Final Degree Project
Aerospace Engineering

Modelling and virtual recreation of the helicopter Mil V-12 with Catia V.5

Author: Ignacio Rosales Silván

Tutor: Laura García Ruesgas

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The tribunal appointed to judge the above Project, composed of the following members:

President:

Vowels:

Secretary:

Agree on granting the calification of:

Sevilla, 2020

Court Clerk

To my family

To my teachers

To my colleagues

Acknowledgements

Firstly, I would like to thank my mother, my brother, my aunt and the rest of my family for the constant support they have given me throughout the degree, giving me their advice and collaborating as much as possible in anything that could help my learning. I am also grateful for the, sometimes excessive, constant insistence and pressure I was subjected to regarding my studies, as their aim was no other than their desire for me to reach my goals as soon as possible. My most sincere thanks from the bottom of my heart because without them, none of this would have been possible.

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At last but not least, thanks to my teachers for all the teachings given during these years, especially Laura García Ruesgas, who attended my request for a final project, showed me her interest on it, and has supported me with any problem that has arisen and any decision taken.

Ignacio Rosales Silván

Escuela Técnica Superior de Ingeniería

Sevilla, 2020

Abstract

The aim of this project is the virtual recreation of the aircraft Mil Mi-12 by using CATIA V5 r19, a helicopter whose production started in Russia in 1965, during the Cold War, with military purposes and an aircraft that achieved eight world records, four of which are still current.

The first part of the project explains the background of its design, the reason why Russia decided to create such aircraft and some other secondary purposes. Knowing the main goals of the helicopter, there will be a short explanation regarding the design process of the aircraft, as well as the configuration of some preliminary prototypes and, after that, there will be introduced its main characteristics and technical specifications, in order to have a general knowledge about its final design. After that, in this same part, there will be mentioned the records achieved by the aircraft and some of the variants that, although some of them were never carried out, their production was in the mind of the engineers in charge of the project. Additionally, there will be commented everything related to its operational history.

Once all the general knowledge about the aircraft has been provided, the following section will be dedicated to the main purpose of this project, the 3D modelling of the Mi-12. In order to do so, there will be an exhaustive explanation about each of the steps taken during the design process with CATIA. The order followed in this section will be the same carried out while modelling the aircraft, both externally and internally. Therefore, with each of the parts in which the Mi-12 has been divided during the design process completely defined, there will be explained the assembly process, which will provide the complete model of the aircraft.

It is worth to mention that at the end of the project, there have been shown some rendered photographs of the created model in order to imagine how it would look in the actual world.

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1. Introduction

The present work, as its title indicates, will focus on the analysis and design of the helicopter Mil v-12, however, the decision of which aircraft should be designed was not that easy to take. The first decision taken was doing a final project based on the use of CATIA, as the graphic design and 3D modelling has always been something really attractive to the author of this project.

The important decision to take was which aircraft should be modelled. At the beginning all the options envisaged were planes designed and used in the Second World War, however, after some research it became apparent that many of them had already been designed, which would mean that any similar design would not be very innovative, as well as the modelling of any commercial aircraft. For that reason, it was decided to take some other kind of aircrafts into account, helicopters and spaceships. After some research and excluding other options, the aircraft which suited better all the requirements was the helicopter Mil V-12 or Mil Mi-12.

Illustration 1: Mil V-12

Once decided, the project was presented to the professor Laura García Ruesgas, who was immediately interested on the decision of modelling such helicopter, the reasons are evident, it is not a common design project, not only because it is a helicopter, but because of its structure. As it is a huge helicopter, it is anything but simple both internally and externally, moreover, its configuration is not any usual, as the rotors are located over two wings, unlike most of them. Finally, there are some other Mil, as it is the name of a set of helicopters made by a Russian company, it was decided that the helicopter Mil V-12 was the best choice not only because of its structure, but also the world records it achieved, as will be mentioned further on.

Therefore, there are no 3D models of the helicopter Mil V-12 available on the net, so the requirement of making a design of it became obvious, as it could be useful in case somebody wanted to get some information about the structure of such helicopter, check information about its size accurately or even creating a 3D model by printing it with manufacturing purposes.

For that reason, the final step to take is to decide which program should be used to model this aircraft. In this case the answer is evident, not only because there has been a subject delivered which included all the basics of CATIA, but because it is clearly one of the most powerful program regarding to 3D modelling, if not the most powerful one.

2. Mil V-12 helicopter

2.1. Objectives

Design studies for a giant helicopter were started at the Mil OKB in 1959, receiving official sanction in 1961 by the GKAT (Gosudarstvenny Komitet po Aviatsionnoy Tekhnike – State committee on Aircraft Technology) instructing Mil to develop a helicopter capable of lifting 20 to 25 tons.

In order to accomplish these objectives, the Mi-12 project was started in 1965 with the aim of producing a vertical take-off aircraft capable of carrying soldiers, equipment and supplies. Actually, as it can be seen, this aircraft was built during the Cold War, and that is why the main elements that would have been moved on by the Mil Mi-12 were heavy nuclear missiles and other loads compatible with those of the four-engine Antonov An-22.

It is worth to mention that the bureau chose a side-by-side rotor formula, as will be explained later, in order to use the engine-transmission-rotor assembly of the helicopters of the Mi-6 and Mi-10 series with minimal modifications, what would highly reduce the costs and the time spent.

Even though this is the main reason behind the design of the helicopter Mi-12, there are two more of them which had an important weight on the decisions taken. The first one is that at this period, Soviet Union and the US were racing with each other in a technological way. For this reason the government was looking to have the most powerful vehicle, further than because of its use, to show their enemies that they had better aircrafts to assist the military in case of a conflict. The second reason has nothing to do with the military use, as the Mi-12 was probably intended for service with Aeroflot too, especially for deployment in areas of Siberia which are rich on resources but which have very poor communication.

2.2. Design and characteristics

In this sections the main characteristics of both the inside and the outside of the Mi-12 will be mentioned, as well as some of the facts that took place during the design.

At the beginning of the design process, control of the Mi-12 presented several problems to the designers and engineers due to the sheer size as well as rotor layout. Therefore, the Mi-12 was initially thought to have a tandem-rotor layout, however, Mil received early permission to concentrate instead on a twin side-by-side rotor configuration, which the design bureau claimed as having better reliability, fatigue life and stability.

The wings, unlike in most of the planes, have an inverse taper from the root to the wingtips. The following photograph shows a scale model with the first configuration contemplated for this aircraft. However, as it has been explained, such project was never carried out.

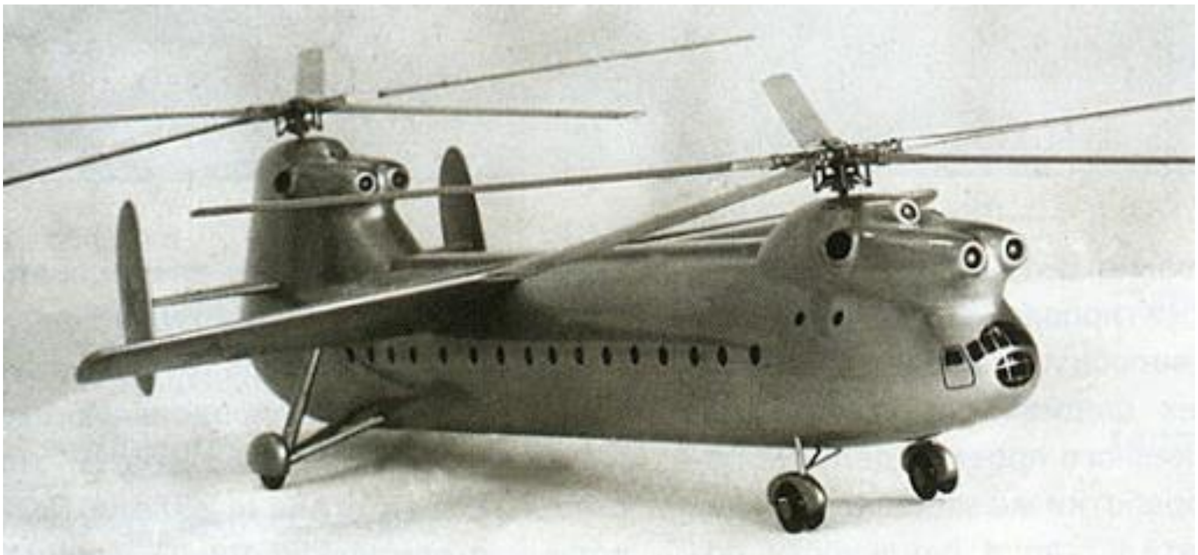

Illustration 2: Mi-12 scale model with tandem-rotor configuration

For this reason, in the final configuration the two engines are located side-by-side with twin intakes, and drive five-blade metal rotors. The left rotor rotates anti-clockwise and the right unit clockwise. Both units are connected by transverse shafting to ensure synchronization and the continued rotation of both units in the event of engine failure at either wingtip. The lower part of each cowling can be dropped to form a working platform for mechanics and fuel is housed in two cylindrical tanks mounted externally on the lower fuselage sides. On the ground, the helicopter was supported by fixed tricycle landing gear with two wheels each unit, which are supported by a plethora of struts bracing the wings and running from the lower fuselage, wings and engines. The last thing to mention about the outside components of the aircraft is the large end-plate fin tail unit that can be found mounted at the rear of the fuselage, with moving vertical and horizontal surfaces.

Illustration 3: Mi-12 scale model

It is interesting that the use of twin counter-rotating main rotors eliminated the requirement for a tail rotor, which can be found in most helicopters.

Regarding the inside of the helicopter, the fuselage has a conventional semi-monocoque structure, with a large clamshell loading doors at the rear to facilitate the handing of bulky loads. The cabin is composed by two floors, the lower one could host four crewmembers, the flight deck is on the upper floor of the cabin and there were two more crewmembers in this floor when the aircraft was flown. The pilot and co-pilot sat in the lower flight deck with a wide expanse of windows to grant excellent visibility of the surroundings.

Finally, although it will not be modelled in this project, the control system should be at least mentioned. The control system of the Mi-12 is complex due to the sheer size of the aircraft and the need to compensate the aeroelastic deformation that the structure suffers, as well as the very large friction loads of the control rods, levers, etc. To keep the control forces felt by the pilots to a minimum, the control system is divided in three stages. The first one is a direct mechanical control from pilot input forces, which are fed into a second stage, half powered control system with low powered hydraulic boosters, which transfer the commands to stage three, the high powered rapid action control actuators at the main gearboxes, operating the swashplates directly.

2.3. Operational history

The first prototype of the Mi-12 tried to fly unsuccessfully on 27th June 1967, as the flight ended prematurely due to oscillations caused by control problems, one set of main wheels contacted the ground hard, bursting a tyre and bending a wheel hub. The cause of the oscillations proved to be a harmonic amplification of vibrations in the cockpit floor, feeding back into the control column when a roll demand was input into the cyclic stick. Most of the media reported erroneously that the aircraft had been totally destroyed.

The first complete flight was done on 10th July 1968 by this same prototype, from the Mil factory *pad* in Panki to the Mil OKB test flight facility in Lyubertsy. In February 1969, this same aircraft lifted a weight of more than 31 tons payload to 2951m, achieving a world record. On August of the same year, it would achieve another world record, lifting more than 44 tons to a height of 2255m.

The second prototype was also assembled at the Mil experimental production facility in Panki. However, it was not until one year later, in March 1973, that it made the exactly same flight that its first prototype, as it had to stay in the workshop for a full year awaiting for engines.

This prototype, the V-12s, outperformed their design specifications, setting numerous world records, some of which still stand today, as we will see further on. It also brought its designers several awards such as the prestigious Sikorsky price, awarded by the American Helicopter Society for outstanding achievements in helicopter technology. This design was patented in United States, United Kingdom and other countries.

Despite all of these achievements the Soviet Air Force refused to accept the helicopter for state acceptance trials for many reasons, the most important one was that the main reason of having design such helicopter did no longer exist at that date, which was the rapid deployment of heavy strategic ballistic missiles. This same fact did also lead to a reduction on the production of its counterpart, the Antonov An-22.

The first prototype made a series of flights over Europe in June 1971, culminating in an appearance at the Paris Air Show at Le Bourget.

Even having been presented in the Paris Air Show, the programme was definitely stopped in 1974. Whilst no other equal aircraft ever came off the production line, there are only two prototypes produces, which today are on display near Moscow, one in the Russian Air Force museum and the other on the manufacturer's premises.

2.4. Technical specifications

Despite some of the specifications below are not necessary in the process of design of the aircraft, some others, like distances o areas are highly necessary. On the other hand, the rest of specifications are interesting to have an overall view of the possibilities of this helicopter and the reasons why it could achieve so many world records.

General characteristics

Crew: 6 (pilot, copilot, flight engineer, electrician, navigator, radio operator)

Capacity: 196 passengers

Normal: 20,000 kg (44,000 lb)

Maximum: 40,000 kg (88,000 lb)

Length: 37 m (121 ft 5 in)

Wingspan: 67 m (219 ft 10 in) across rotors

Height: 12.5 m (41 ft 0 in)

Empty weight: 69,100 kg (152,339 lb)

Gross weight: 97,000 kg (213,848 lb)

Max takeoff weight: 105,000 kg (231,485 lb)

Freight compartment: 28.15×4.4×4.4 m (92.4×14.4×14.4 ft)

Powerplant: 4 × Soloviev D-25VF turboshaft engines, 4,800 kW each 26,000 HP total

Main rotor diameter: 2× 35 m (114 ft 10 in)

Main rotor area: 962 m^2 (10,350 sq ft) two 5-bladed rotors located transversely, area is per rotor (1 924 m2 total area)

Performance

Maximum speed: 260 km/h (160 mph, 140 kn)

Cruise speed: 240 km/h (150 mph, 130 kn)

Range: 500 km (310 mi, 270 nmi)

Ferry range: 1,000 km (620 mi, 540 nmi) with external fuel tanks

Service ceiling: 3,500 m (11,500 ft)

Disk loading: 50.5 kg/m^2 (10.3 lb/sq ft) at gross weight

Hovering ceiling in ground effect: 600 m (2,000 ft)

Hovering ceiling out of ground effect: 10 m (33 ft)

2.5. Records Achieved

In the table below we can see all the world records achieved by the Mi-12, which were all certified by the Fédération Aéuronautique Internationale. It is a total of eight records, four of which are still current.

These records were obtained in two different flights, the crew involved in such flights was:

First flight, 22th February 1969:

Pilot - Vasily Kolochenko

Crew – L.V. Vlassov, V.V. Journaliov, V.P. Bartchenko, S.G. Ribalko, A.I. Krutchkov

Second flight, 6th August 1969:

Pilot - Vasily Kolochenko

Crew – L.V. Vlassov, V.V. Juravlev, V.P. Bartchenko, S.G. Ribalko, A.I. Krutchkov

Date	Record description	Achievement	Current
22 February 1969	Altitude with 15,000 kg (33,000 lb) payload	2,951 m (9,682 ft)	No
22 February 1969	Altitude with 20,000 kg (44,000 lb) payload	2,951 m (9,682 ft)	No
22 February 1969	Altitude with 25,000 kg (55,000 lb) payload	2,951 m (9,682 ft)	No
22 February 1969	Altitude with 30,000 kg (66,000 lb) payload	2,951 m (9,682 ft)	Yes
22 February 1969	Maximum load to 2,000 m (6,600 ft)	31,030 kg (68,410 lb)	No
6 August 1969	Altitude with 35,000 kg (77,000 lb) payload	2,255 m (7,398 ft)	Yes
6 August 1969	Altitude with 40,000 kg (88,000 lb) payload	2,255 m (7,398 ft)	Yes
6 August 1969	Maximum load to 2,000 m (6,600 ft)	40,204 kg (88,635 lb)	Yes

Illustration 4: Table of world records achieved

2.6. Variants

On the ongoing of the design and manufacturing of the Mi-12, there have been three versions of the same, the first two of them are essentially equal, and are the ones modelled in this project, the final one is slightly different.

V-12

OKB designation of the two prototypes of the proposed Mi-12 production version

Mi-12

Designation reserved for the expected production version.

Mi-12M

A further proposed refinement of the V-16 with two Soloviev D-30V turboshafts driving six bladed rotors to transport 20 tons over 500 km or 40 tons over 200 km. This project was cancelled at the mock up stage when the V-12 development programme was cancelled.

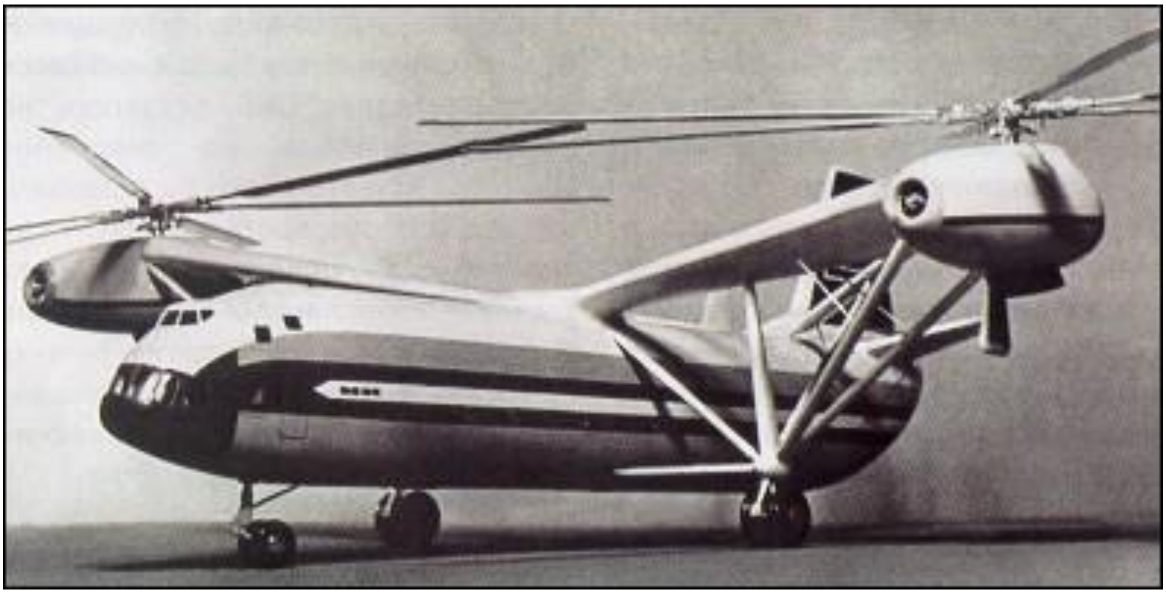

Illustration 5: Scale model of the Mi-12M variant

3. Preliminary steps

As it was already mentioned in the introduction of this project, the program chosen to model the Mi-12 is CATIA-V5. Because of that, before explaining the design process itself, it was necessary to decide how the aircraft should be modelled, as well as the documents that would be used with that aim.

