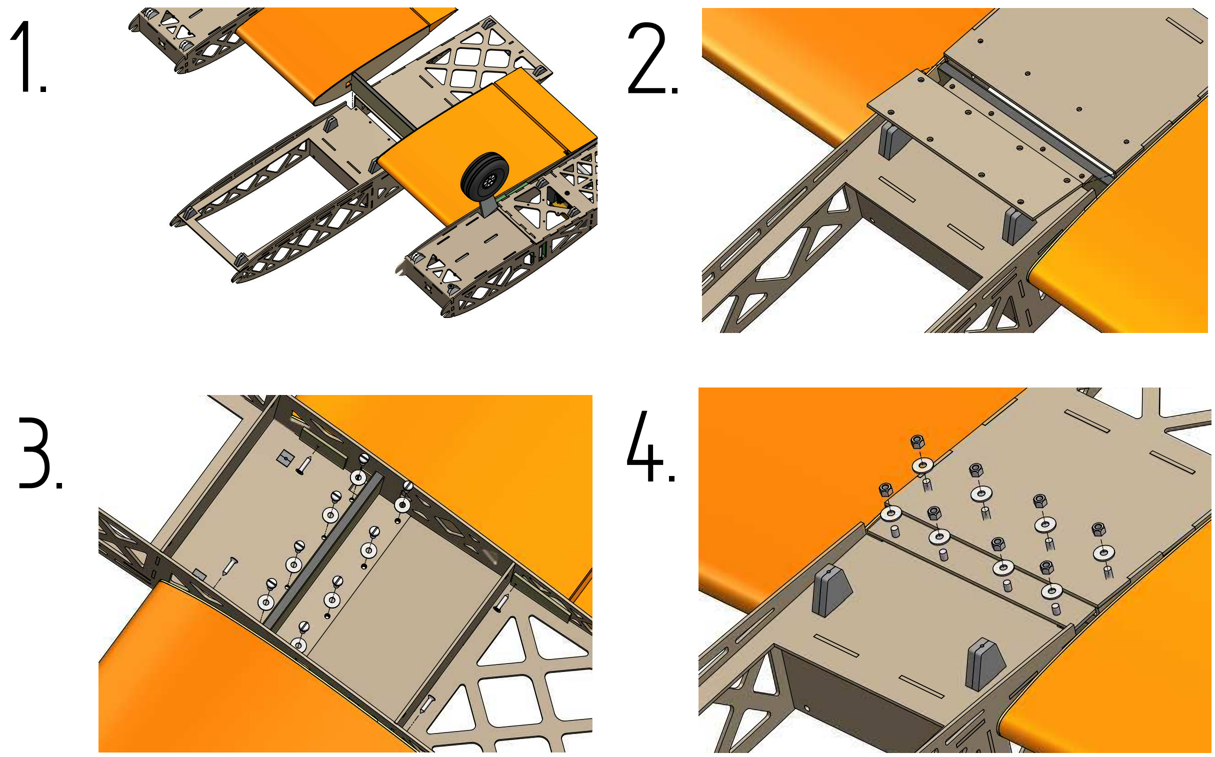


Figure 7.5. Fuselage installation

7.4 Horizontal stabilizer installation

The installation steps of the horizontal stabilizer are shown in Fig. 7.6. The stabilizer's spars are glued in the tailboom's cut-outs with epoxy glue (*step 1*). Before that spacers are glued on the top side of the tailboom to ensure the correct position of the spars (small white parts on the left side of the figure). To make the tail stiffer, corner elements are glued on the longer carbon rod (*step 2*).

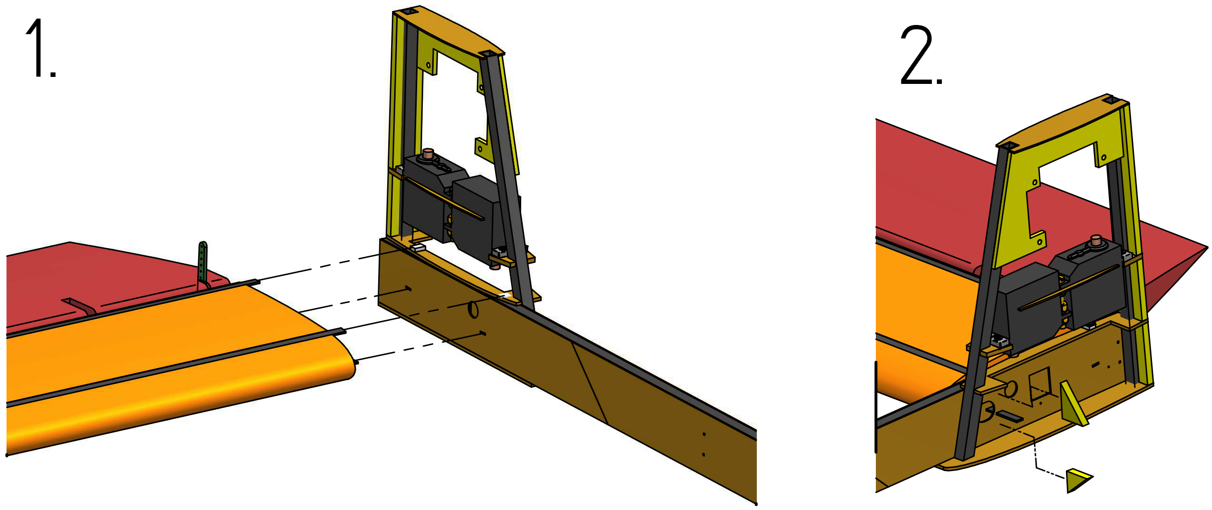


Figure 7.6. Installation of the horizontal stabilizer

7.4.1 Wing connecting parts

As the outer wing section is removable, connecting parts are needed to fix it to the nacelles. T-nuts are installed to the wing section's root under a spar rib. Another plywood part is needed to allow enough thickness for the hooks of the nut, and also to provide bigger connecting surface with the foam. Rivets with spherical head are ensuring the identical setting of the wing for every installation, as their head fit into holes on the nacelles. An exploded view of this connecting parts is in Fig. 7.7. To provide space for the connecting parts, and routing for the servo cables, some material has to be cut (or grinded) out. The T-nuts are hammered to the wooden parts, the rivets are glued in, and the rib is glued with filler mixed epoxy.

7.5 Diagonal stiffeners

This section refers to the version with the stabilator, it does not apply to the version with the split horizontal tail. The diagonal wires make the tail stiffer and prevent jamming of the horizontal stabilizer. The stiffeneres are made from fishing line. A fishing line type with low elasticity and high breaking strength (at least 14 kg) is recommended. Four diagonal holes are drilled for the wires trough the tailboom, where in Fig. 7.9 the green lines intersect the spars, approximately through the center of the spar's cross-section. One