Therefore, the first step taken was an exhaustive search of information through the net, with the objective of finding any blueprint, painting, model or photograph related to the Mi-12 that could be useful in the modelling process. Doing this, it was found that there were available a couple of documents defining the main external geometry of the helicopter, with a decent quality. Although the measures were not exactly the right ones, these blueprints could be used by taking into account the proportionality between the distances of the different elements.

The blueprints in question are the following ones:

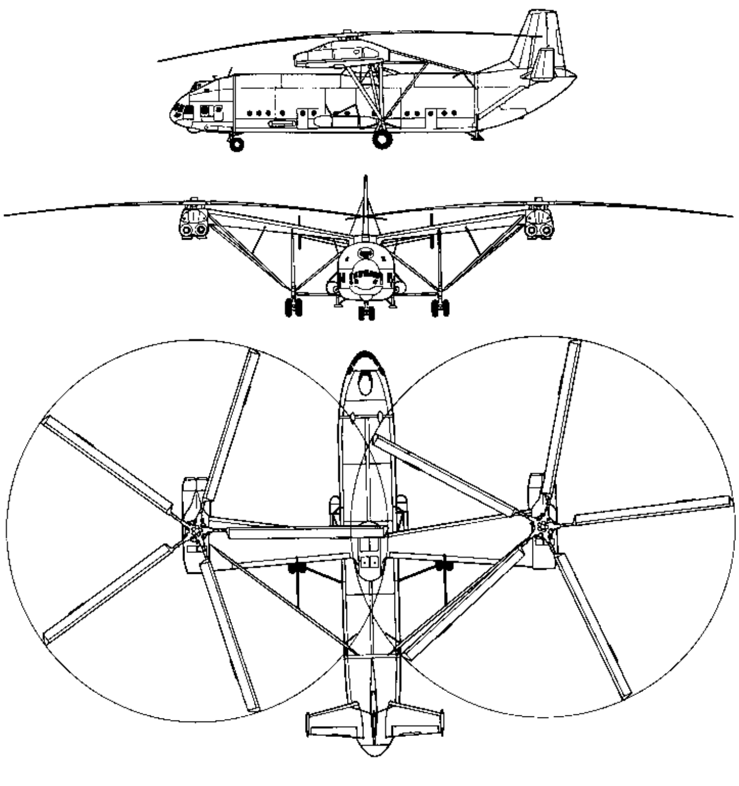

Illustration 6: Secondary blueprint

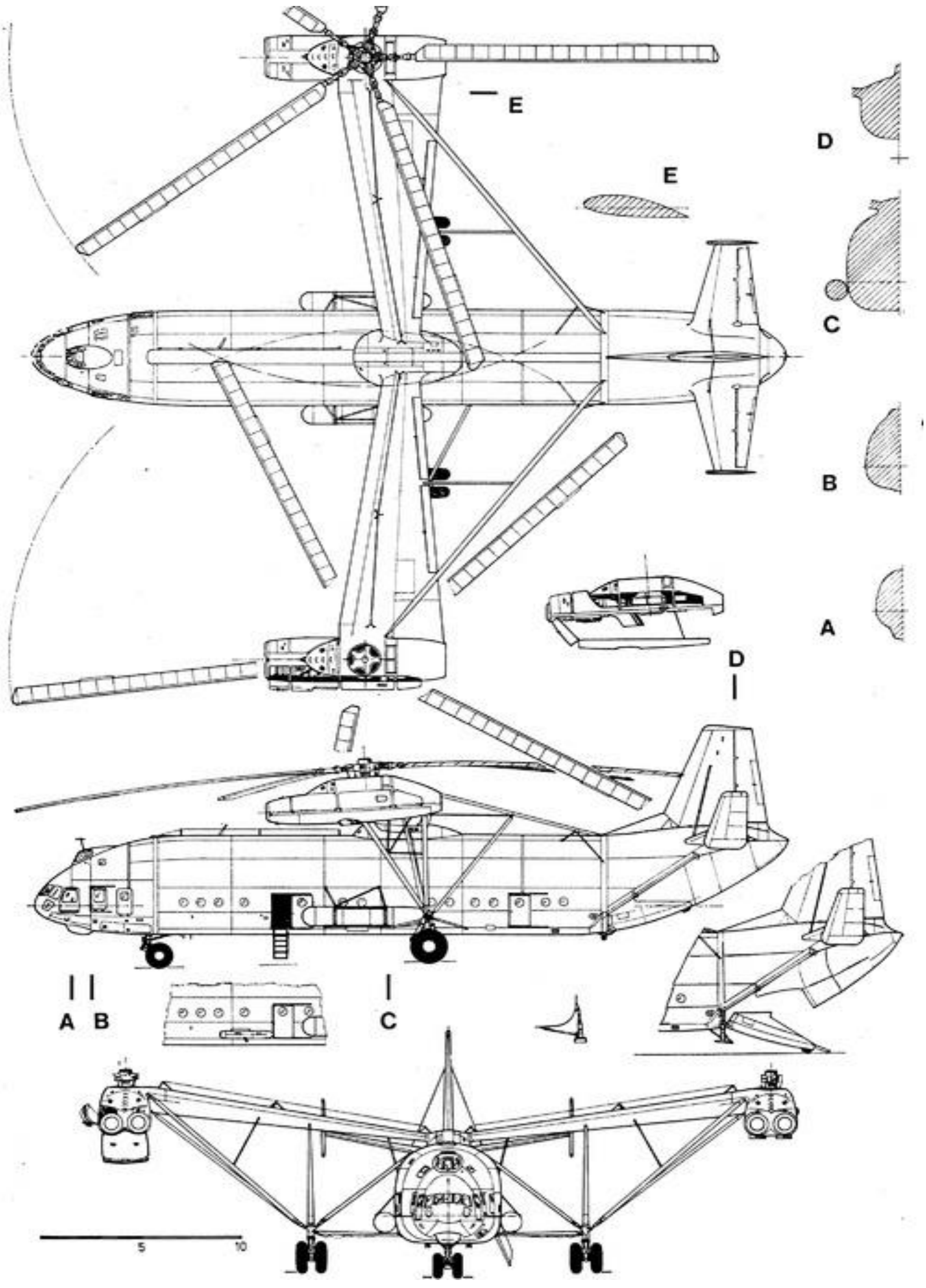

Illustration 7: Main blueprint

Both blueprints have been used in the design process, especially the second one, which, as can be seen, includes the approximate shape of some profiles along the aircraft, as well as a section of the wing. It should be mentioned that, although the scale is indicated in the second blueprint, it did not correspond accurately with all the measures, probably because the dimensions of the blueprint might have been modified when being uploaded to the net.

As it is evident, these blueprints present a level of detail truly decent of the main structure, but not enough regarding the detail of the structure. For that reason it could be anticipated that there would me some approximations during the modelling process. Also, as we can see, in the pictures above we can barely find any detail related to the inside of the structure, which is planned to be designed too. For this reason, it was necessary to get other documents which provided such information, like photographs or videos, some of which will be shown in future sections of this project.

The next step to take was to decide which would be the modelling process. At the beginning, the design was thought to be divided into seven different parts, which would be fuselage, nose, tail, stabilizers, wings, engines and other details, however, at the end the design was divided into four sections, which have been fuselage, nose, tail and stabilizers in the third division, and the last one which contains the wings, engines and any other detail of the structure, such as fuel tanks or bars, all designed in that order. With all the different parts, firstly it was modelled the external structure, followed by the internal one.

The CATIA modules employed in this project are three, *part design*, *generative shape design* and *assembly design*, each of which will be mentioned when used in the following sections. From now on, in order to differentiate properly the terms related to CATIA, all of them will be written in cursive.

It is necessary to be mentioned that some of the systems of the helicopter will not be modelled in this project, for this reason, no wire will be modelled, as well as will happen with any other subsystem located under the floor of the helicopter, the reasons are simple, the first one that most of them are not rigid parts, so most of them do not have a single configuration, the second one is that some other are moving parts, so the place where they are located can change from some photographs to others, the last one is that the subsystems located under the floor are not able to be designed, as there is no information about their layout.

4. Mil Mi-12 3D modelling

4.1. Fuselage (Body)

The first section to be modelled has been the fuselage, as it is the central part on which all the other divisions will be assembled. For that reason, all the measures and the shape related to the fuselage had to be defined since the beginning.

The section that has been called fuselage, from now on in this project, corresponds to the one included into the blue rectangle in the image below.

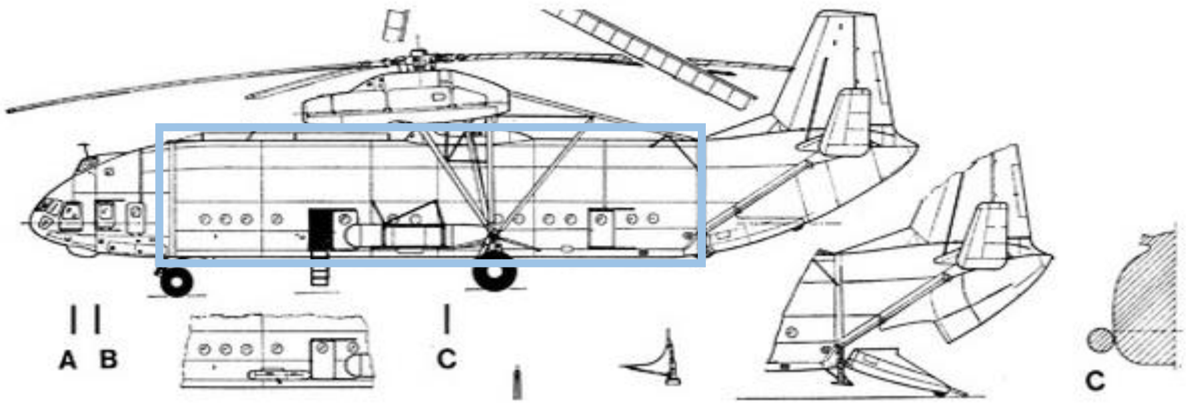

Illustration 8: Fuselage pointed out in the blueprints

4.1.1. External modelling

The starting point in order to design the fuselage is the profile "C" included in the blueprints. As can be seen in the blueprints, the shape of the fuselage is anything but constant in the nose and the tail, however, the height and the width of the fuselage remains constant from the beginning to its last point. This, of course, is a starting hypothesis, but having a look at the blueprints and photographs provided, it can be considered as a quite accurate assumption.

Once decided that the fuselage profile would be constant along the body, the next task has been to design as accurately as possible the shape shown in the previous image as section "C". In order to do so, the measures of eight points have been taken, the highest and lowest points, the points which define the maximum width, and four intermediate points, one between each of the four mentioned. With these points, the first attempt was so make a *spline* using them, however, the result was not the desired, as the curve became wider in points we did not want it to, as well as happened with the lowest and highest points, and in case that it was tried to force a tangent situation in some of the points, the *spline* caused an error.

For that reason, a different approach to the problem was taken, instead of forcing a spline to include the points, it was decided to use the command *connect*, which takes two curves and connect them tangentially. In order to set the extremes, in each of those points it was defined a straight line with the desired tangent direction. Once this was done, the command previously mentioned was used to connect the lines. By default, the line generated with this command has a particular curvature, however, the tension related to each endpoint of the line can be modified, what was done in order to obtain the required shape, as it is shown in the image below. At last, it is worth to mention that, effectively, we have included four straight lines in the design of this curvature, however, as the length of such lines can be set, if has been changed to a length of 1 mm, which can be considered negligible compared to the total width or height, exceeding both the 5 meters. The resulting shape is the showed in the next image.

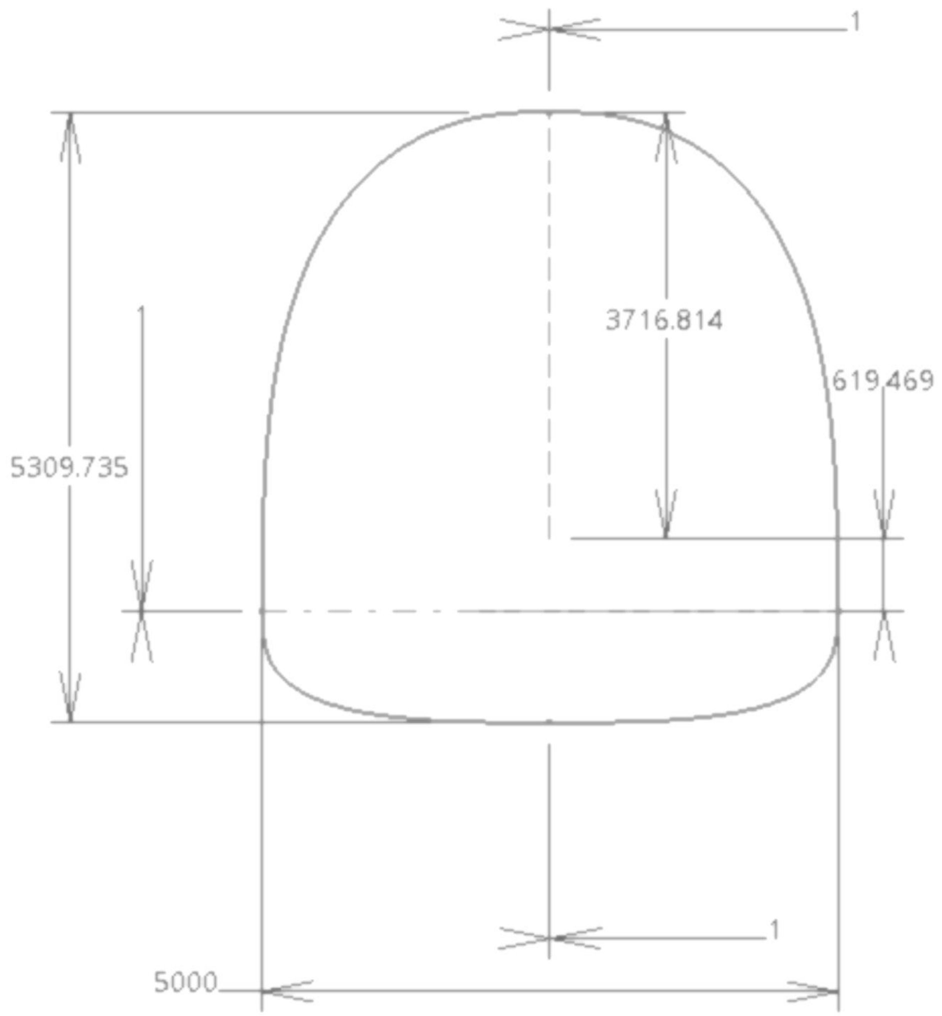

Illustration 9: Fuselage profile

With the profile shape definitely decided, to model the main structure of the fuselage it was applied the module *generative shape design*, more specifically, the command *extrude* along the "Y" axis, resulting into the image below.

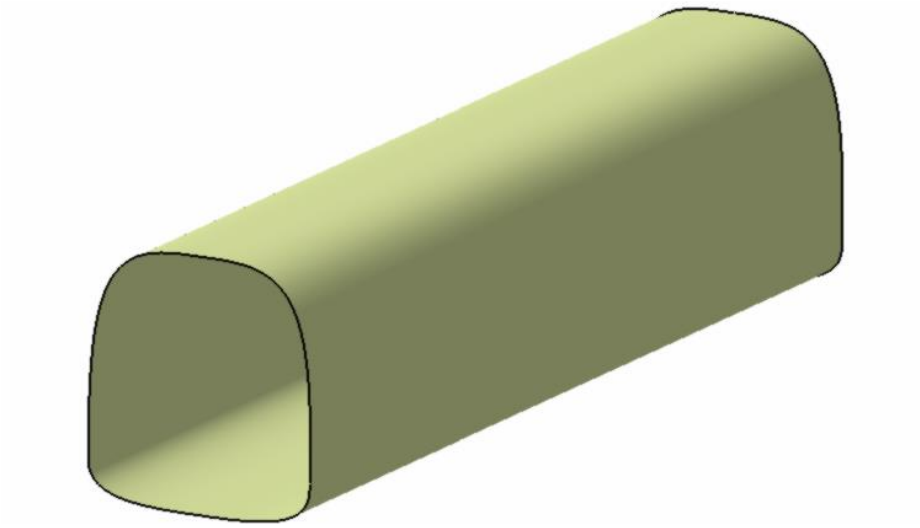

Illustration 10: Fuselage surface

4.1.1.1. Windows

Before applying a thickness to the fuselage surface, it was necessary to make a difference between the places in which there would be a sheet of metal, and the areas where the windows would be positioned, as these two subdivisions had been intended to be designed using different materials, in order to differentiate them properly.

With that aim, the procedure taken was the following. First each of the windows shape was designed in the plane "YZ", taking the measures and positions from the blueprints already mentioned. Secondly, each one of this *sketches* has been projected on both sides of the surface with the command *project*. With these projections made, it was necessary to differentiate the inside and outside area of such projections, what was done with the command *extract*. Finally, the surface was divided into the desired ones by using the command *split* between the main surface of the fuselage and each of the windows, always choosing to keep both parts. The consequent surface is the one shown.

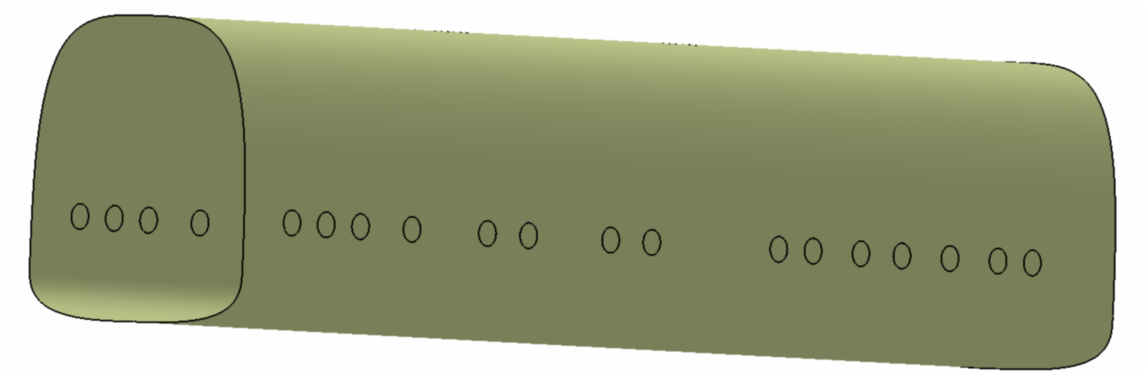

Illustration 11: Fuselage surface with windows shape

Once this structure had been defined, it was time to add a thickness to both the sheet of metal conforming the fuselage and the windows made of glass, it has been done with the command *thick surface*, leading to the following structure.

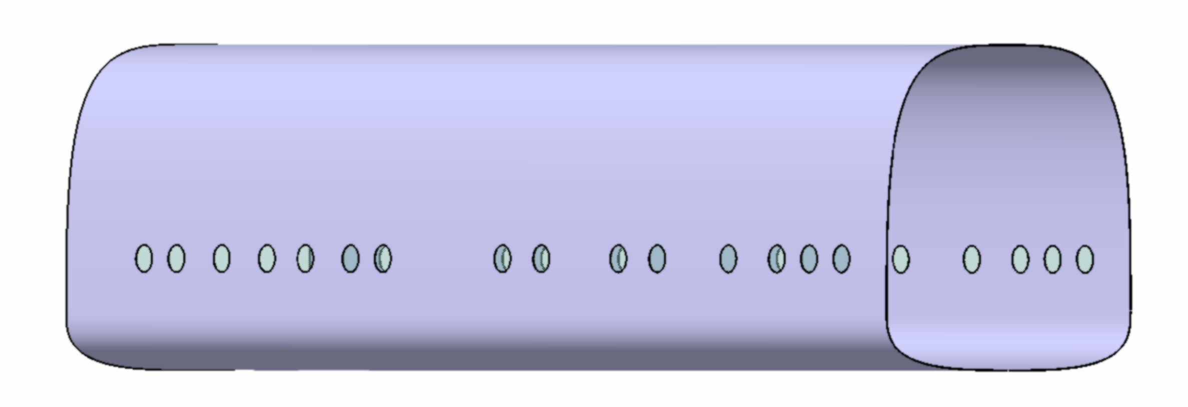

Illustration 12: Fuselage with thickness

4.1.1.2. Doors

The last thing to design regarding the outside of the fuselage are the doors, as we can see in the next image, as well as can be done in the blueprints shown, along the fuselage there are a total of four doors, two on each side, all of them are sliding doors, and guides can be easily observed.

Illustration 13: Mi-12 lateral view

In order to model a door, the first step taken has been to make a hole of 0.1 mm along the contour of the door by using the command *pocket*, its use is purely visual, as there will not be animations included in this project, but it can be useful to differentiate the position of the doors, as well as possibility the future application of animations.

Afterwards, there were designed the guides of the sliding door. In order to do so, as well as it was done with the windows, the projection of the contour that the guide should follow was modelled in a *sketch* in the “YZ” axis, by using the command *project* along the “X” axis, the curve that the guide followed would be set.

At that point, it was only necessary to create a *sketch* in a plane perpendicular to that curve, with the desired shape of the guide, in order to use the command *rib* on that *sketch* over the previously created curve. To finish the details of the guides, two more commands were used to improve its shape, *edge fillet*, to add curvature, and *shaft*, to close some plane surfaces.

Once one door had been designed, two of the other three were modelled too by using the commands *rectangular pattern* and *mirror* on the operations previously mentioned, the last one was created by using the same method of the same door, the reason is that it cannot be done a *mirror* of a *pattern* or vice versa.

The final result is contemplated in the following image.

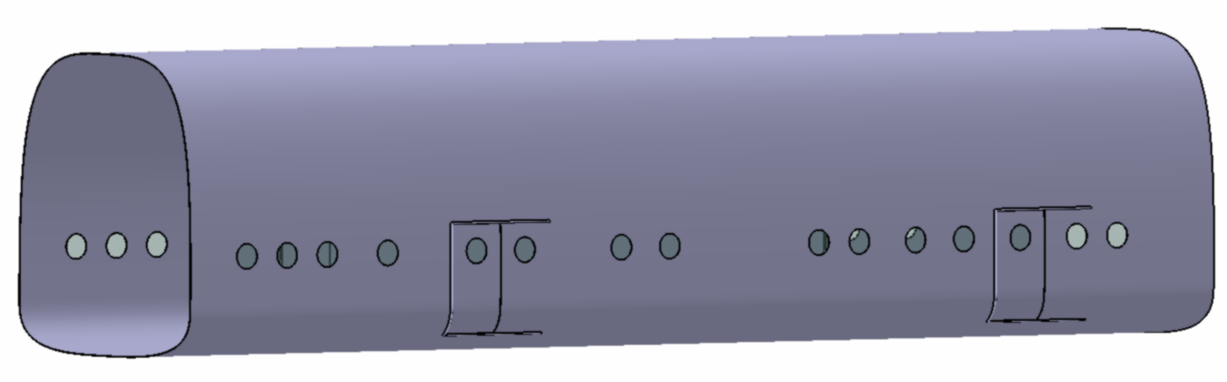

Illustration 14: Complete external fuselage design

4.1.2. Internal modelling

With the external shape completely designed, the next step to take is the design of all the elements which compose the inside of it. The only way to obtain information about the inside of the aircraft has been via photography, as there are no blueprints which show where the different structures are located or their sizes. Therefore, all the designs made in the following sections have all been estimated as accurately as possible, but without specific measures.

First of all, before explaining the design process of each element, it is worth to show a couple of photographs of the inside of the fuselage, as well as two images of the inside of the fuselage fully modelled.

Illustration 15: Real backside of the inside of the fuselage

Illustration 16: Real front side of the inside of the fuselage

The first photograph shows the backside of the fuselage, while the second one illustrates the front side of it, showing a wall with a door, which would connect to the cockpit.

As it was previously mentioned, all the wires that can be seen, most of which are attached to the top of the fuselage, will not be modelled. Instead, there has been designed a duct, which would hold them.

On the third image it can be seen the mentioned fully modelled fuselage, which, in order to grant a better view, has been cut before making the photograph.

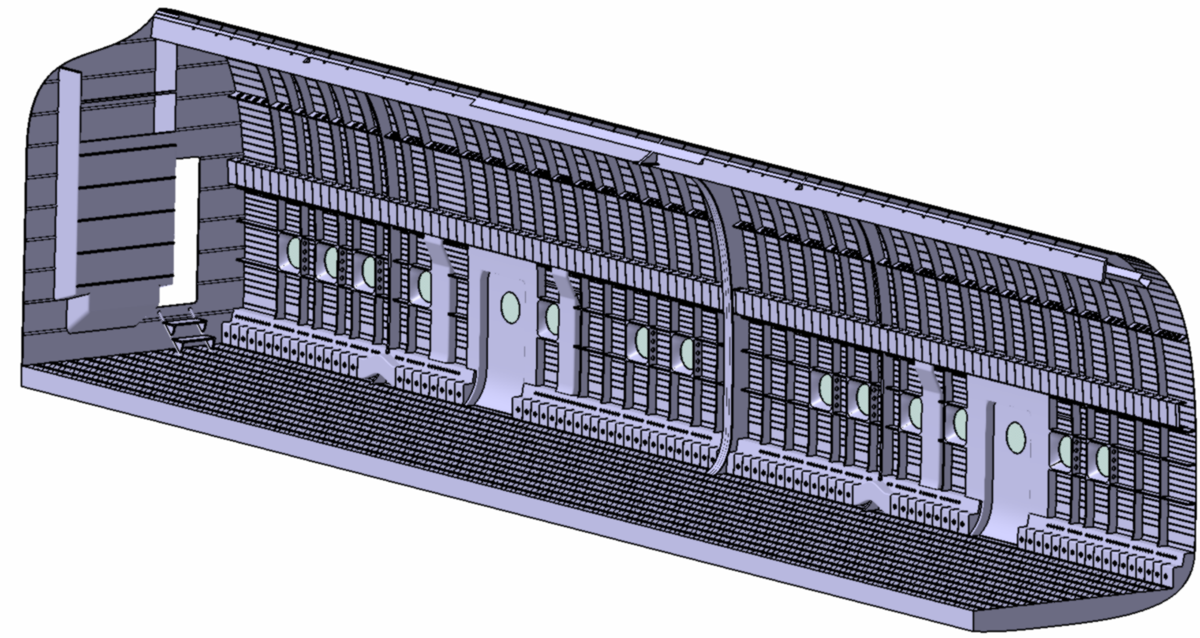

Illustration 17: Inside of the modelled fuselage

The main objective of showing these illustrations is to have an idea about the location of the elements which are going to be designed in the following sections, therefore most of them will just be mentioned and make a reference to these images, in order to avoid the repeatability of providing a photograph of the real element for each section.The order followed in the sections below is the same order of design processes that have taken place.

4.1.2.1. Floor

The floor has been truly easy to design, it has been modelled at the desired height by using the command *pad*, by setting the limit in *up to next*. As it was said in previous sections, the floor is not completely a solid, but it has been created as one in this project, in order to simplify the operations and make it visually more attractive.

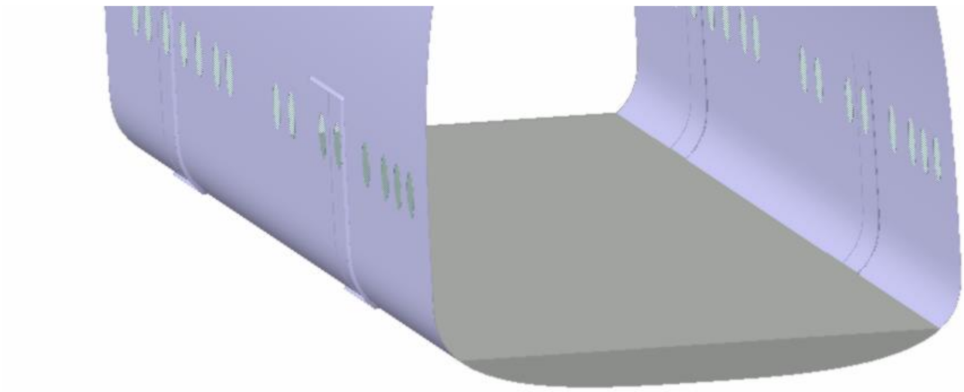

Illustration 18: Floor of the fuselage

4.1.2.2. Floor structure

As it can be seen in the photographs which show the inside of the fuselage, there is a structure placed in the corners of the floor, one at each side of the body. It is actually some kind of duct, probably intended to grant ventilation to the down part of the floor, or to host some of the subsystems or wires. The fact is that, as it can be observed, it has many holes along its length.

The main structure has been modelled in one side with a *pad*, it has been given curvature in the corners with the command *edge fillet*, the holes and the several clefts observed have been created by using a *pocket*, moreover, the holes have been applied the color black, in order to simulate the darkness inside them. To apply this process to the rest of the length and the other side of the floor, the commands *rectangular pattern* and *mirror* have been used.

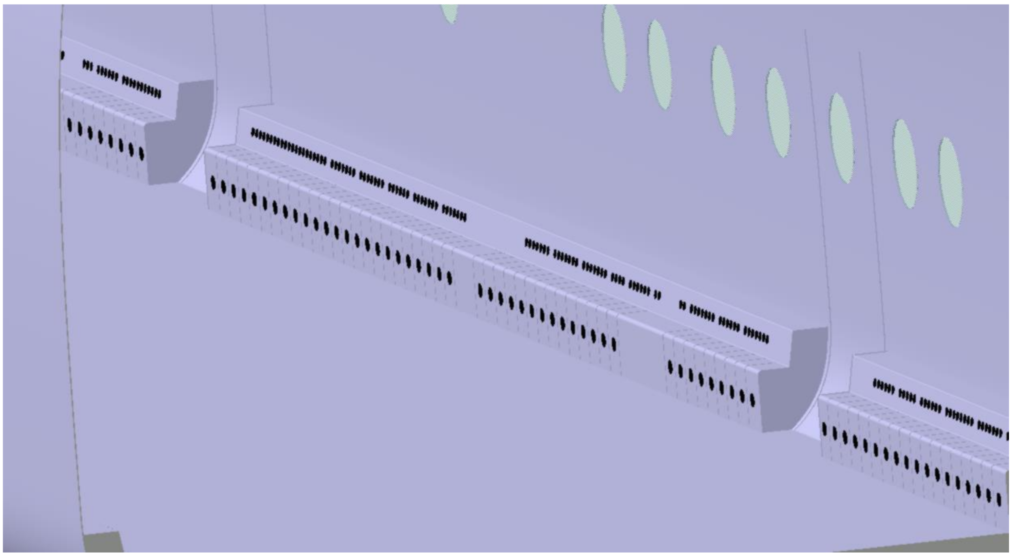

Illustration 19: Fuselage floor structure

4.1.2.3. Fuselage complete formers

By paying attention to the photograph exposed, it can be seen that there are three different types of former, there is one former in the middle of the fuselage which is larger than the others, two medium size formers and several of them which are a little bit smaller. All of them have been designed by using *pads* with the required shapes, *rectangular patterns* and *edge fillets*.

At that point, as can be seen in the image below, only the formers which cover the whole monocoque structure have been modelled, avoiding the upper area of the doors, the reason is that the formers which should be there, are placed on a structure which surrounds the door still to be modelled.

The following picture shows only half of the fuselage in order to visualize it better.

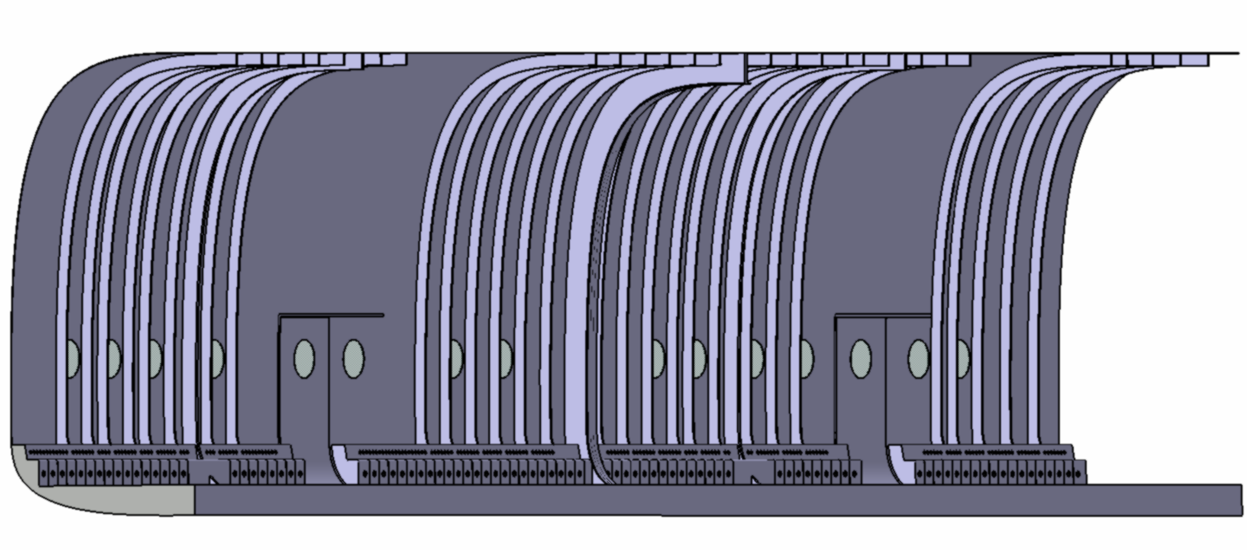

Illustration 20: Fuselage complete formers

4.1.2.4. Floor structure details

At that point, when the formers are designed, it can be observed that the floor structure previously modelled is diverted in the areas where there are the defined medium size formers, for that reason, it was necessary to reflect such deviance.

The process executed was quite simple, it was used the command *pocket* to create the hole, a *pad* to model the deviance, and *edge fillets* to apply the required curvature to the corners of the created structure.