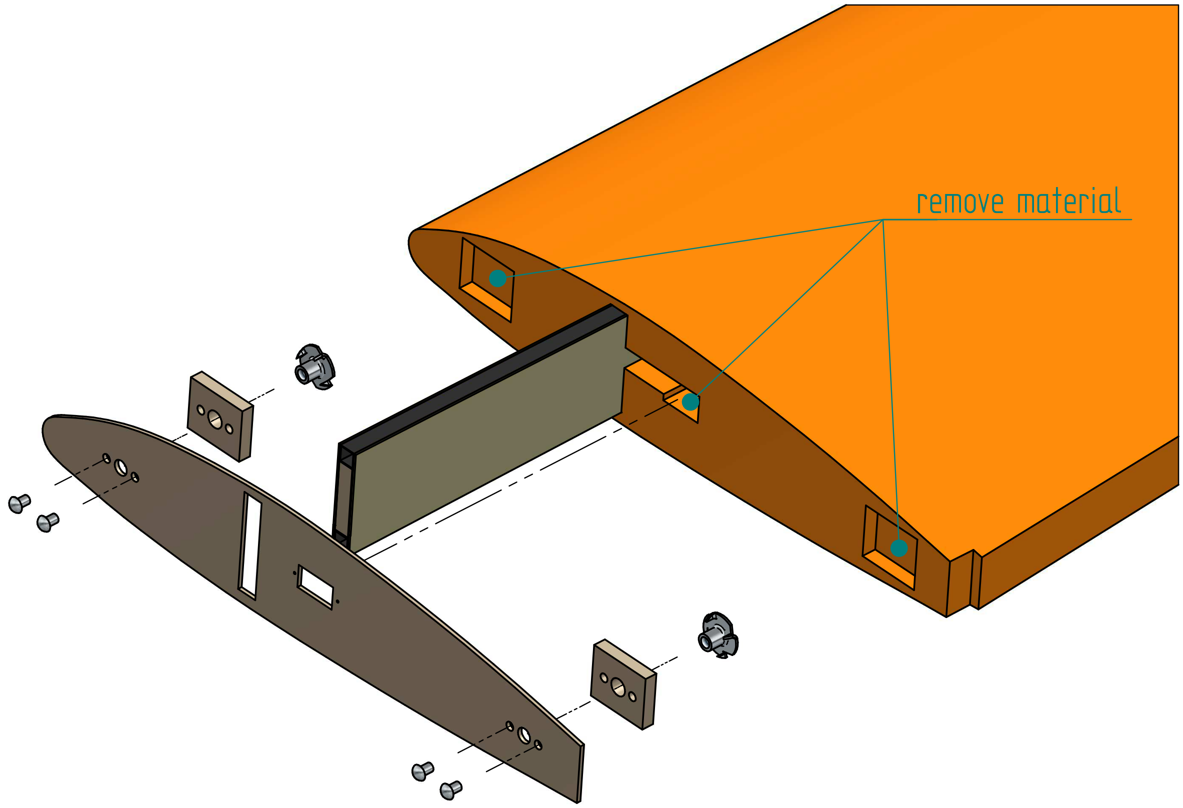


Figure 7.7. Assembly of the wing connecting parts

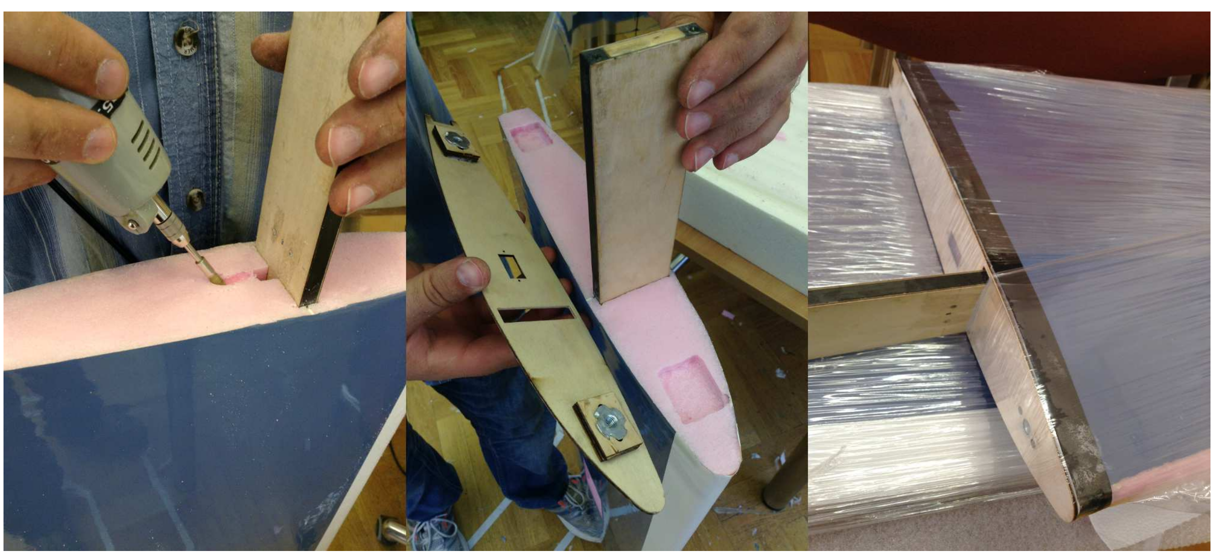


Figure 7.8. Gluing in the connecting parts

end of the wire is knotted to a small cylindrical object (for example a screw, that is longer than the diameter of the hole), the other end is pulled through the holes. When the wire is adequately spanned, cyanoacrylate glue is dripped on it.

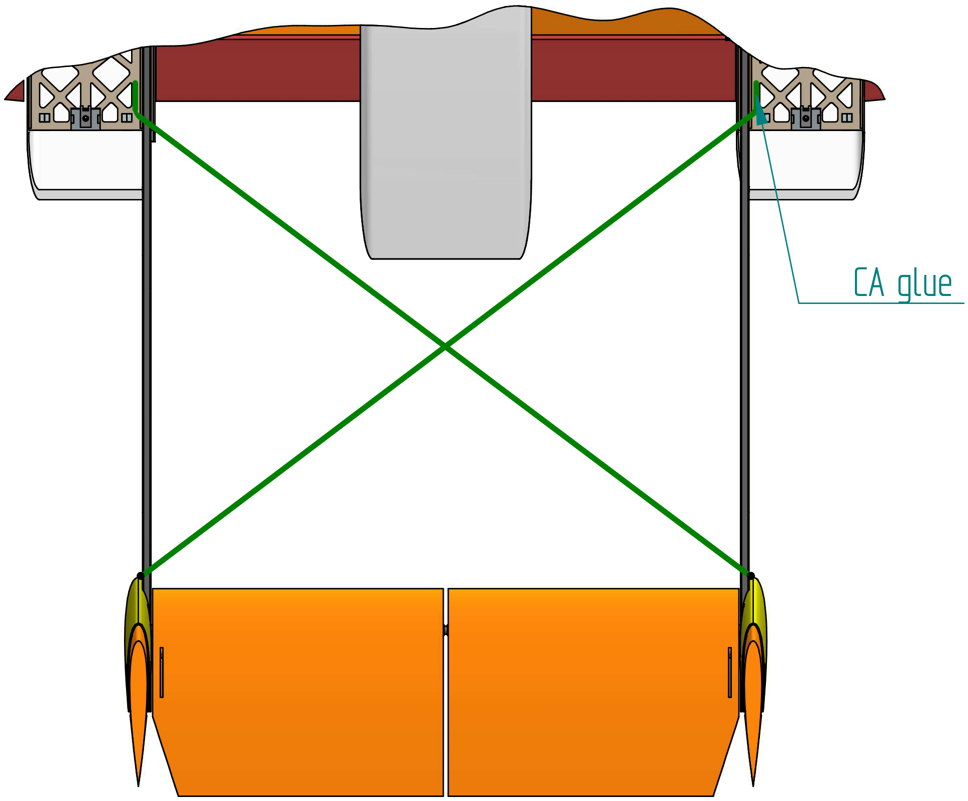


Figure 7.9. Diagonal stiffeners

7.6 Vertical tail covering

The assembly steps of the vertical tail covering are shown in Fig. 7.10. The foam core is divided into two parts (*step 2*). The leading edge is part of the assembly, the rest of the foam is functioning as a pattern for the balsa parts and it will be removed later. The rear section is covered by cling film (*step 3*) then the two parts are connected by small needles (*step 4*). The balsa sheets are glued with epoxy to the polystyrene leading edge (*step 5*). Two layers of glass fiber are applied to the leading edge (*step 6*), and two layers are glued on the balsa sheets with the method described in Chapter 6 (*step 7*). After the curing of epoxy the foam part is removed. The holes for the elevator and rudder servo rods are cut out with a sharp blade. The last step is the gluing of balsa lath at the rear section of the covering (see CAD drawings).