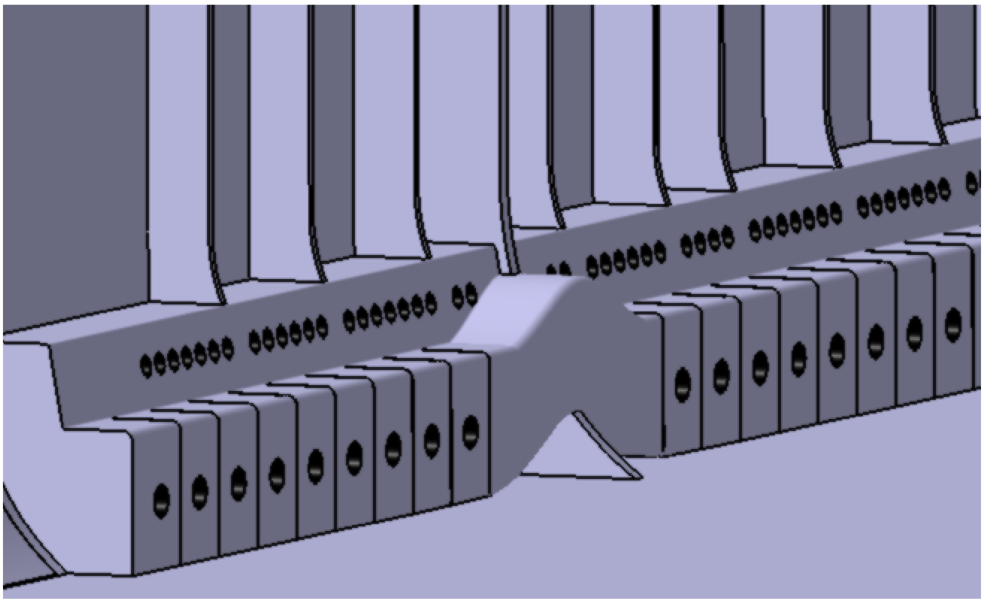

Illustration 21: Fuselage floor structure details

4.1.2.5. Vertical structures

Illustration 22: Real vertical structures

As it can be better observed in the photograph above, there are some vertical structures around the doors of the fuselage. These structures go from the floor duct to the medium height one, which is still to be modelled. The two front doors are surrounded by two of these structures each, while there is only one next to each rear door.

As well as most of the structures already mentioned, the commands used to model these vertical ducts have been *pad*s*, edge fillets*, *rectangular patterns* and *mirrors*.

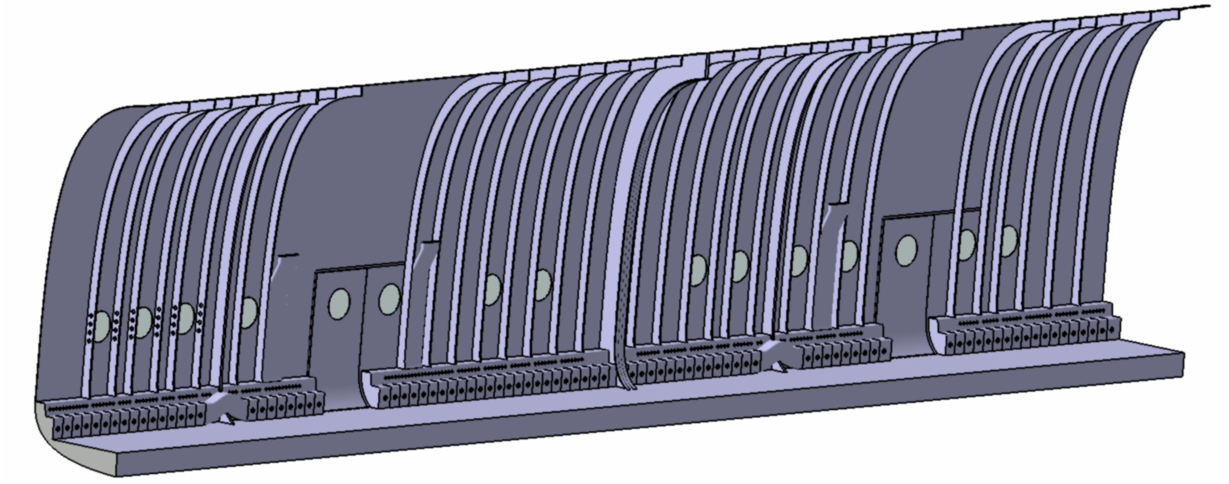

Illustration 23: Fuselage vertical structures

4.1.2.6. Door structures and other formers

As it was said when the complete formers were designed, there are some of them that depend on the door structures, which can be seen in the provided photographs. Such door structures have been modelled with *pads* and *edge fillets*, while the creation process of the new formers has been analogue to the previous one.

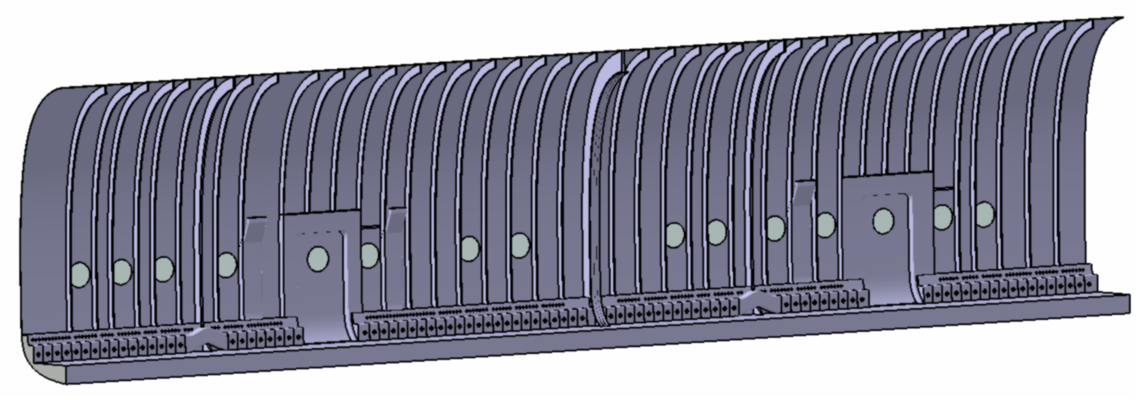

Illustration 24: Door structures and all formers

4.1.2.7. Longerons and longitudinal ducts

There is a total number of ten longerons along the fuselage, as well as two ducts at medium height, one for each side. Additionally, another couple of ducts has been designed in order to model the conduits that would contain the wires attached to the top of the fuselage, this configuration is anything but far from reality, as this has been the measure taken nowadays in the exposed Mi-12 in Russia.

All the longerons and ducts have been modelled by using *pads*. And for the clefts of the medium height duct, once again, there have been used the commands *pocket* and *rectangular pattern*.

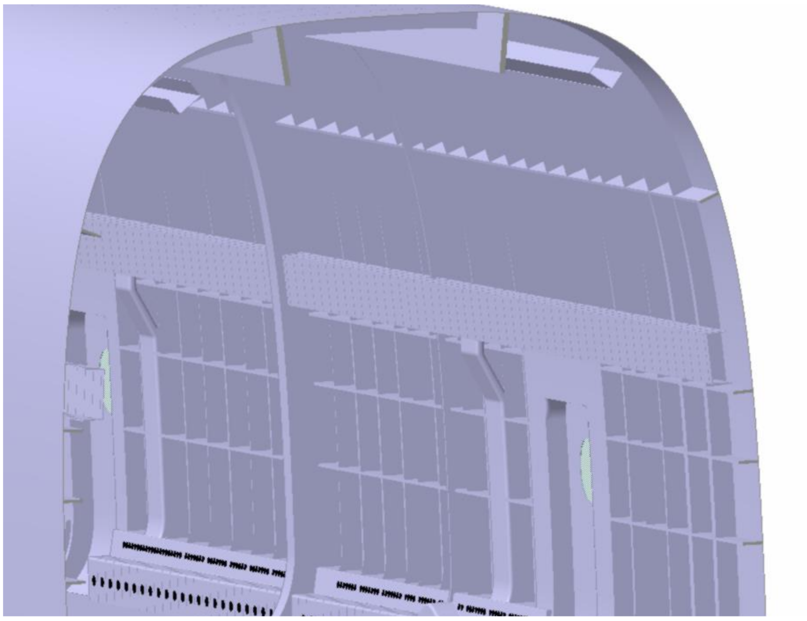

Illustration 25: Fuselage longerons and longitudinal ducts

4.1.2.8. Ceiling structure

As it can be seen in the photographs of the document, in the upper side of the fuselage, in the middle of its length, it can be found a structure with numerous holes. Such element has been modelled with a *pad* and a few *pockets*, once again, a black color has been applied to the *pockets*.

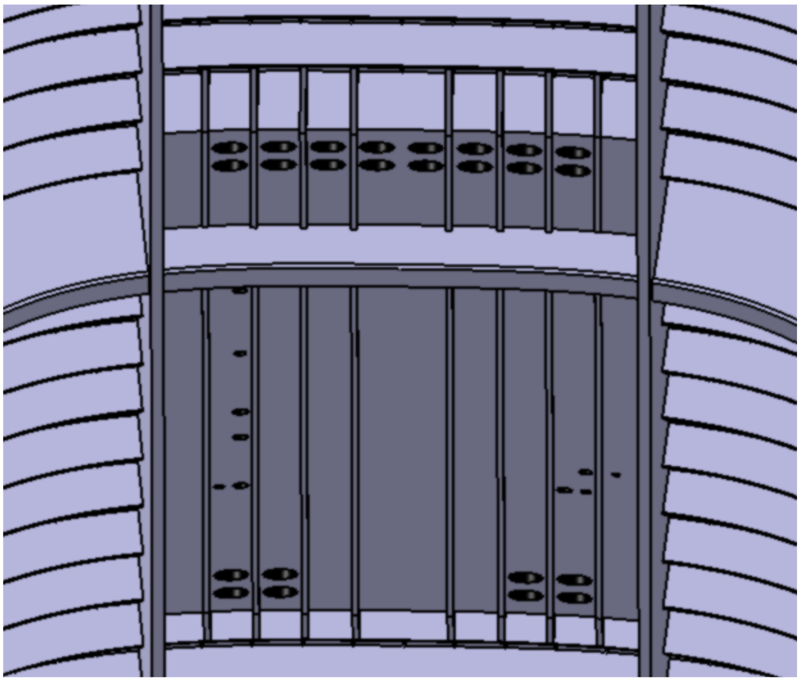

Illustration 26: Ceiling structure

4.1.2.9. Floor details

Illustration 27: Real fuselage floor

In the photograph above it can be seen a great approximation of the shape of the floors, and how the sheets of metal which compose it are distributed. Something similar happens with the rivets.

Consequently, the shape of the floor has been modelled with a *pad* and a *rectangular pattern*, whilst the rivets have been designed using a *shaft* and another *rectangular pattern*.

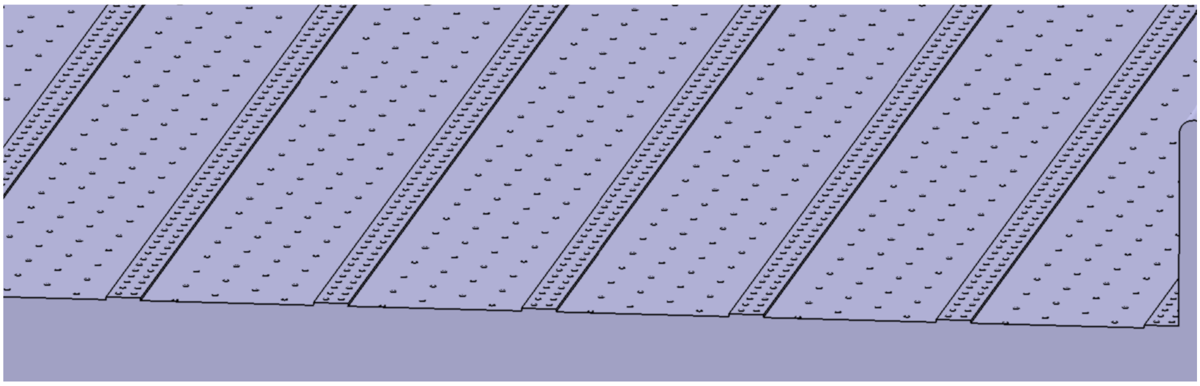

Illustration 28: Fuselage floor details

4.1.2.10. Stringers

Along the fuselage there can be found several stringers, some of them cover the whole length of the body, but many others are discontinuous due to the windows, the doors or both of them. As the shape of the contour of the fuselage is not a simple one, and the total number of stringers is extremely high to model them one by one, there has been the necessity to make a few *user patterns*, more specifically three of them.

The procedure to create a *user pattern* is simple, firstly, it was made a *sketck* in which the curve defining the area of the inside of the fuselage it was desired to work with would be projected. Afterwards, using the command *equidistant points* on such curve, the required number of points would be created. When using the command *user pattern* and choosing this *sketch* as the pattern, the element would be reproduced in every point of the *sketch*.

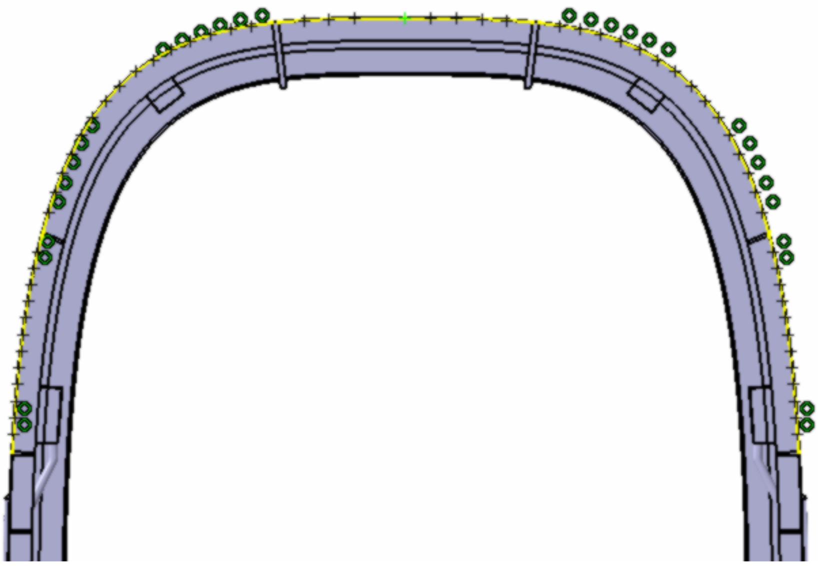

Illustration 29: User pattern example

One of the patterns, the shown in the picture above, defines the points where the stringers that cover the whole length will be placed. The other two patterns have been made in an analogue way, one of them for the stringers that only have doors on their way, and the other one for stringers which have to avoid both doors and windows.

With this method, a task that could involve the use of hundreds of *pads*, is reduced to the application of a few *pads* and *user patterns*. The final result, seen on a half of the fuselage, is the following one.

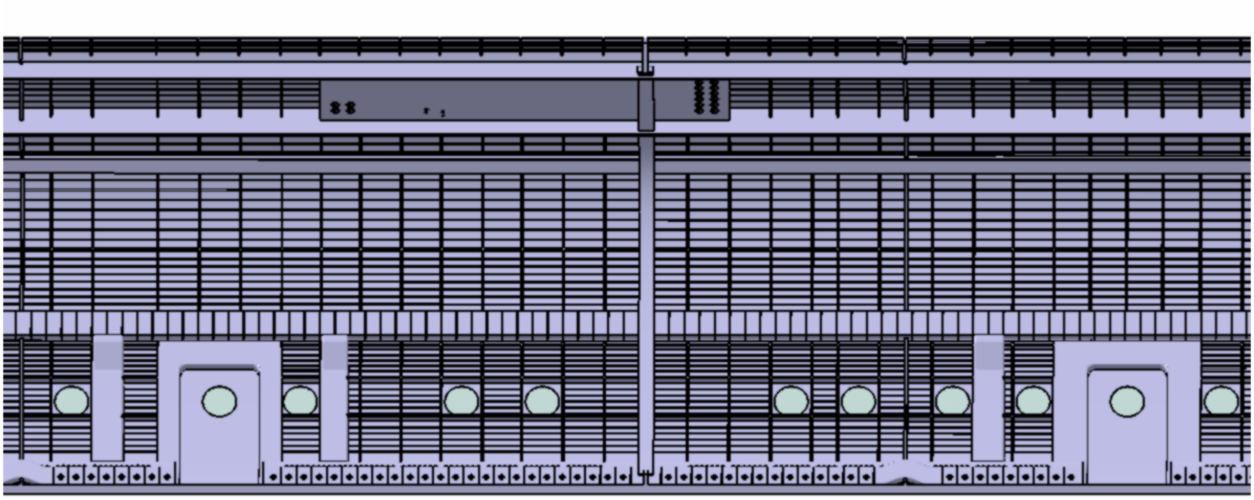

Illustration 30: Fuselage with stringers

4.1.2.11. Windows

The windows design has been anything but trivial, as can be seen, there is a surface that connects the contour of the windows with the formers and longerons that surround each one of them. The point is that the surface defined by the longerons and formers is not a plane, in consequence, there has been the need to work with the *generative shape design* once again.

With this module, it has been created a curved surface with the command *fill*. Over this surface, there has been projected a curve created in a *sketch* in the plane “YZ” by using the command *project*, the reason of creating such curve is simple, there is an intention to create a *multi-section surface* using the shape of the window and the outer profile, but as the window is defined by a circle, the outer shape should not have any corners. Once created the new curve, there is going to be used the command *split* on it, keeping only the outer surface. Afterwards, it will be created a *multi-section surface* with the two already mentioned profiles. Finally, there will be made two *pads up to surface*, in order to fill the desired area.

At last, it can be seen that the formers surrounding each window have four holes at this same height, all these holes have been modelled with *pockets*.

The final result of the windows can be contemplated on the picture below.

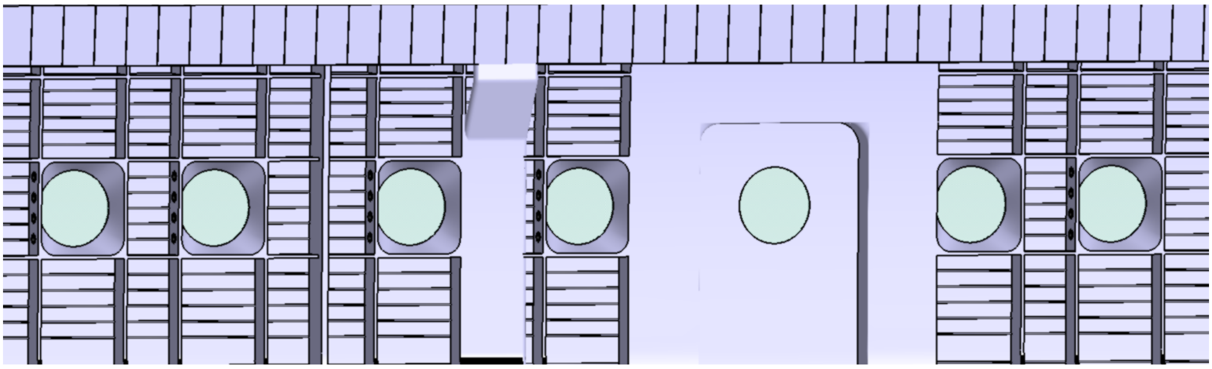

Illustration 31: Fuselage Windows

4.1.2.12. Longeron details

By paying attention, it can be observed that one of the longerons, and its symmetrical one, have several holes along them. In order to model these holes, as the distance between them is not equal, it has been decided to create a *user pattern*, leading to this result.

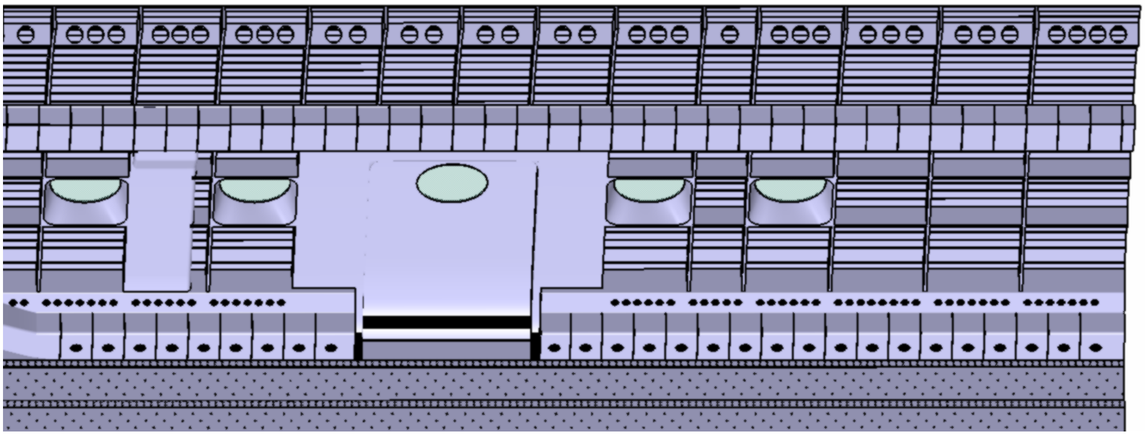

Illustration 32: Longeron details:

4.1.2.13. Fuselage to cockpit wall

The last thing to be modelled in the fuselage has been the wall that connected the main body with the cockpit, which was shown in the second photograph of the section 4.1.2. As can be seen, there are mainly four elements to design: the wall itself, with its stiffeners, the hole that would simulate the door, the stairs and the structure located on the middle of the wall, which also has some stiffeners.

The wall, the structure and all the stiffeners have been created with *pads,* and *pockets* have been used to create the door hole. Some details of the structure have been designed with the use of *drafts* and *pockets*. Finally, to model the stairs there have been applied the commands *rib* and *pad*.

The modelled wall can be contemplated in the next image.

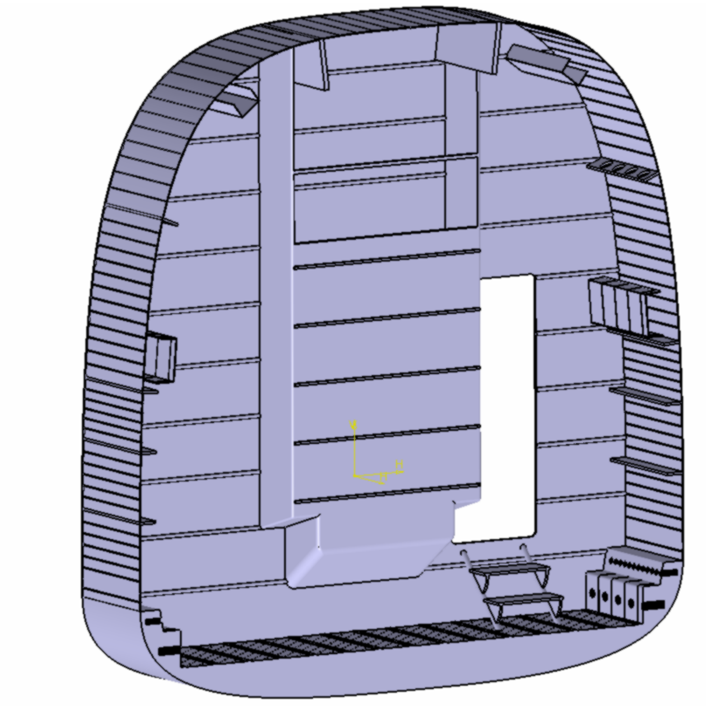

Illustration 33: Fuselage to cockpit Wall

It is worth to mention that the wall has been designed after the nose, this is the reason why there has not been modelled the door in this *part*, because it has been created in the nose modelling.

With all these structures created, the complete fuselage has been fully modelled both internally and externally, once again, it is shown an image of the final result, in order to observe all the elements created one by one together.

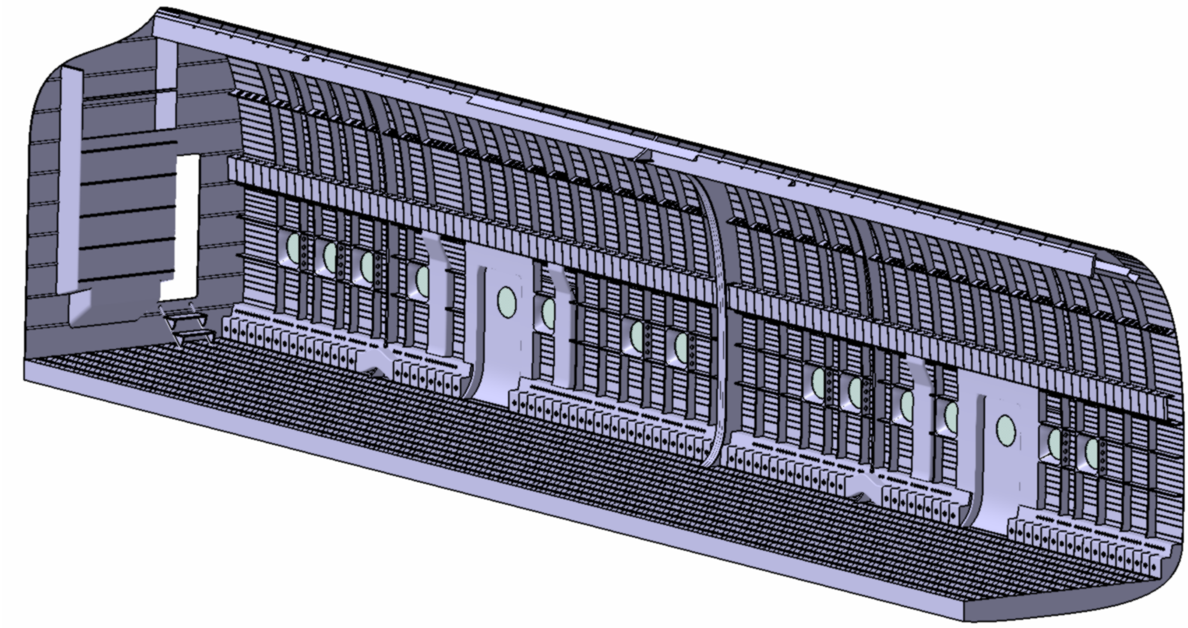

Illustration 34: Fuselage final design

4.2. Nose

The next section modelled has been the nose of the aircraft, both externally and internally. At that point there is only one specific limitation, the last profile of the cockpit (the closer one to the fuselage) must coincide with the constant profile employed to generate the body in both shape and size, as the target is to assemble all the parts.

The nose, from now on called cockpit when it is being talked about the internal side of it, corresponds to the section inside the orange rectangle seen below.

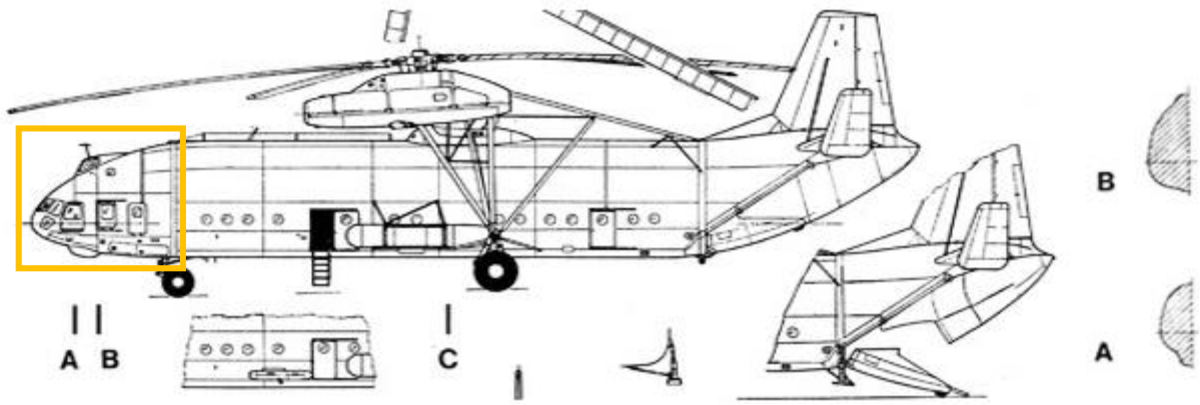

Illustration 35: Nose pointed out in the blueprints

4.2.1. External modelling

Before explaining the modelling, the following images illustrate the real and the modelled outside of the nose, the purpose of showing this is, as it was done with the inside of the fuselage, show a general overview, in order to know the position of the elements that will be designed further on, as well as the final result.

Illustration 36: Nose of the Mi-12

4.2.1.1. General shape

Therefore, the starting point to design the shape of the nose is to impose the profile of the fuselage at the end of its length. This time, however, the section of the nose is anything but constant along its length, so, in order to model it, there have been taken the total height and width of twelve sections by measuring the blueprints at its corresponding defined points. The problem was that, as it can be seen taking a look at the sections “A” and “B” in the image above, not only the size of the profiles do change along the “Y” axis, but also their curvature.

To solve this problem, there has been made an approximation, there have been used the measurements and shapes taken from the three profiles (the both mentioned and the imposed one at the end), and the other eight have been extrapolated. In order to do so, it has been extremely useful to having employed the command connect, which has been already explained in previous sections. The point of its utility is that, once there have been set the required tensions from each extreme for every curve, in order to achieve the desired shape in the three shapes that are known, the intermediate sections can use a tension dependence between them, what has highly facilitated the task.

The twelve *sketches* are shown in the following image.

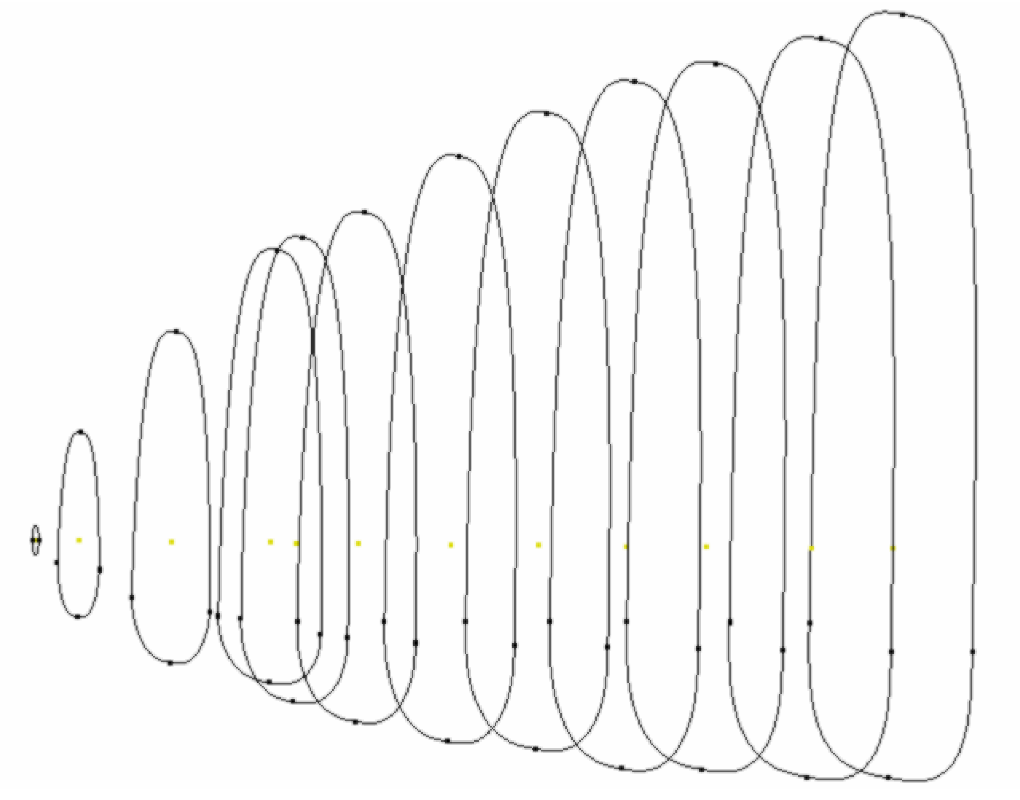

Illustration 37: Nose sketches

With all the *sketches* defined, it was time to create the surface. In order to do that, it has been used once again the module *generative shape design*, but in this case, all of these profiles has been applied the command *multi-sections surface*.

As it can be foreseen, the initial shape was not a very accurate one, mainly because the measurements had been taken from the print of the blueprints, which did not have a good enough quality.

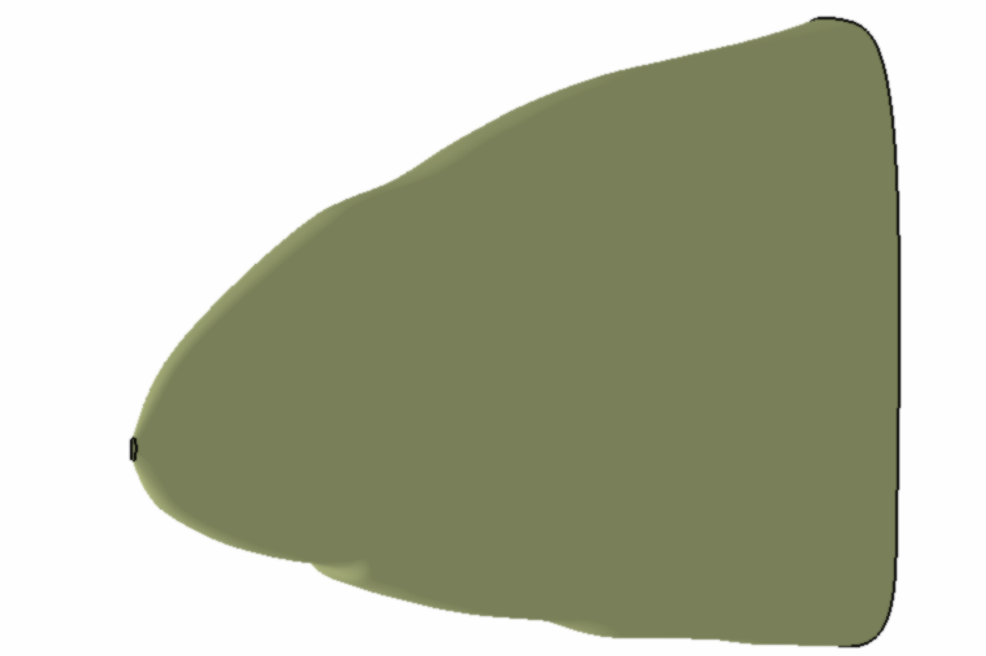

Illustration 38: Nose first design

Consequently, some of the profiles were redefined, moreover, there was taken the decision of using only seven *sketches*, as taking too many of them with wrong measures would only contribute in a negative way, in this case, it became obvious that it is better to use only a few accurate sections rather than many of them if some are not the exactly ones.