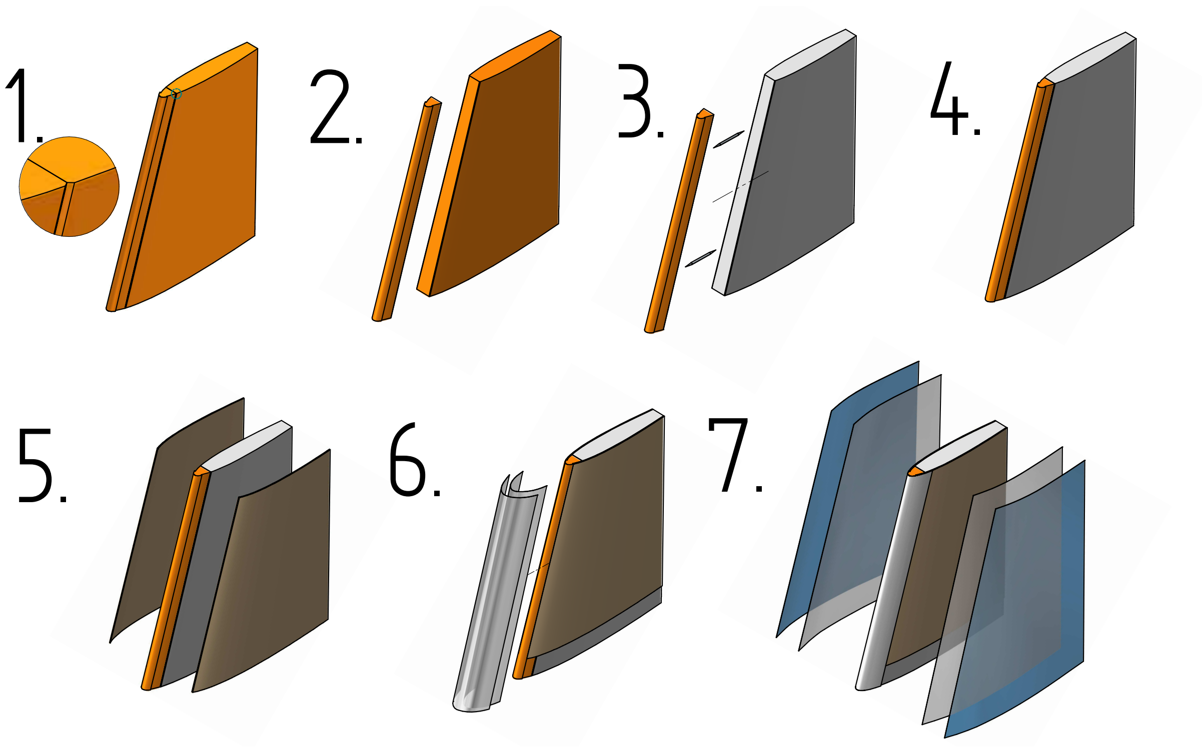
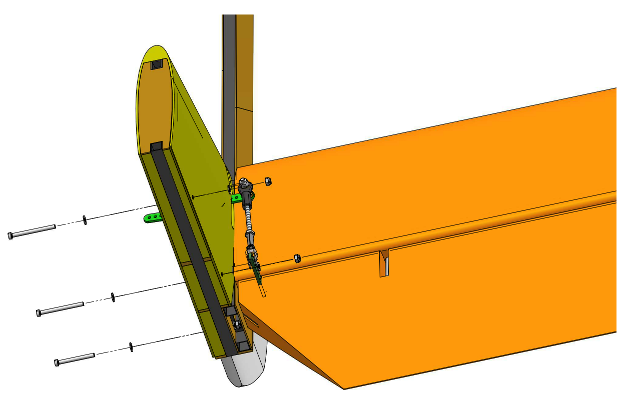


Figure 7.10. Vertical tail covering assembly steps

The vertical tail coverings are fixed with 3 bolts. Holes are drilled through the coverings, through the balsa parts next to the rear spar and through the rear carbon rod. Self-locking nuts have to be used to fix the bolts. Washers are used on both sides. The bolts have to be fastened carefully and not too tightly to avoid the damage of the balsa and fiber glass composite sheets. The installation of the bolts and the assembled vertical fin are shown on Fig. 7.11



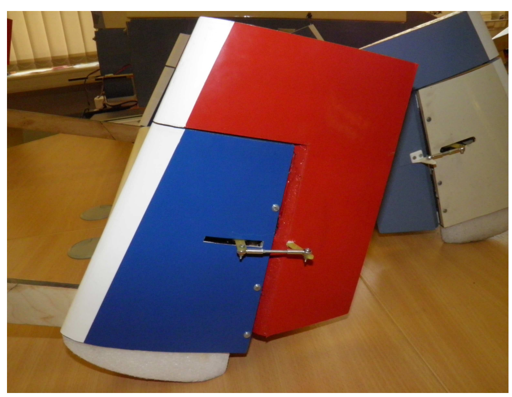


Figure 7.11. Vetical tail covering

7.7 Servo installation

7.7.1 Aileron servo housing

The servo for the aileron is housed in the outer wing section. A sufficient box is have to be carved to the wing. The location and dimensions are shown in Fig. 7.12, the depth is 25 mm. The servo assembly is shown in Fig. 7.13. The servo is fixed to plywood parts with screws, and these parts are glued on a plywood board. The covering is a laminated balsa sheet, which is also glued to the plywood board. To fix this assembly, laser cut plywood frame is glued to the foam, with epoxy. The servo board is fixed to this frame by 4 screws. Position this frame carefully, to make the fitted cover flush with the outer surface of the wing.

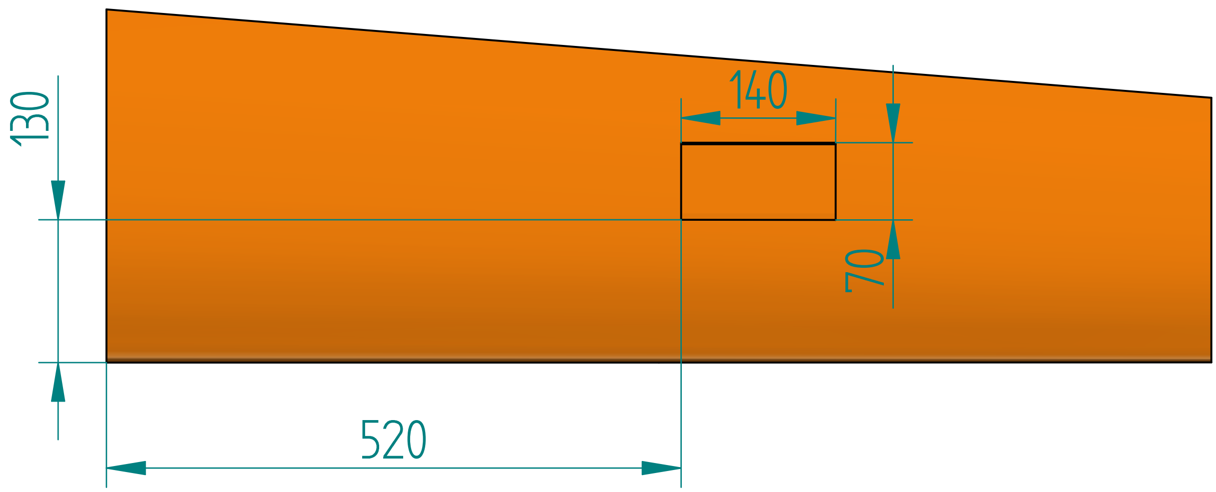


Figure 7.12. Placement of the servo housing

7.7.2 Flap servos

The aircraft is equipped with four flaps. Each flap has independent actuators. The assembly of the servomotors with their plywood holders is seen in Fig. 7.15 . It is necessary to rough-drill plywood parts, otherwise the screws could cause high tension in the plywood part and the layers of ply could separate from each other. The servomotors of all four flaps are placed in the nacelles (see Fig. 7.16,Fig. 7.17). The bottom plywood part is screwed in, the top plywood part is glued with wood glue to the rear plywood wall (*step 2*). The servos remain detachable after this step, but they will be difficultly accessible with a screwdriver, therefore it is recommended to follow the steps described here.