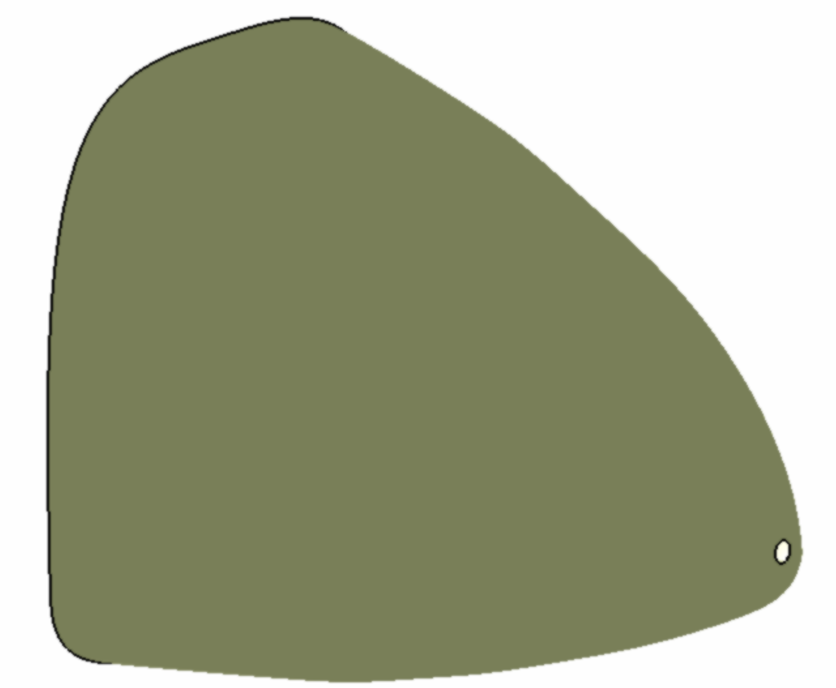

Illustration 39: Nose final design

4.2.1.2. Upper structure

In order to create the upper structure of the nose, it has been used the module *generative shape design*. More specifically, it has been modelled the shape of the hole in a horizontal plane and projected on the upper surface of the nose with the command *project*. Such projection has been applied a *split* and, with another created *sketch* to define the ceiling of the structure, the whole surface has been closed with a *multi-section surface* and a *fill*.

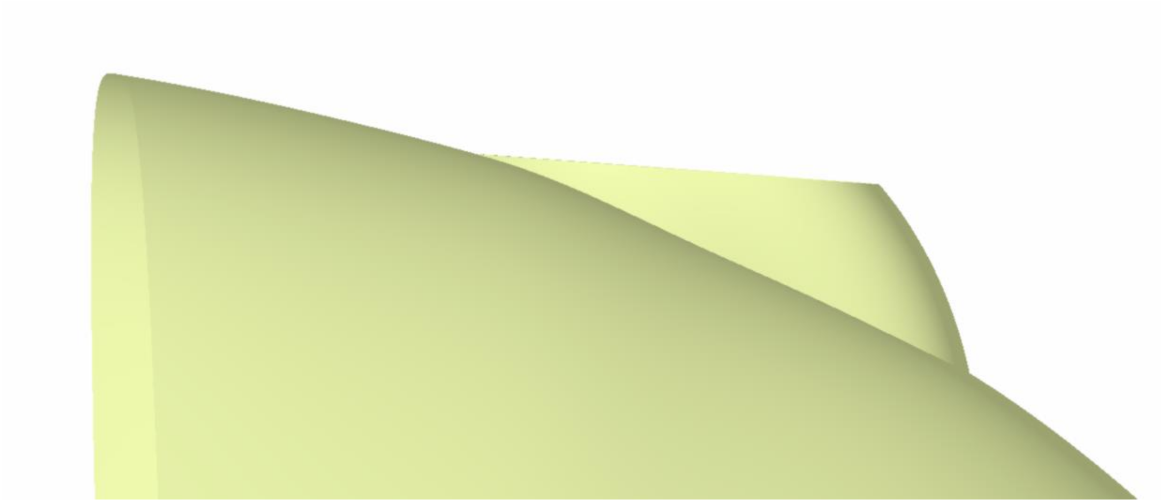

Illustration 40: nose upper structure

4.2.1.3. Windows and thickness

After having created the whole external shape of the nose, it is time now to create the windows and add a thickness to them and the sheets of metal. The windows have to be modelled before applying the thickness for the same reason mentioned when the fuselage was created.

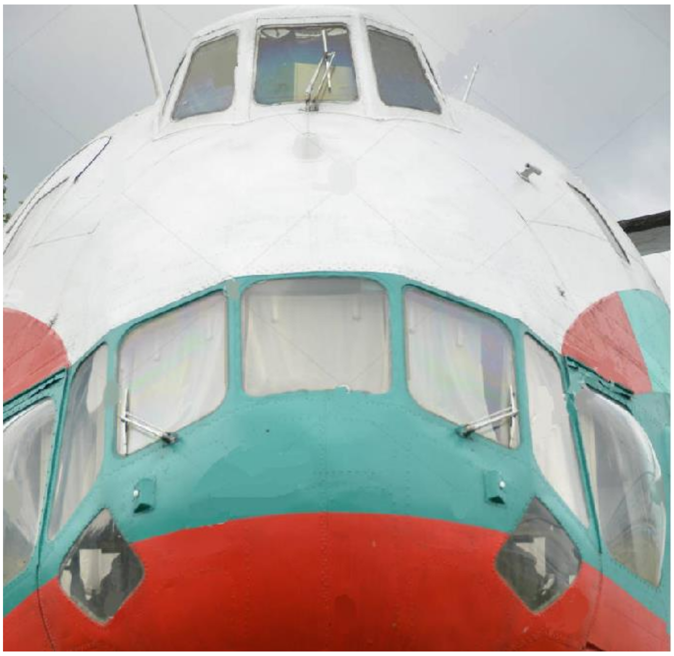

Illustration 41: Real nose external detailed image

Following the same steps, some *sketches*, which define the shapes of the windows, have been projected on all the required positions, then, applying the commands *split* and *thick surface,* the windows have been created. There are two windows that do not follow the curvature of the nose, it is something a bit hard to realize, but it is possible to check it by watching the previous image in detail.

Due to this reason, these windows have been modelled with the command *fill*, which allows the user to choose a passing point. There has been designed the furthest point to the original curvature in the middle of the window. Finally, there has been used the command *thick surface* of the module *part design* to add thickness to both the sheet of metal and the windows, each one with its corresponding material application.

Additionally, the hole of the tip of the nose has already been closed.

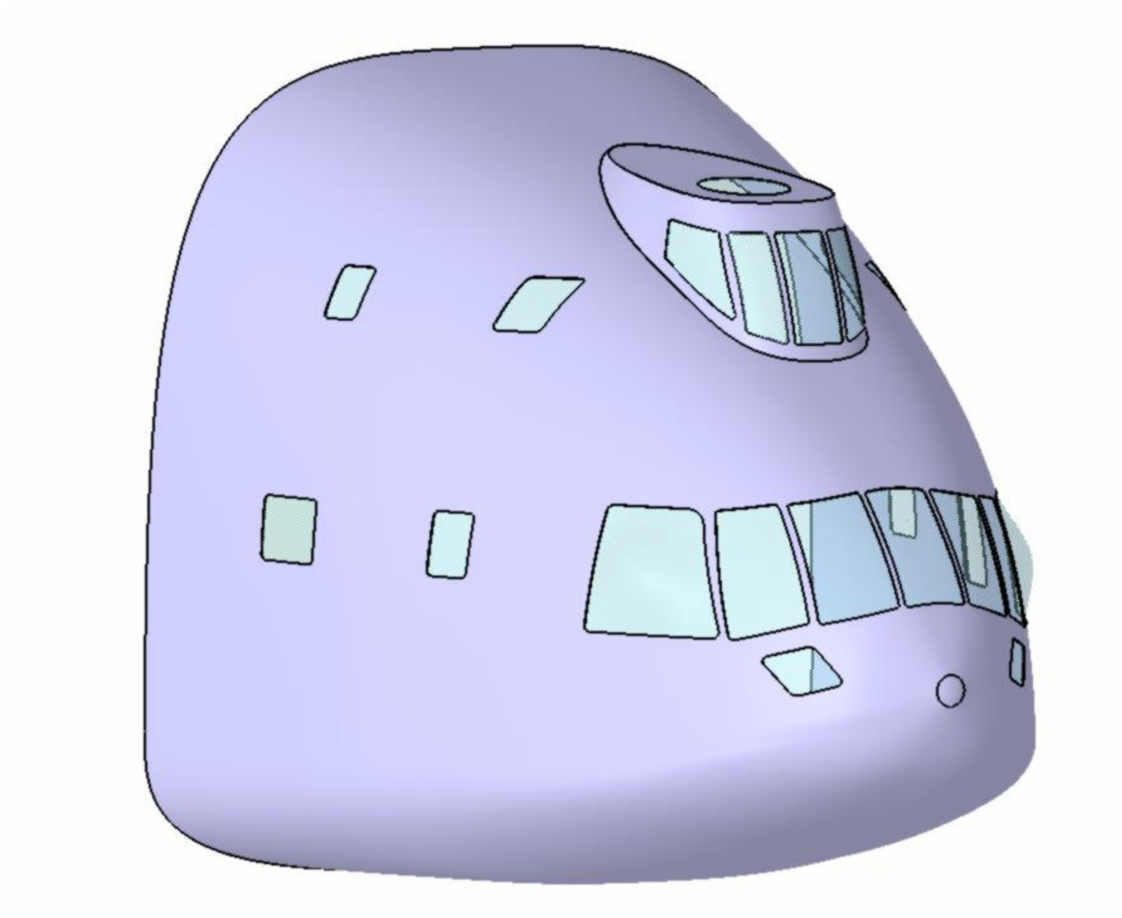

Illustration 42: Modelled nose with Windows

It is worth to mention that some of the windows created belong to the doors, for this reason, when the doors design is explained, the modelling of the windows which are inside them will be omitted

4.2.1.4. Downside structure

On the low part of the nose it can be found a semi ellipsoidal structure, which has been modelled, as it is evident, with a *shaft*. It has been applied white color, which corresponds with the real color, in order to be differentiated properly

Illustration 43: Real nose low side structure

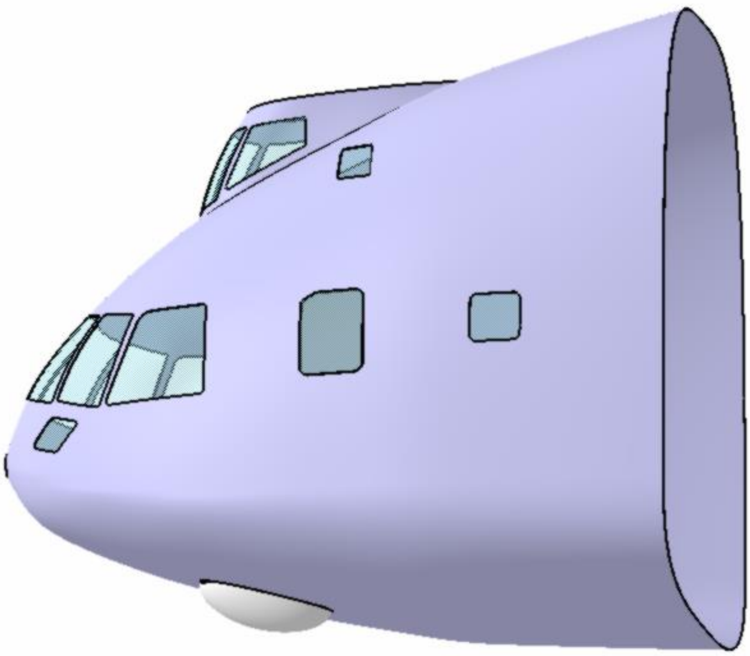

Illustration 44: Nose low side structure

4.2.1.5. Doors

In this section, the doors and all the details related to them are going to be designed. Regarding the doors, the nose is anything but symmetrical, as there are three doors on the left side of the nose, and four on the right side, having all of them different size and shape. However, the doors can be divided into three different types. Type 1, two of the doors correspond with the windows of the extremes of the set of windows located in the front of the aircraft. Type 2, other two doors are sliding doors, and therefore they have guides, fastening elements and one of them also has a platform to aid the entrance. Type 3, the last three doors, as the following image shows, have a pair of joints in the down side.

Illustration 45: Close real view of the nose

Once defined the three kinds of doors, the next task has been deciding how to model them. Firstly, all the doors have been applied a *pocket* of less than 1 mm to define their contours, just the same way that it was done with the fuselage, with this, the doors of type one can be considered to be already modelled. After that, the joints and the trims of the type three of doors have been created by using *pads* and *ribs.* To create the curve that the *rib* had to follow, it has been projected a *sketch* over the surface with the command *project* once again.

Finally, to design the type two doors, everything has been modelled by using once again *pads, projects* and *ribs*, from the guides to the handle of the door.

All the requested resultant edges have been converted into soft surfaces with the command *edge fillet*.

In the following two pictures, both sides of the nose are shown, the lack of symmetry can be observed.

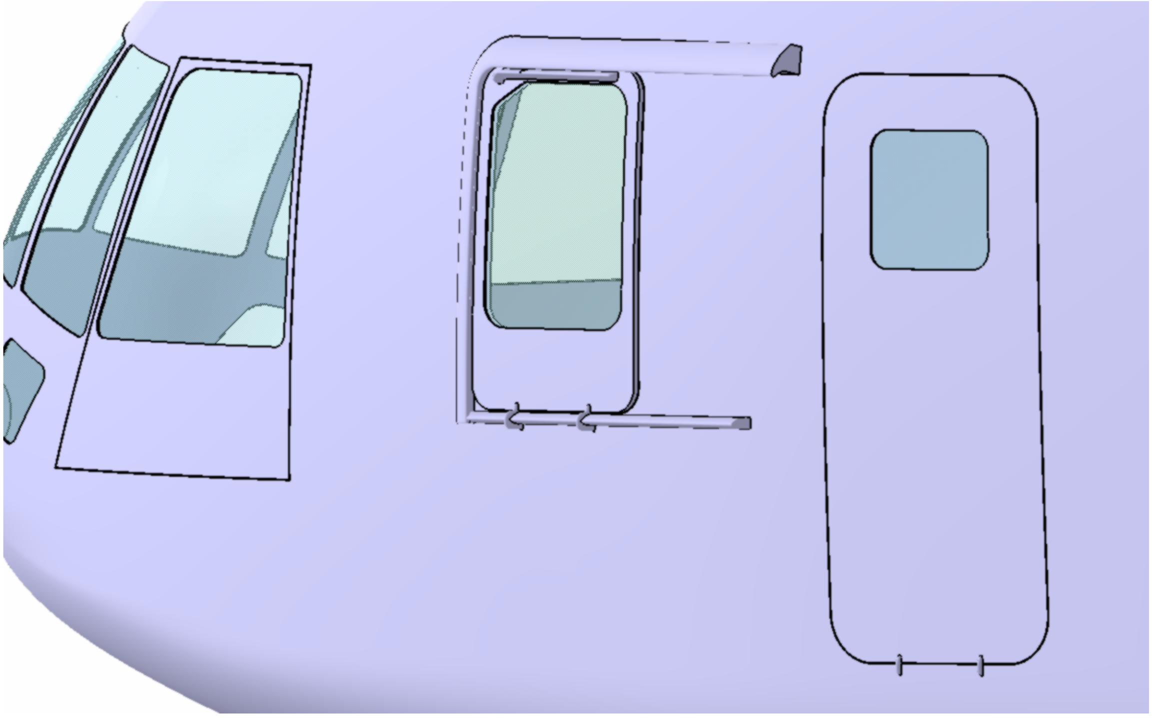

Illustration 46: Left side of the nose

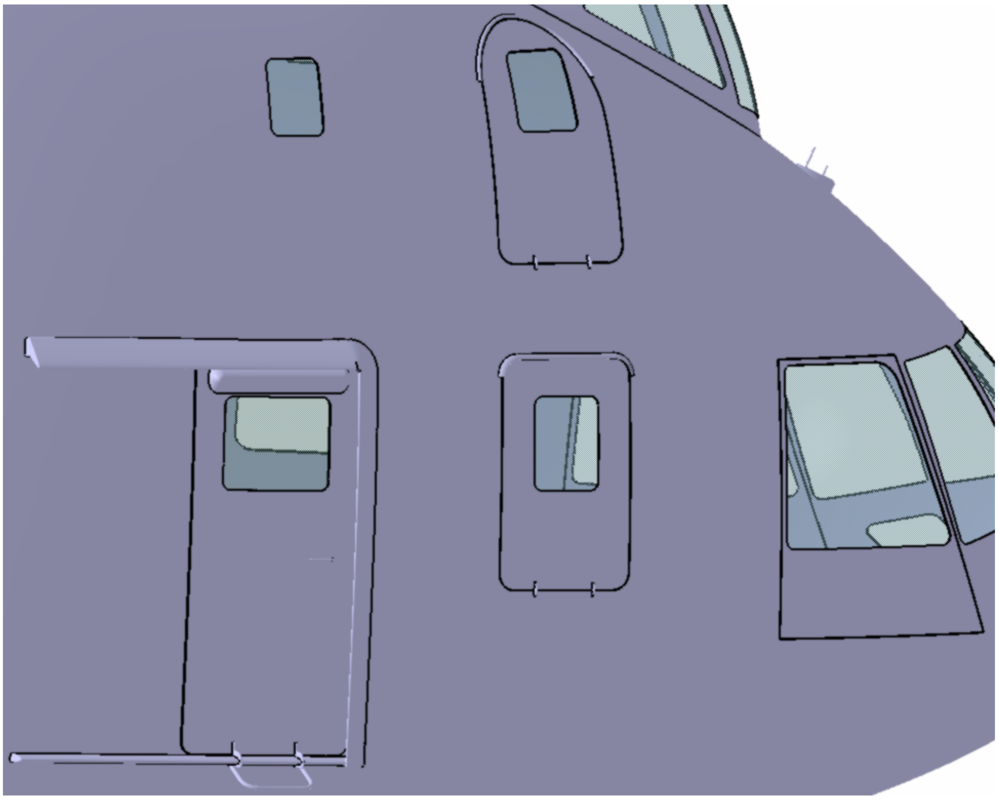

Illustration 47: Right side of the nose

4.2.1.6. External details

There are only some details still to be designed at that point, mainly three of them, two antennas and a hatch.