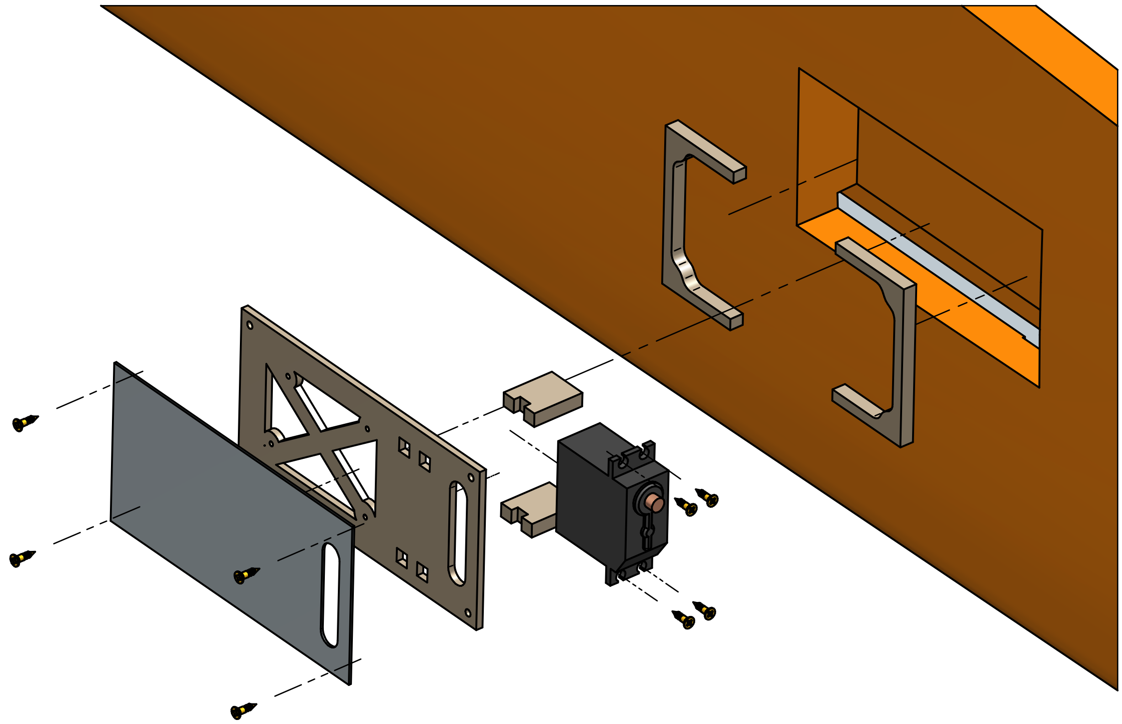


Figure 7.13. Servo box

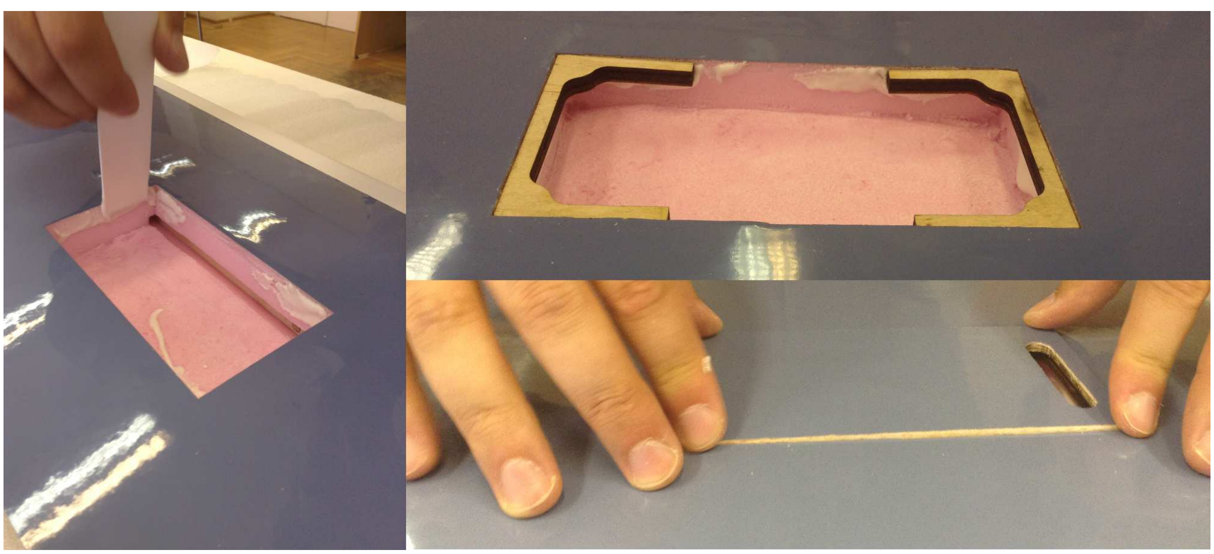


Figure 7.14. Assemply of the servo box

Each flap is moved by an aluminium rod. The aluminium rods are connected to the servomotors with lever arms made from PCB material and servo snappers. The PCB levers are glued with epoxy to the 10×1.5 aluminium rods. The dimensions of the

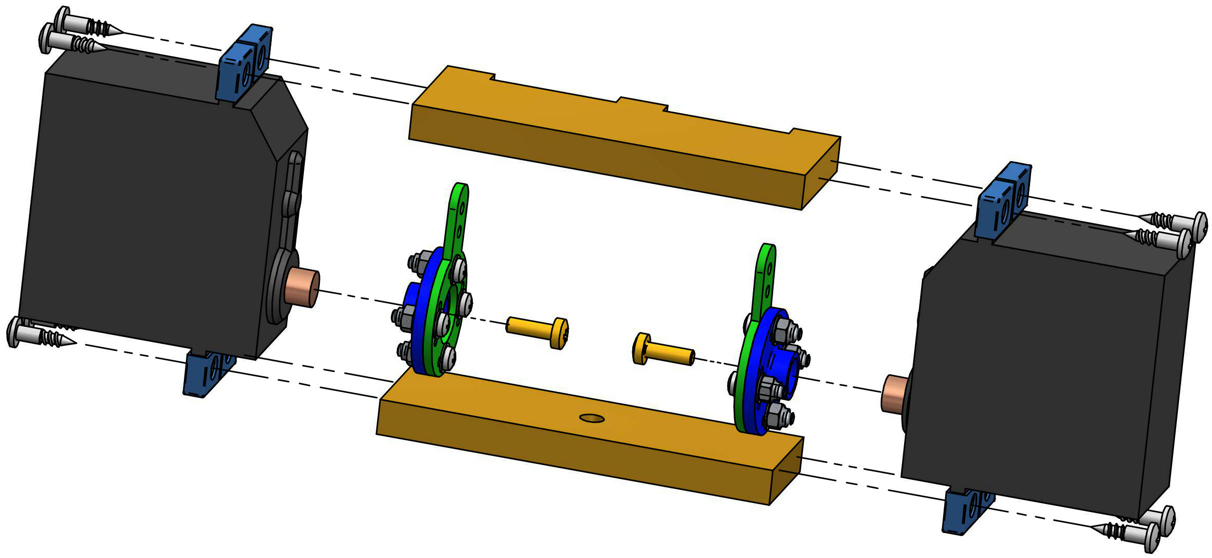


Figure 7.15. Flap servomotor assembly

aluminium rods are shown on Fig 7.18 *step 1.* The cutouts could be made with a hand saw or with a grinding machine. For precise positioning the holes should be drilled with a pillar-type drilling machine.

The ball bearings of the aluminium rods are rotating around small shafts, which are made of socket screws. The threaded part of the screw is cut off. The remaining parts shaft's length is equal to the width of the ball bearing (see Fig 7.18 *step 2*). The socket screw's head slightly hangs out from the aluminium rod (ca. half millimeter), otherwise the bearing could not rotate.

The bearing-bracket is made from three plywood parts. The assembly is shown in Fig 7.16 *step 1.* The parts of the bracket are glued together with wood glue. Positioning holes help the precise assembly. Due to the different geometry of the inner and outer flaps (the outer flaps rotating axis is slant) the parts of the bracket are also different (the outer rod's bearing is positioned farther back than the other one). The brackets are fixed to the nacelle's floor panel with two wood screws, which could be mounted from the bottom side (*step 2* if Fig 7.16).

After the servomotors and the brackets are mounted in the nacelle, the aluminium rods are fastened to the outer flap's lever arms with screws. Before this step, holes are drilled for the screws in the flap's lever arms, trough the amuminium rods. Each screw is fixed with a hexagon nut and a self-locking nut (*step 3* Fig 7.16). The screws are screwed off, each time the wings are dismounted. Thanks to the hexagon nuts the self-lock nuts could be mounted faster and they will be wearing out slower. As a final step, the snappers

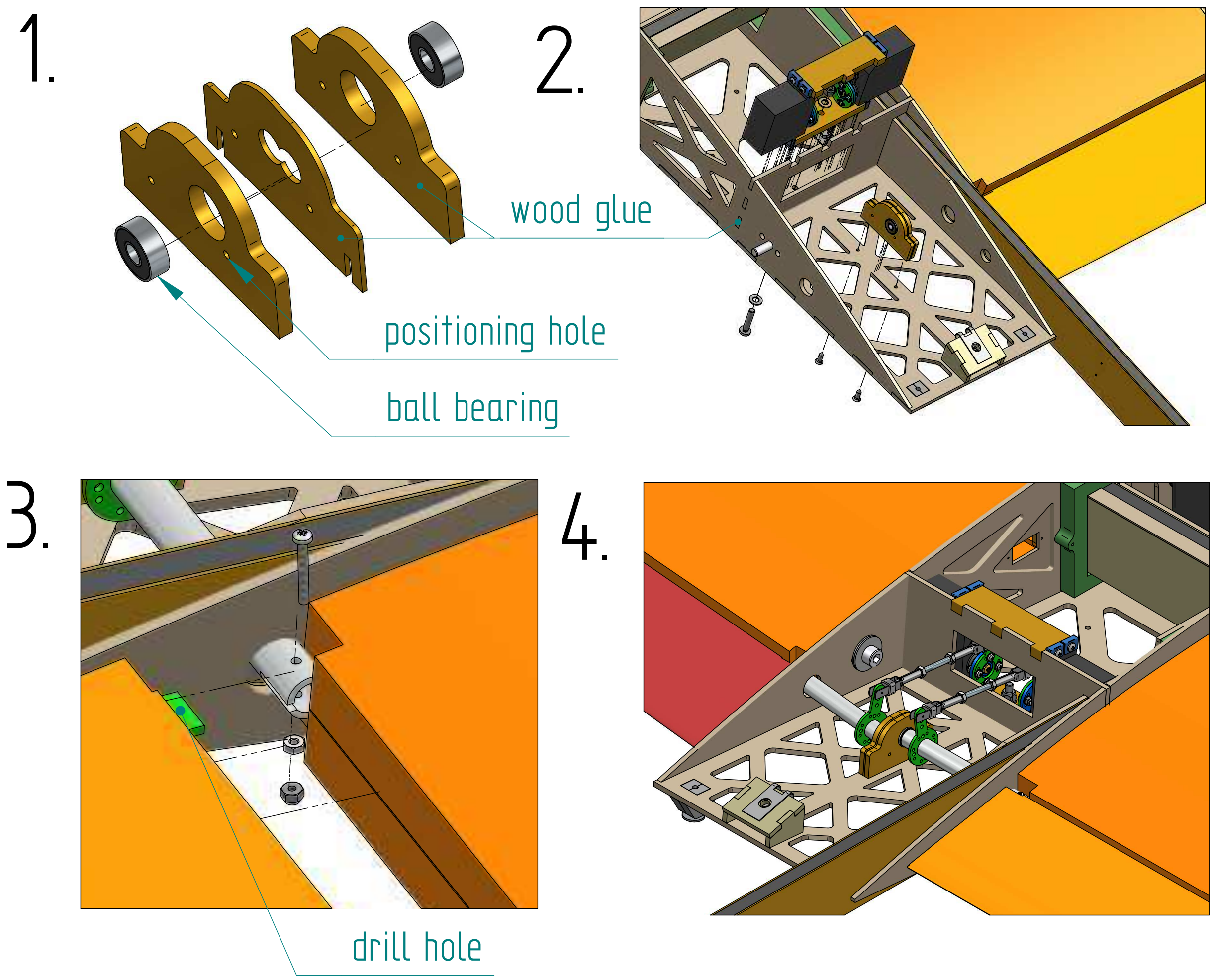


Figure 7.16. Flap servo installation steps

are mounted on the servomotor's and on the lever arms, which are glued to the aluminum rods (*step 4* Fig 7.16). The assembled mechanism can be seen on Fig. 7.17

7.7.3 Servo rods

The control surfaces except the flaps are connected to the servos with snappers and threaded rods. The snappers are connected to horns made from printed circuit board core material. The servo rods of the stabilator and the elevator can be seen in Fig. 7.19. In this case the use of ball-headed snappers is recommended. The length of the rods can be adjusted with nuts. The snappers are fixed with a thin rubber band (2-3 milimeters wide) cut off from a rubber tube.

Similar solution was used on the servos of the ailerons and rudders. The pictures of these servo rods are shown in Fig. 7.20.

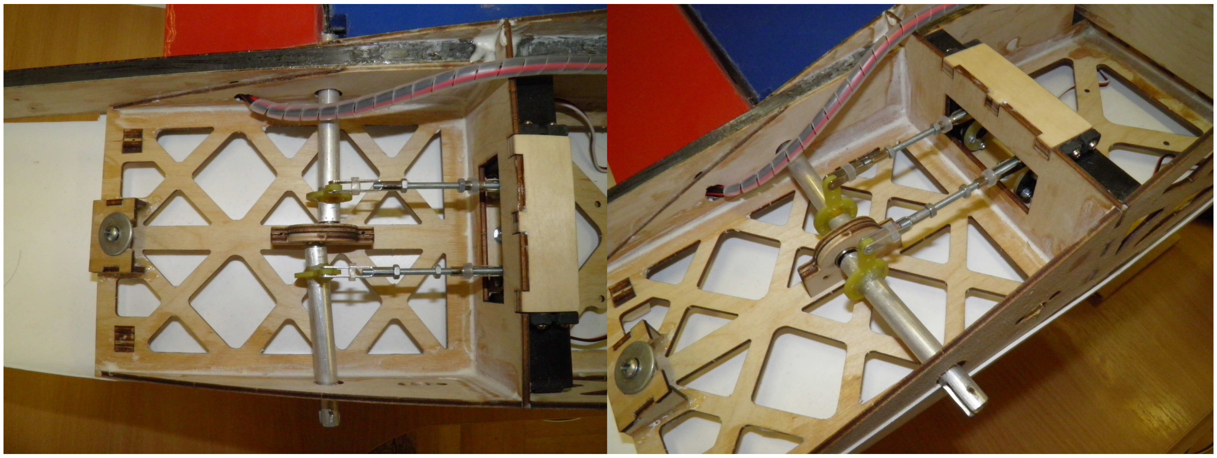


Figure 7.17. Assembled flap servo mechanism

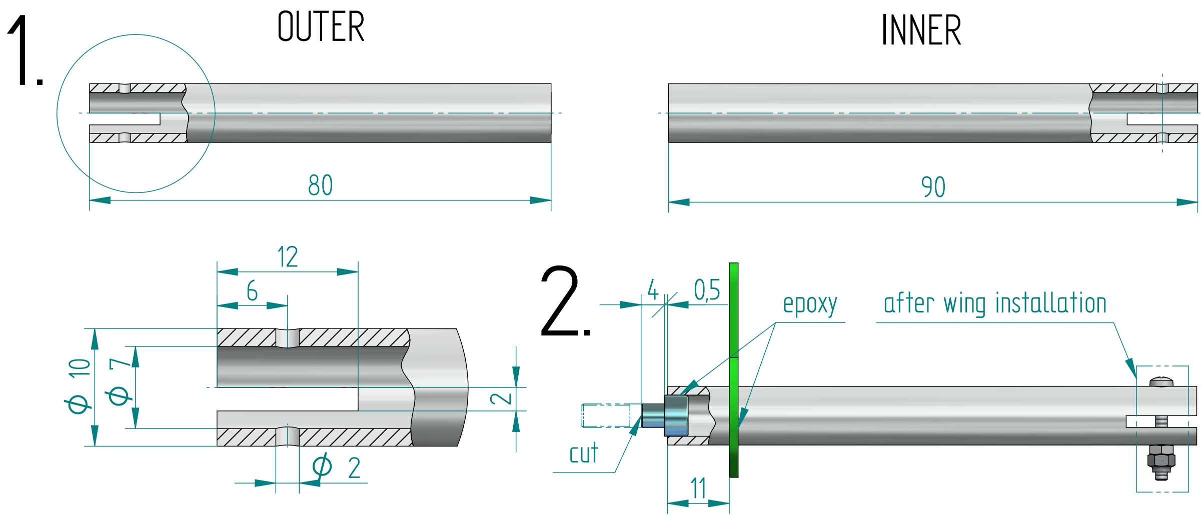


Figure 7.18. Aluminium rods

Figure 7.19. Servo rods on the stabilator (left) and elevator (right)

Figure 7.20. Servo rods on the rudder (left) and aileron (right)

7.7.4 Servos, Motors

Chapter 8

Pre-flight checks

After the execution of the assembly steps described in the previous chapters the aircraft is nearly completed. To make it ready to fly, several checks are needed before the maiden flight. These checks must be carried out before each flight.