The first antenna, which is located in the symmetry plane of the helicopter, has been fully modelled by using only *pads.* The second one, on the other hand, has a variable section, for this reason, it has been created with a *multi-sections solid*, adding some details on it with *pads.*

Finally, to design the hatch, is has been made a *pocket*, with the same purpose of the doors, and a *rib* to create the handlers. Once again, *edge fillet* has been used on all these creations.

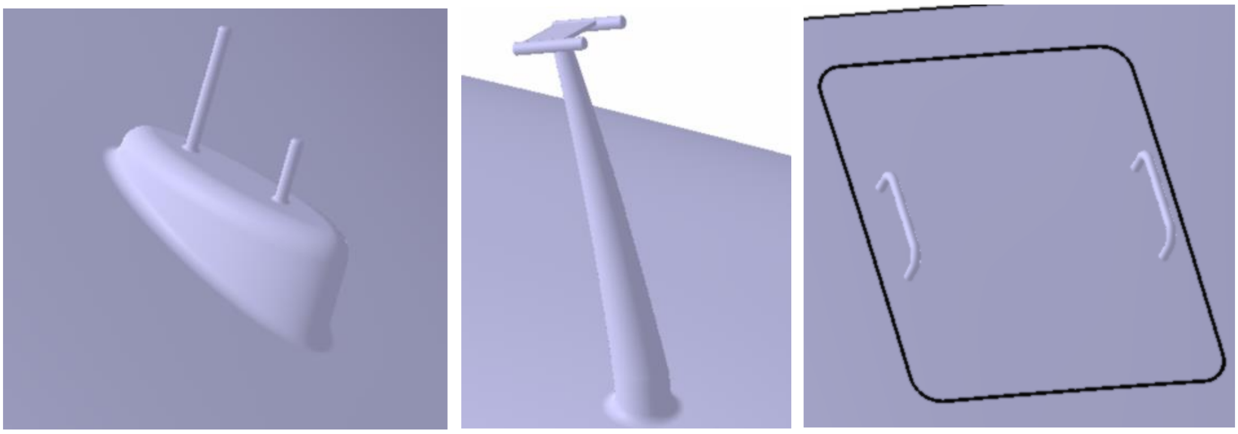

Illustration 48: Antennas and hatch

The final result obtained of the outside of the nose except for the landing gear is shown in the next image.

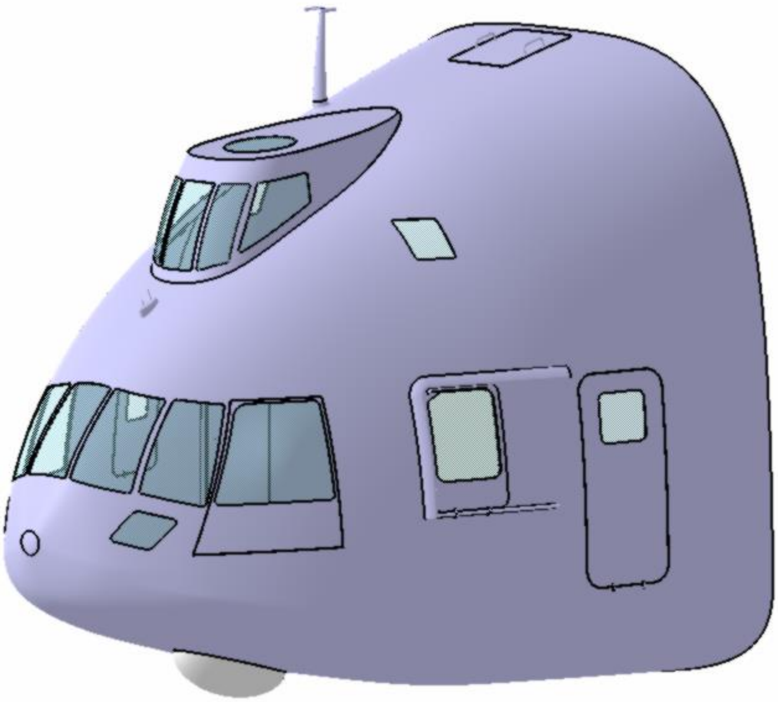

Illustration 49: Outside view of the nose design without landing gear

4.2.1.7. Front wheel of the landing gear

The last thing to be designed is the front wheel of the landing gear. Although it was designed at the very end of the project, because it was firstly thought to be designed as an element belonging to the wings structure, it was finally modelled as part of the nose, and it is in the outside, so it will be modelled in this section.

In the design process, there have been used *pads* and *edge fillets* to generate the rods, and *pads, ribs* and *mirrors* to create the wheels.

The final result of the nose watched from the outside can be seen in the image below.

Illustration 50: Final outside nose geometry

4.2.2. Internal modelling

With the outside of the nose designed, the next step to take is to define and model every element that can be found inside the cockpit.

As well as it happened with the fuselage, there are no blueprints of the inside area, what means that all the elements have been fully created based on photographs and, in some cases, a poster. Some of the images which are relevant and the poster are shown on the following illustrations, as well as the completely modelled results.

Illustration 51: Cockpit real lower floor

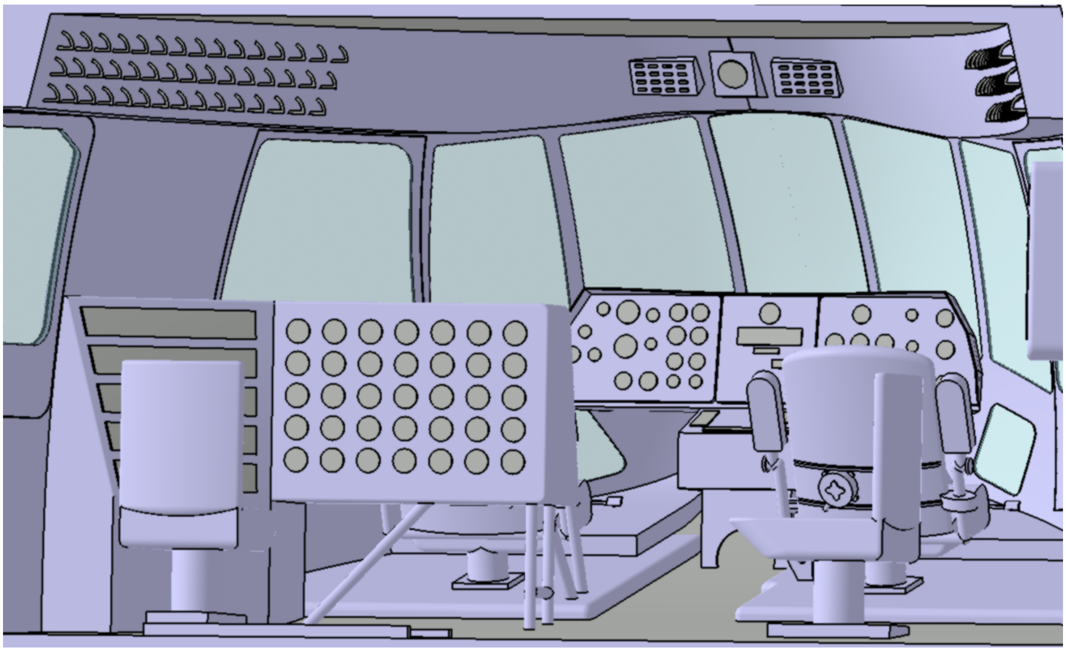

Illustration 52: Cockpit modelled lower floor

The two images already exposed show the lower floor of the cockpit, and the following two illustrate the upper floor.

Illustration 53: Cockpit real upper floor

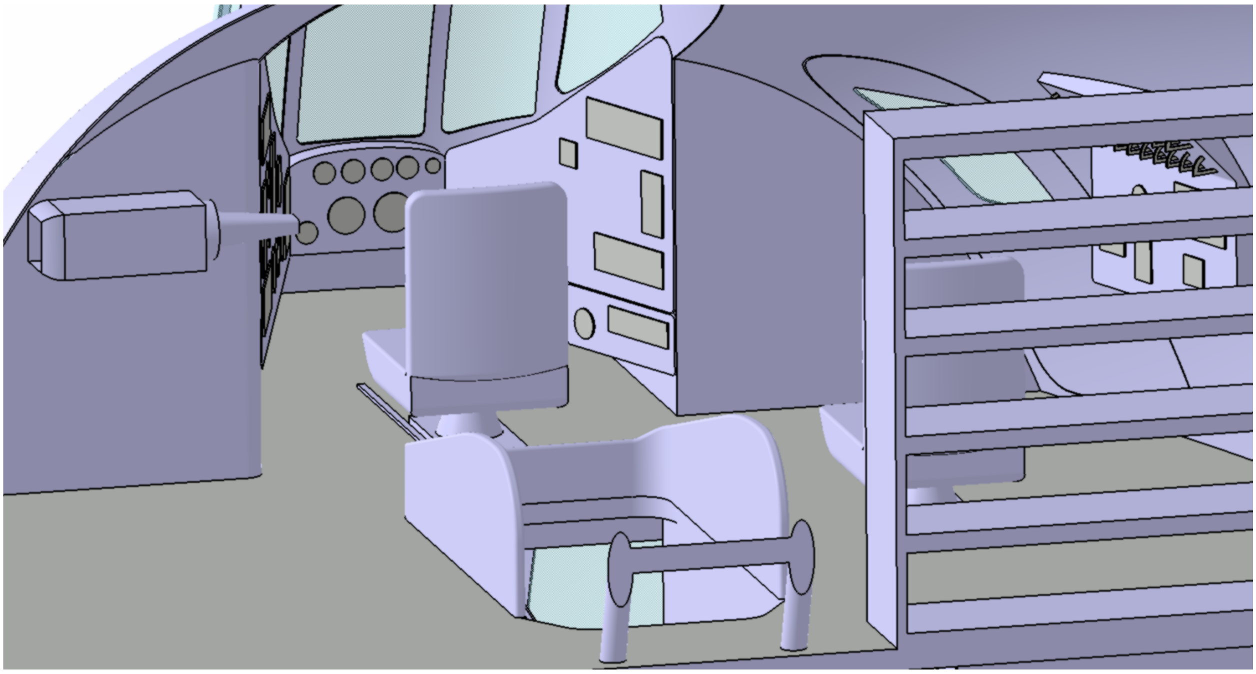

Illustration 54: Cockpit modelled upper floor

Additionally, although it is in the lower floor, there is a corridor separated from the cockpit by a wall. However, if has been modelled as a part of the nose of the aircraft. Such corridor can be seen below.

Illustration 55: Dockpit real corridor

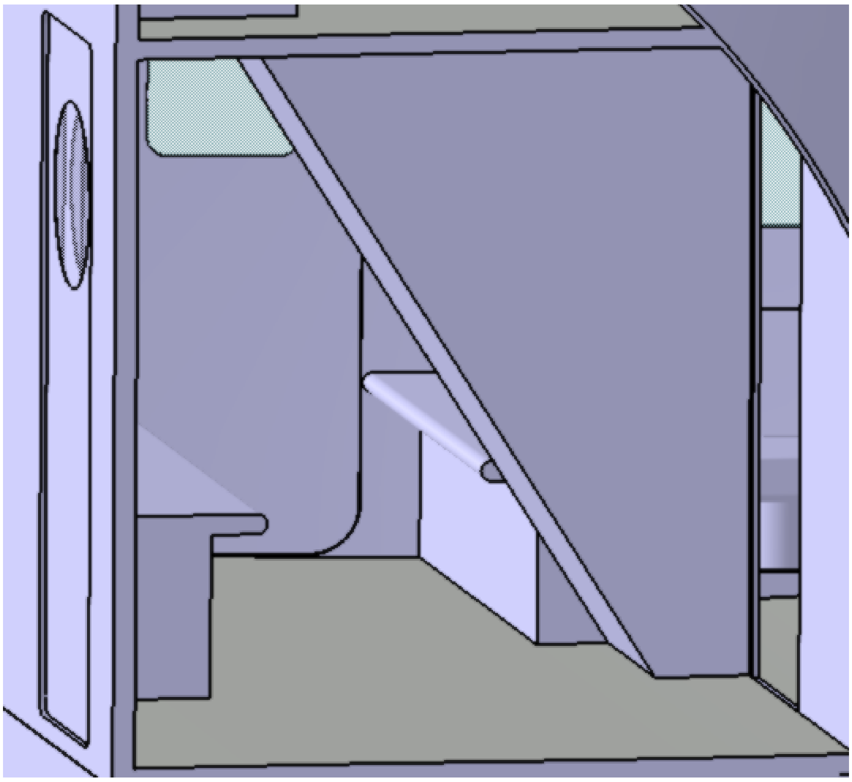

Illustration 56: Dockpit modelled corridor

Finally, although everything has been modelled based on the photographs already given, in some occasions it has been helpful to check the following poster.

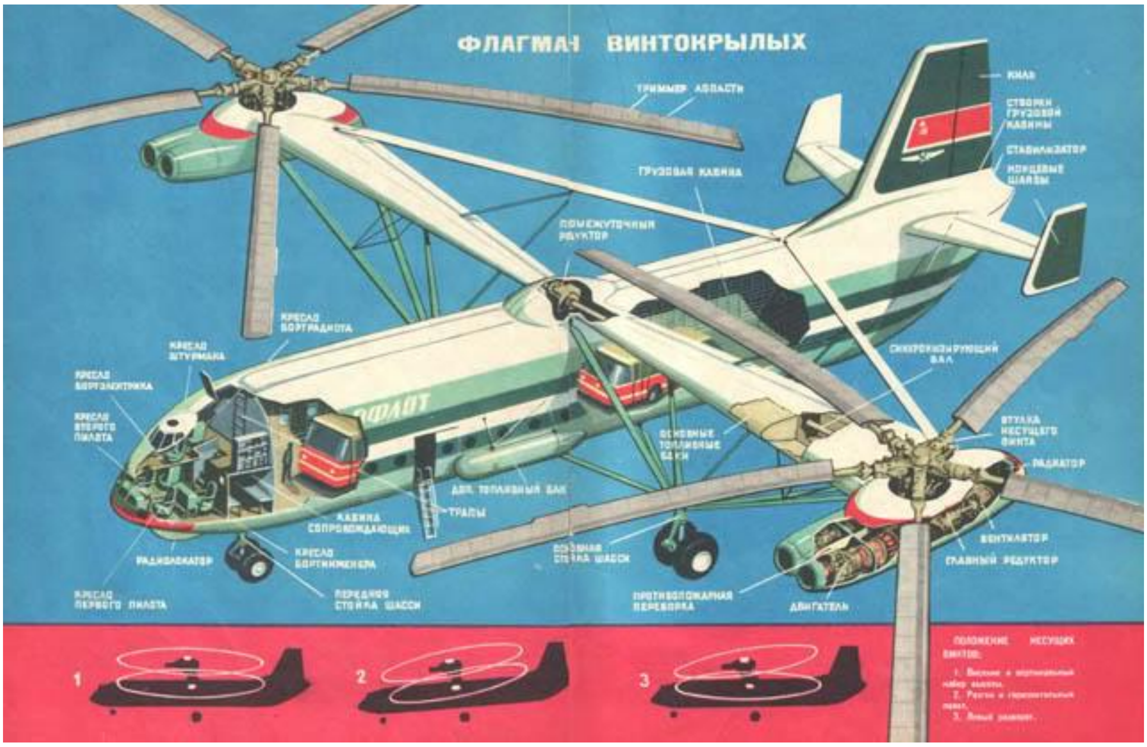

Illustration 57: Mil Mi-12 poster

From now on, it will be assumed that the position of every element designed is already known, as all of them appear in the images shown. As well as it happened in the fuselage with the wires, in this section the cloth that covers the ceiling of both floors will not be modelled.

The design order will be: first the lower floor, secondly the corridor and at last the upper floor. Some of the elements modelling, like the chairs, which are equal in both floors, will not be modelled again in the second one to avoid redundancies.

4.2.2.1. Control Panel

In this section it has been avoided the explanation of the floor has been crated, as the procedure has been the exactly same that the followed with the floor of the fuselage, which consisted on doing a *pad* with the limit option set in *up to next*.

First of all, there have been created two platforms, over which the seats of the pilot and copilot will be located, there is not a section to define them because it has been simply modelled with *pads* and *edge fillets*.

Regarding the control panel design, it can be observed that it has a certain inclination from the panel itself and its intersection with the fuselage. In order to recreate the shape as accurately as possible, plenty of commands have been used, mostly *pads*, *pockets*, *multi-sections solids*, *slots* and *mirrors*.

Once the main structure has been built, there have been added several *pads*, which have been painted in a grey color with the only purpose to represent the indicators of the panel.