To assemble and disassemble the aircraft before and after flights some tools will be needed, including a set of screwdrivers (for the nacelle and fuselage covering screw), a set of hex keys (for the wing root screws and for the diagonal stiffener in the fuselage), a fork wrench (for the airscrews).

The checking of the structural elements in the airframe and wings always needs attention. Since the diagonal stiffener in the fuselage is a structural element, the socket screws always have to be fastened, otherwise the stiffness of the fuselage won't be sufficient enough. This element is located over the middle payload rack in the fuselage, in consequence the stiffener will be likely removed often to gain access to the payload. For this reason, the stiffener must be checked before every flight. All parts of the payload, sensors and other equipment must be throughly anchored. The center of gravity has to be checked before flight. The wingspar in the outer section of the wing is a good point of reference. If the aircraft is bolstered up in this point, and it remains in equilibrium or is slightly nose-heavy, than the center of gravity is in good position. Otherwise the CG must be adjusted with the rearrangement of the payload or with adding additional balance weights placed in the forepart of the fuselage. It is specifically dangerous, if the aircraft is tail-heavy in the above mentioned point of support, because in this case it might become unstable in flight. It is recommended to estimate the center of gravity before flights by including the payload in the CAD model or by hand calculations.

After mounting and positioning the wing (wing a thin plywood wedge), the wing root screws are screwed in, and fastened. This must be done carefully, because applying too

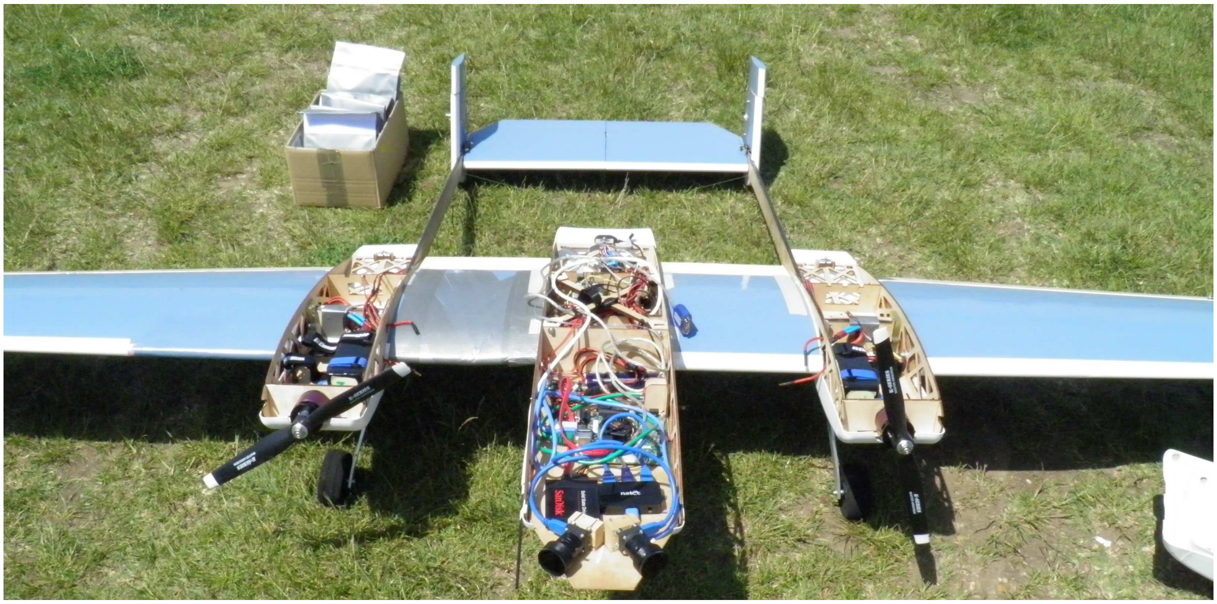


Figure 8.1. The aircraft before a flight measurement

much torque could damage the plywood parts. The condition of fuselage and nacelle covering must be also checked. This includes searching for cracks in the plastic, checking the plywood discs and finally the screws.

In case of the version equipped with a stabilator, the diagonal stiffener wires' tenseness must be also monitored. If the wires had elongated, they have to be replaced.

Before flights it has to be also checked, that the control surfaces are deflecting in both directions to their end postions, they are deflecting in the right direction according to the control input and that the servo rods are fastened and in good condition.

To make these necessary inspections easier, it is advisable to carry a written checklist including the above mentioned points.

Appendix

This chapter contains several additional information about the assembly process. The flowchart of the assembly is shown in Fig. 2 and 3. The steps of the production are basically the same for all versions of the airplane.

The main dimensions of the aircraft are included in Table 1, the overall dimensions are also marked in Fig. 4.

The templates for the engine orifice cut-outs are provided in Fig. 5 for five different orifice diameter (60, 65, 70, 75, 80 mm).

Used materials

The following materials are recommended to be used during the assembly of the aircraft.

Epolam 2017 - Laminating epoxy resin [3].

Properties:

- Improved reactivity vs Epolam 2015
- Good wet ability
- Available in large and small packaging
- Different hardeners available
- Improved health and safety
- Wood bonding abilities

Epolam 2015 Resin - Epolam 2015 resin designed for production of composite structures by wet lay-up methods and offered with a choice of three different speed hardeners. This allows the selection of a pot life suitable to the size of the part being produced. Well suited for wood impregnation [4].

Applications:

– Suitable for vacuum-bagging, RTM and filament winding

Properties:

– Low viscosity

– Readily wets out fabrics

– Good mechanical properties

F 19 Fastcast Polyuretane Resin - Low viscosity, long potlife resin [5].

Properties :

– Very low shrinkage

– Low viscosity even filled

– Easy to use mix ratio (1:1 by weight)

– High filler content possible

Oscar's M-700 release agent - Carnauba base mould release paste wax [6].

Properties :

– Formulated for easier application to polyester- and epoxy moulds

– Outstanding mould protection

– Easy release of finished parts

Printed circuit board core material FR-4 - a grade designation assigned to glass-reinforced epoxy laminate sheets, tubes, rods and printed circuit boards (PCB). FR-4 is a composite material composed of woven fiberglass cloth with an epoxy resin binder that is flame resistant [7]

Properties [5]:

– Density: 1.85 g/cm^3

– Rockwell hardness: 110 M

– Tensile strength: 310 MPa

Carbon rod - Square carbon composite rod is used for manufactruing spars and tail booms. RC model stores sells this type of part.

Properties:

- Dimensons:8x8x1000 mm
- Wall thickness: 1 mm
- Most of the cases the value of the tensile and compressional strength is not known. 1GPa is assumed for both factor in the fiber direction.

Fibre glass fabric - Used on the wings, tail and control surfaces.

Properties:

- Weight per area: 24 g/m^2

Plywood - Laser-cutted birch plywood was used.

Polystyrene foam - Austrotherm extruded polystyrene foam [8]. Used on the aircraft as wing and control surface core material.

Properties:

- Density: ca. 30 kg/m^3
- Closed cell structure
- Low water absorption
- high mechanical strength
- Slow aging
- Good recyclability

Ongropack Ongrofoam - Low density free-foamed PVC sheet [9]. Used on the aircraft for nacelle and fuselage coverings.

Properties:

- Thickness: 1 mm
- Density: ca. 475 kg/m^3 (measured)
- Fire resistant, self-extinguishing

Klöckner Pentaclear PVC - Transparent packaging PVC sheet. Used on the aircraft for transfer printing method [10].

- Thickness: 0.3 mm

OBI 2 in 1 - Water based acrylic color. [11]. Includes both surfacer and lacquer. This paint was used for the transfer printing method on every surfaces.

- Surface-dry: 1 hour
- Repaintable: 12 hours

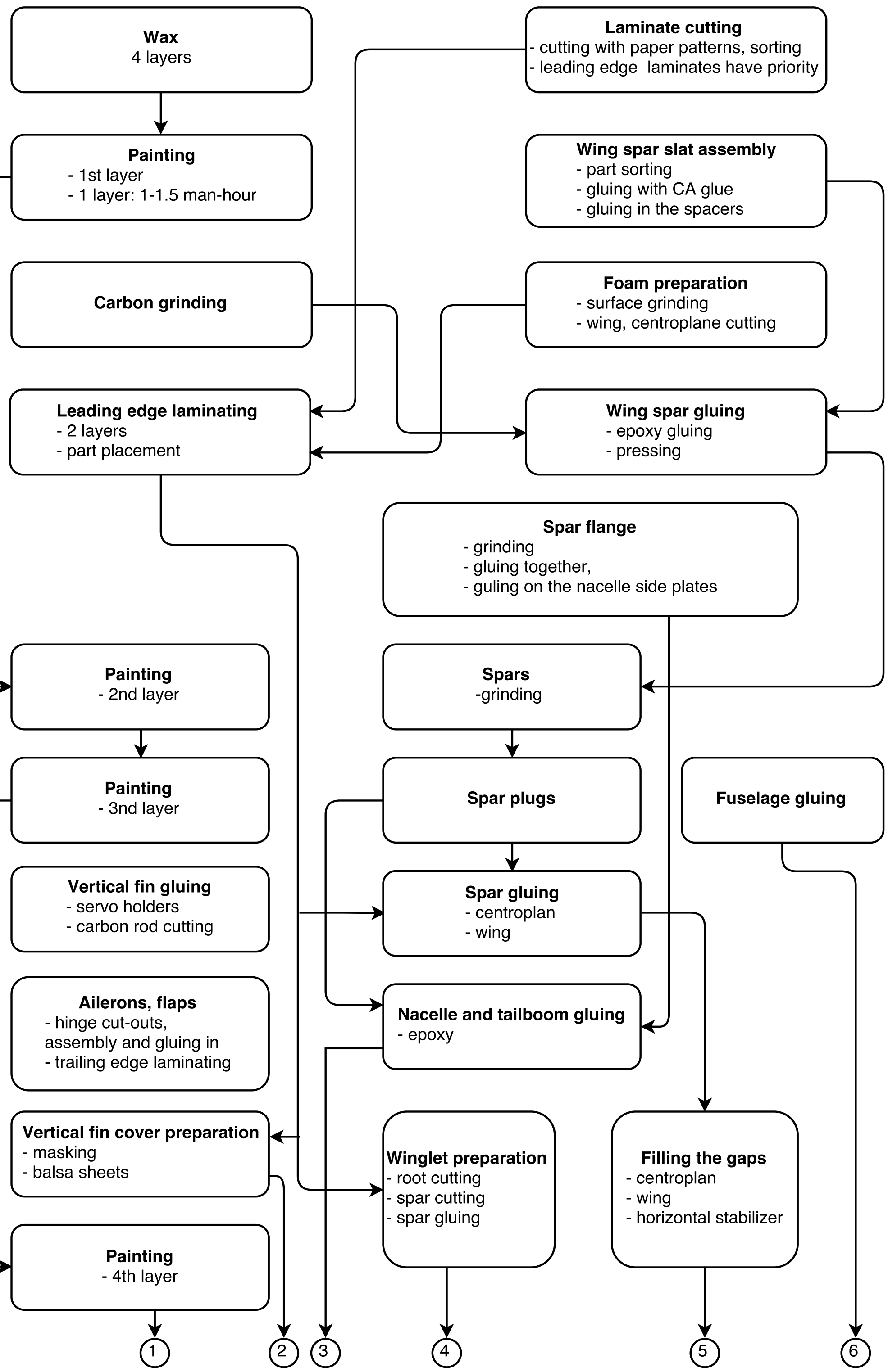


Figure 2. Assembly flowchart

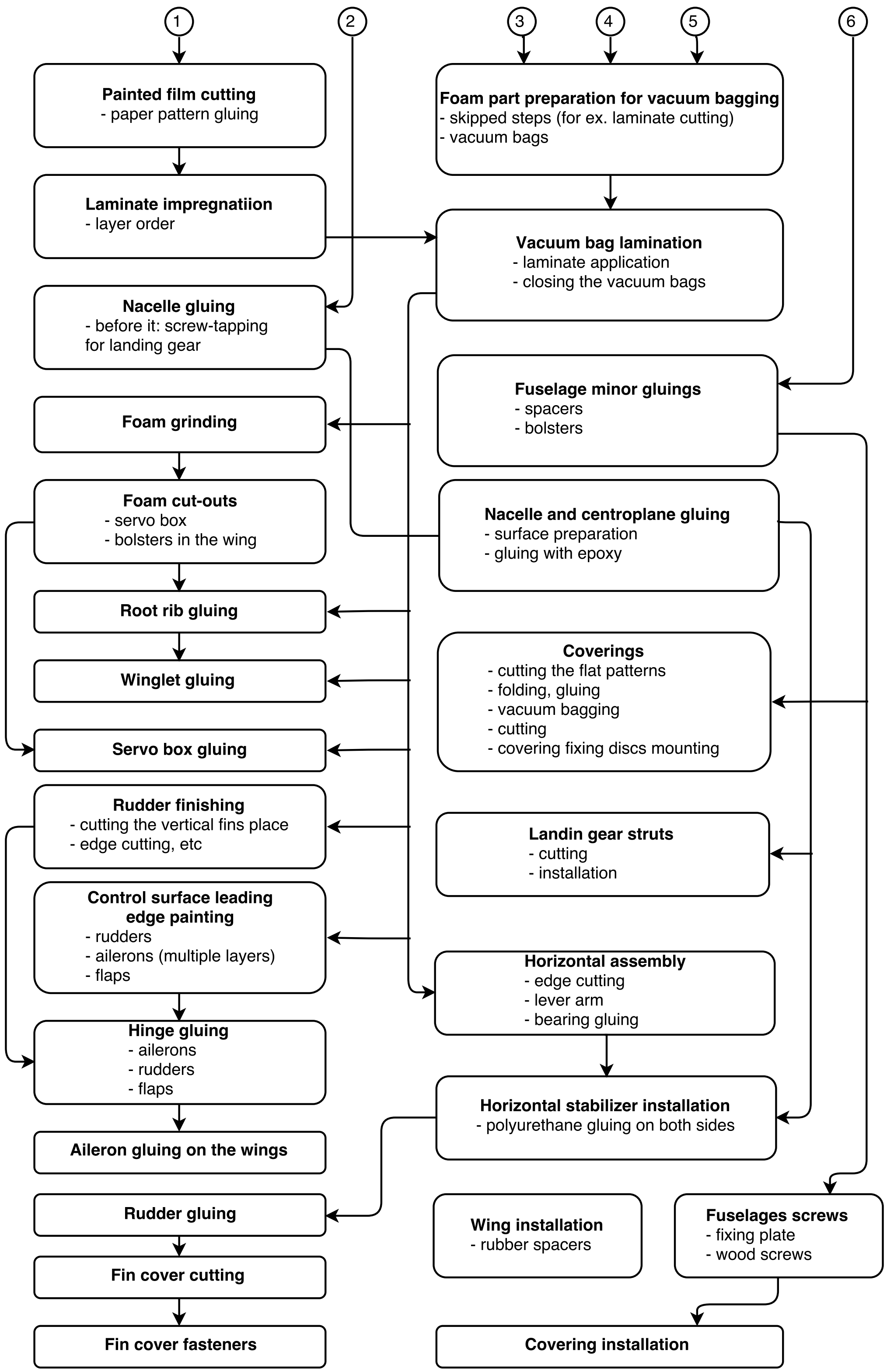


Figure 3. Assembly flowchart

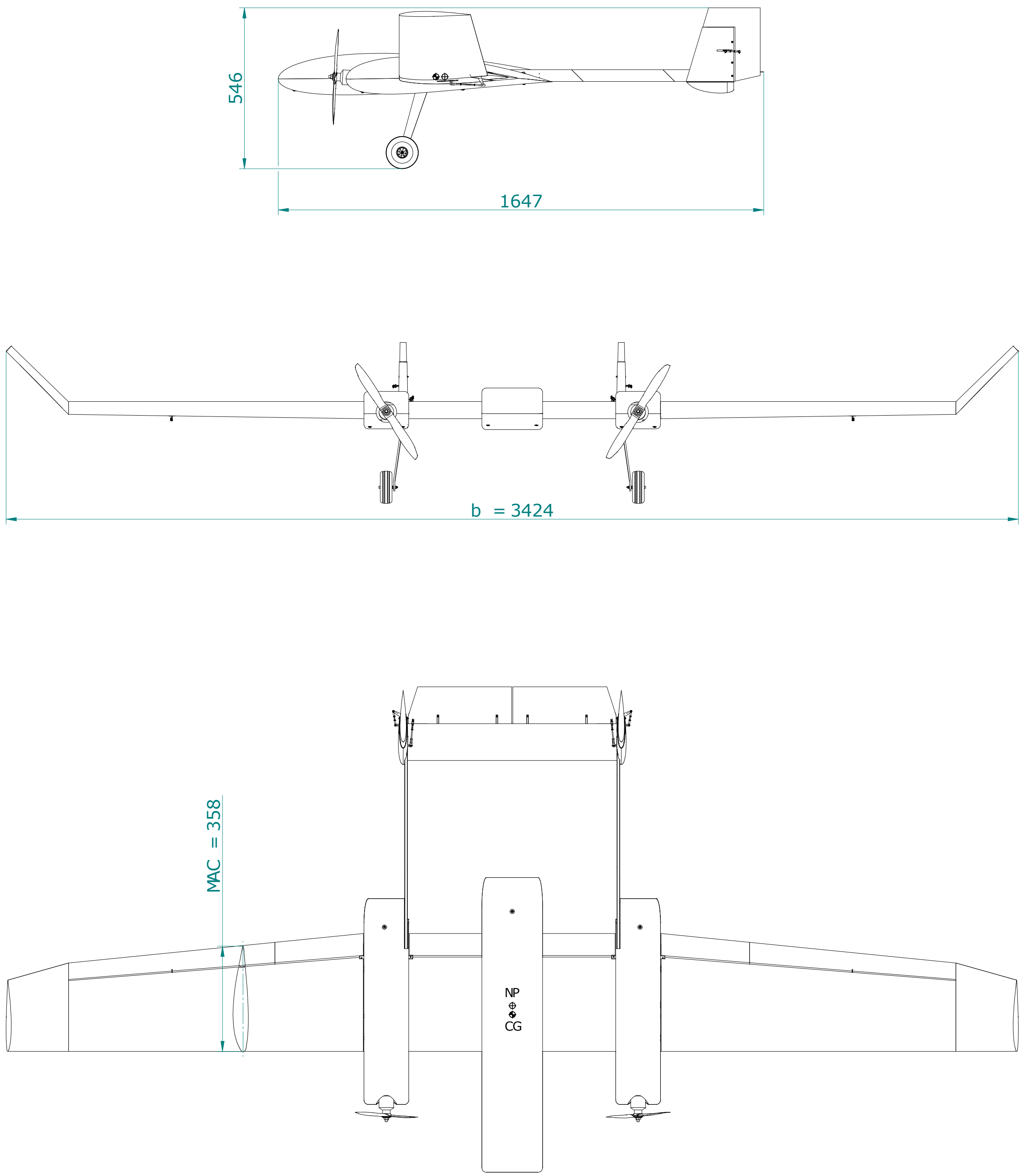


Figure 4. 3-view drawing

Table 1. Main dimensions

Wing		
Root chord	400	mm
Tip chord	250	mm
Main aerodynamic chord	358	mm
Wingspan	3424	mm
Root airfoil	Avistar	
Tip airfoil	Avistar	10.3%
Wing planform area	1.213	m^2
Taper ratio	0.625	
Aspect ratio	9.67	
Horizontal stabilizer		
Chord	250	mm
Span	740	mm
Airfoil	NACA 0012 H	
Area	0.1745	m^2
Aspect ratio	3.14	
Wing incidence angle	-1.4	
Vertical fin		
Root chord	250	mm
Tip chord	175	mm
Span	250	mm
Airfoil	NACA 0012	
Area	0.1325	m^2
Taper ratio	0.7	
Aspect ratio	0.85	

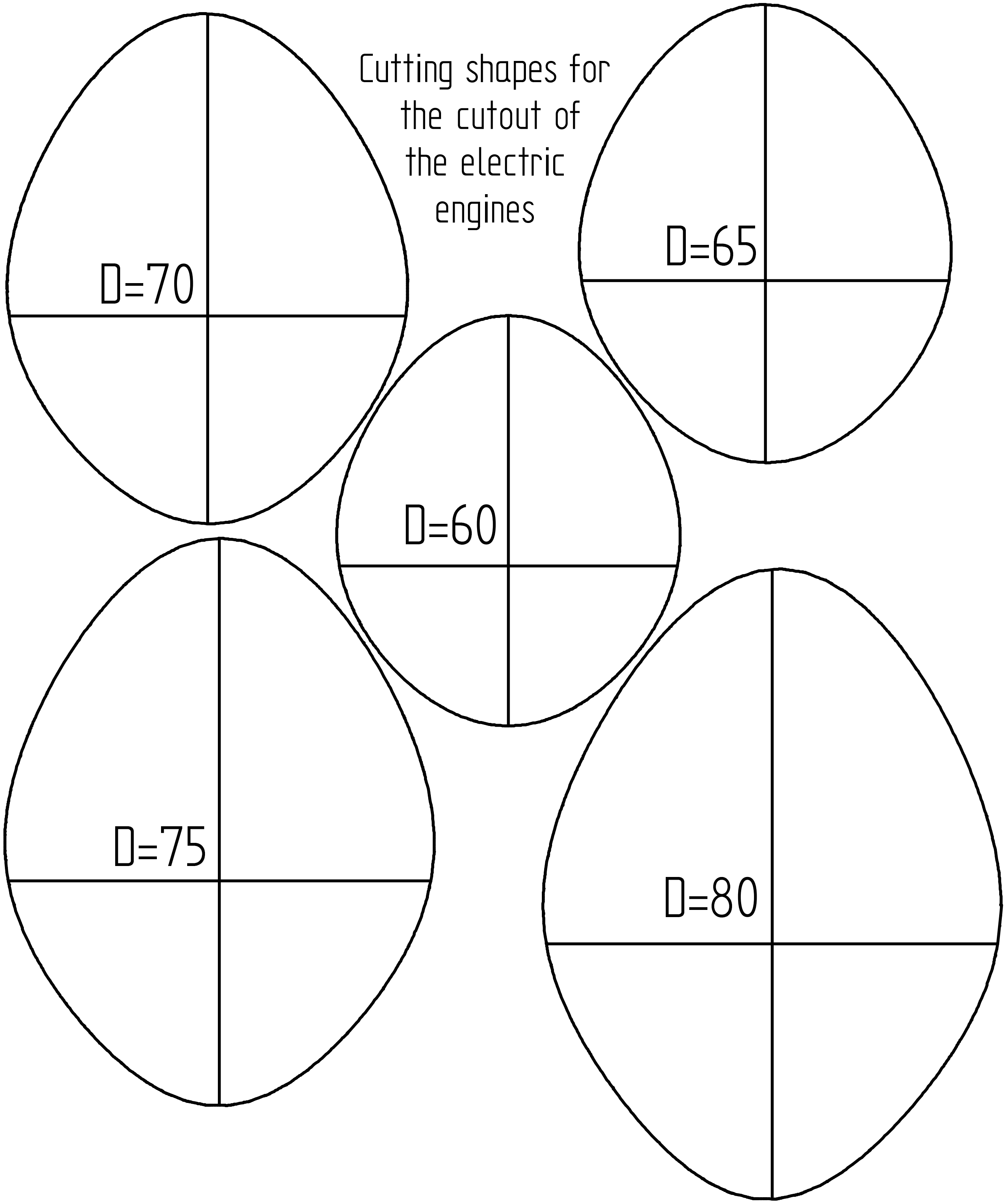


Figure 5. Engine cut-outs

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