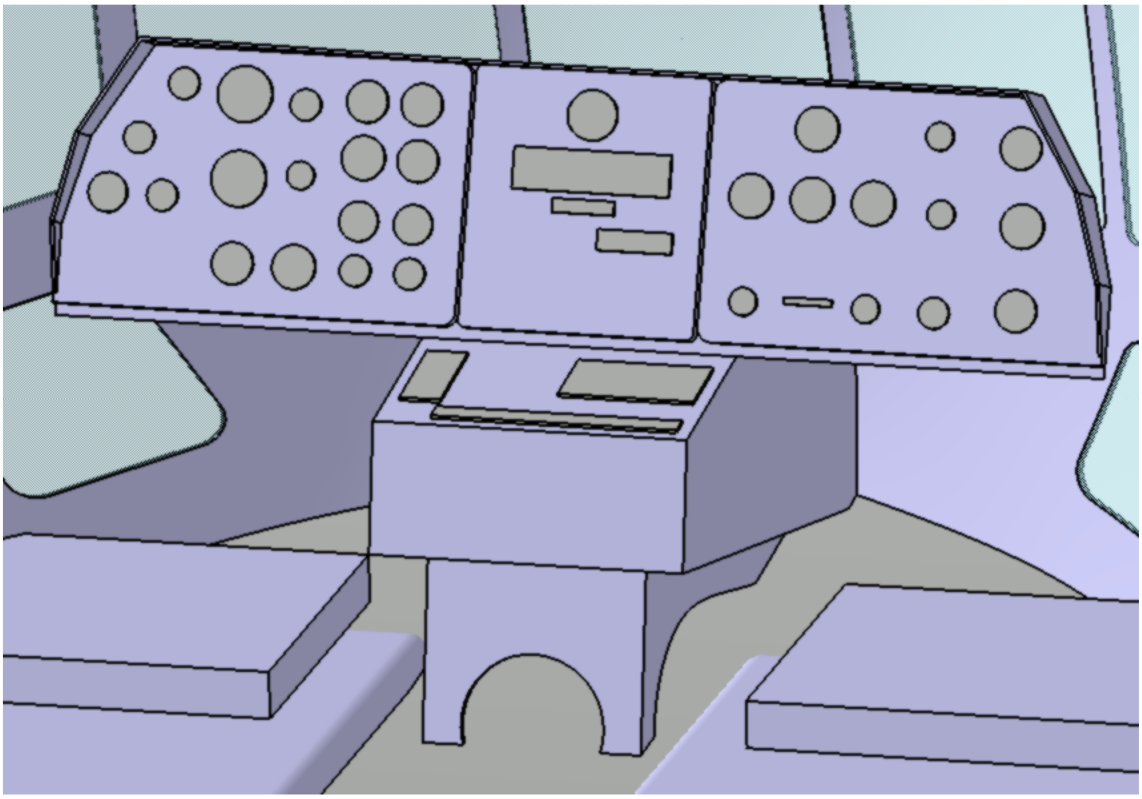

Illustration 58: Main control panel

4.2.2.2. Gas lever and pedals

Both pilot and copilot do have a gas lever and a pair of pedals in front of their seats. Both elements have a platform which has been created with a *pad*, and also both of them are composed by curved rods, for that reason, it has been necessary to create *sketches* with the curves that each profile should follow, and by defining their profiles, using the command *rib* over such curves. Finally, some of the edges have been applied an *edge fillet*. The gas lever and pedal of the opposite side have been created with a *mirror*.

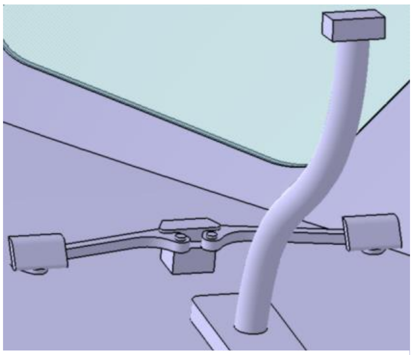

Illustration 59: Gas lever and pedals

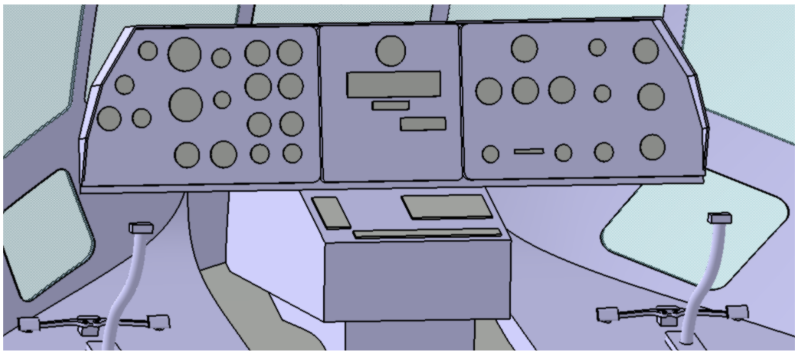

Illustration 60: Cockpit with gas levers and pedals

4.2.2.3. Pilot and copilot seats

The pilot and copilot seats have many details, all of which have had taken into account. First of all, it has a platform which has been created with a *pad*. Secondly there have been done the seat itself and the back, which have been designed with the commands *pad*, *edge fillet* and *shaft*. Finally, the rest of details, such as the armrests, two stiffeners located on the back of the endorsement or an inclination regulator, have being modelled by using these same commands.

Illustration 61: Front view of pilot modelled seat

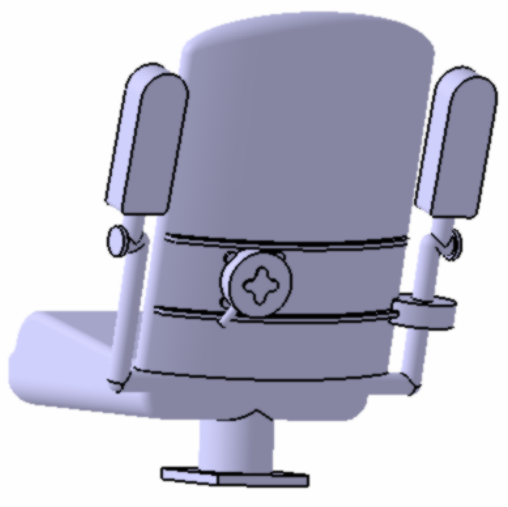

Illustration 62: Back view of pilot modelled seat

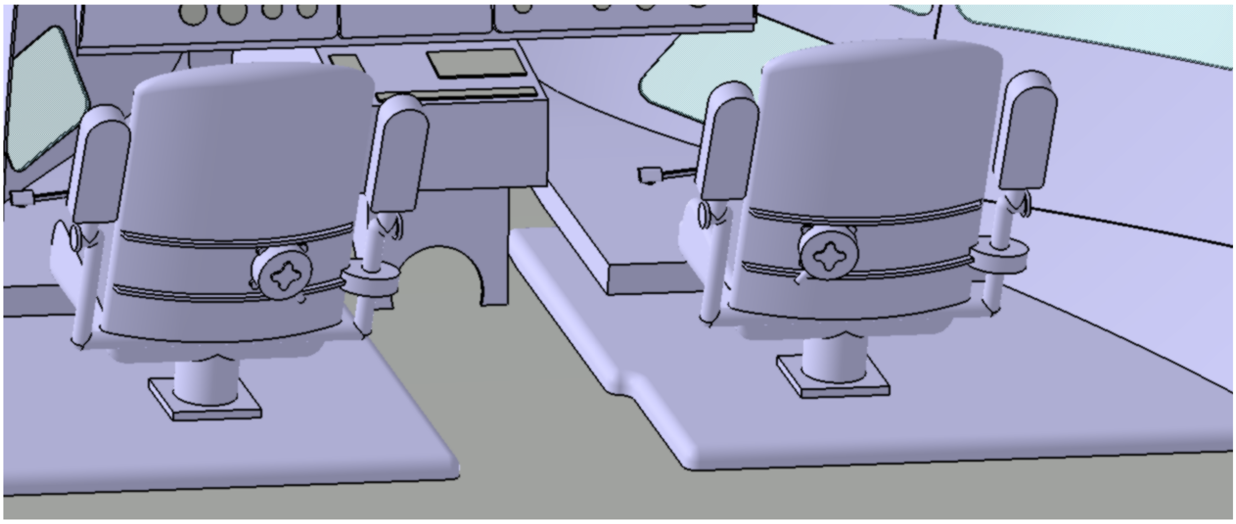

Illustration 63: Cockpit with pilot and copilot seats

4.2.2.4. Copilot handle

As it can be seen in the photographs, there is a handle on the left of copilot seat, which could most likely be the handbrake of the wheels of the helicopter. It is a structure composed by plenty of bars and stiffeners, which is connected to some kind of box.

It is worth to mention that the real handbrake is connected to something under the floor, as it can be barely seen in some images that there is a hole on the floor around the brake. However, as it can be considered to be part of a subsystem held inside the floor and it cannot be seen how it is connected, such hole has not been modelled.

With the aim of creating the handbrake, the commands used have been *pads*, *edge fillets*, *mirrors*, *pockets* and *rectangular patterns.*

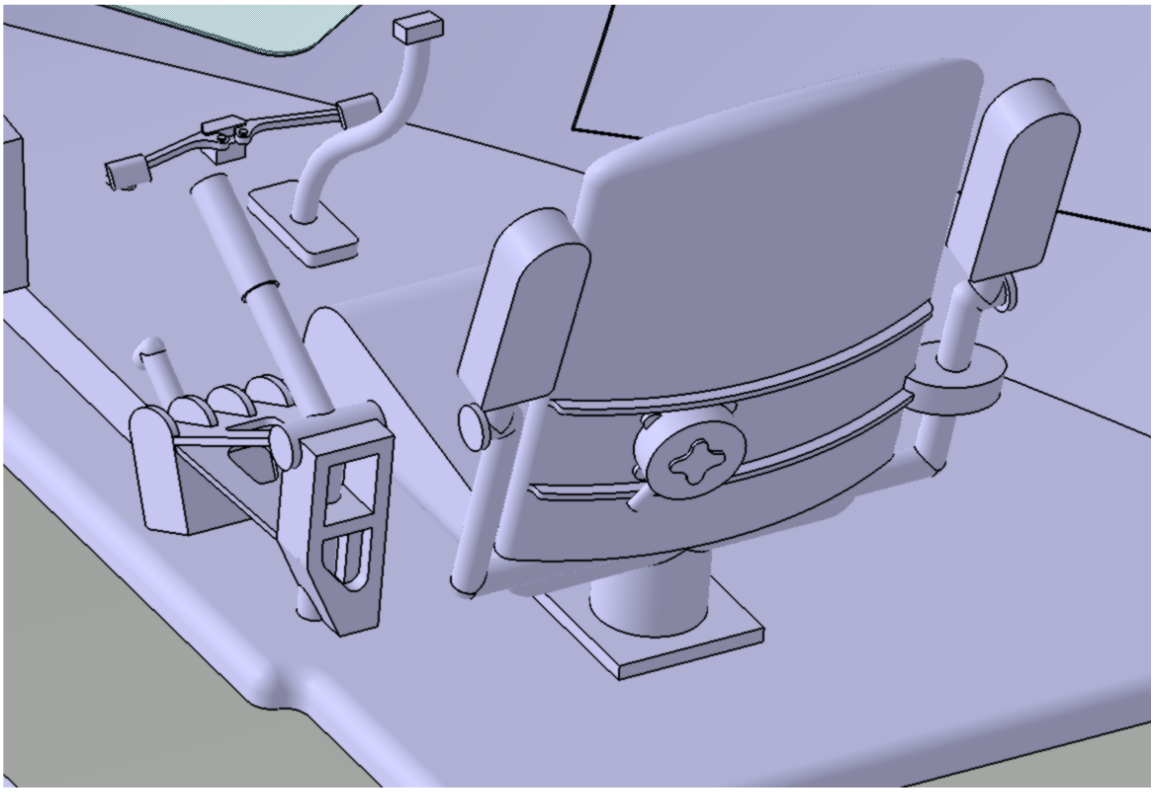

Illustration 64: Copilot area with modelled handbrake

4.2.2.5. Secondary control panels

Although the nomenclature "secondary" control panel is not the most accurate one, from now on all the designed panels in this point will be named that way in order to differentiate them from others.

There are only three secondary panels, two of them are inside the lower floor whilst the other one is in the upper side of the aircraft. The left side panels is fixed to the floor, and its shape is not easy enough to be modelled simply with *pads*, for this reason, it has been necessary to apply some *multi-sections solids*, defining the desired profiles on the specific points and generating then part of the structure whose modelling is not trivial.

The rest of this control panel and the other two secondary panels can be easily modelled with the methods applied along the project until this moment. Therefore, there have been used the commands *pad*, *rib*, *edge fillet* and *rectangular pattern* to generate them.

As it was done with the main panel, there have been created grey colored *pads* which represent the indicators and some buttons or switches.

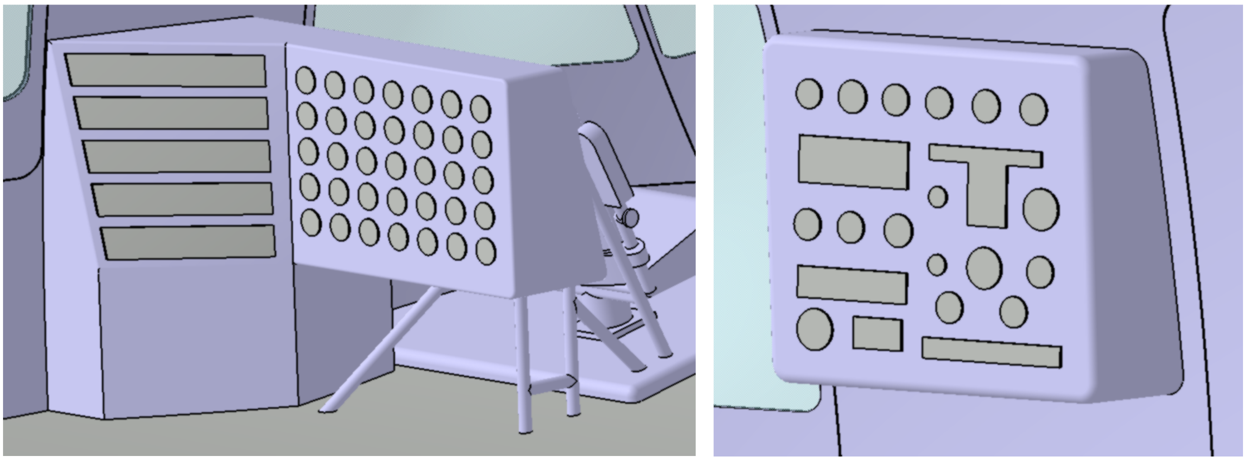

Illustration 65: Secondary control panels

4.2.2.6. Other seats

There are a total number of four seats for the other crewmembers, two of them are in the first floor of the cockpit and the other two are located in the second floor. The modelling of them is simpler than the design of the pilot and copilot seats, however, additionally to the operations *pad, edge fillet, pocket* and *shaft,* there have been used a *multi-sections solid* and a *draft* in order to represent in the most accurately possible way the original shape of the seats.

In the first image of the following two, it is shown a sliding seat. Two of them are sliding seats whilst the other two are not, the only modelling difference is the addition of two sliding guides. The reason why two of the seats have sliding guides and the other two do not is related to the control panel each crewmember has assigned. As it can be seen, the control panels with a higher size have a sliding seat next to them, while the smaller ones are next to a fixed seat.

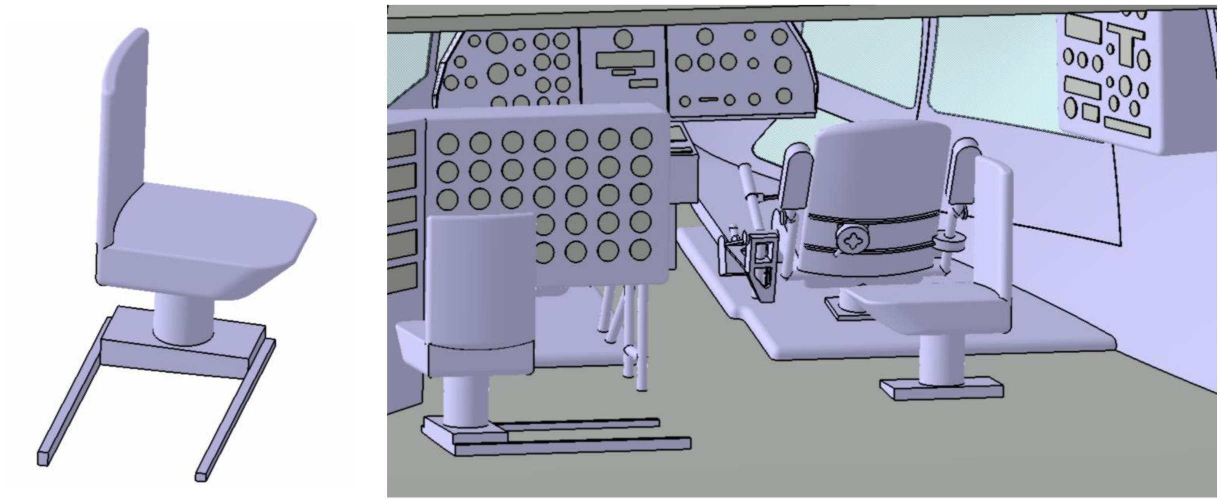

Illustration 66: Other seats modelling

4.2.2.7. First floor upper control panel

As it can be observed in the ceiling of the photograph of the lower floor, there is a control panel and a structure which covers the whole contour. In the modelling process of such structure, the first step taken was dedicating some time to think about the most suitable way to design it. Even though the contour of the ceiling is defined, there was no chance to make a *rib* successfully for two reasons, the first, that the curvature of the wall changes along the contour, so any command that uses a constant shape would not be useful. The second reason is that, if it is observed carefully, it can be seen that the height of the structure varies along the contour. Therefore, the decision taken has been doing a *multi-sections solid* with some guides and a few *sketches*.

During the modelling process a total number of 20 *sketches* has been created, two per each window. Every *sketch* contains the shape of the profile of the structure, and is contained in a plane perpendicular to the curvature of the aircraft in that point. With all these *sketches*, there has only been necessary to create a guide line, defined by the points of the edge of the structure along the wall of the cockpit, and with this guide and the one defined by the contour of the ceiling, there are 20 *sketches* and 2 guides available, which have been used in a *multi-sections solid*.

It is worth to mention that the first time that this structure was tried to model, there was the intention to use only 10 *sketches*, the ones related to one side of the cockpit, and then make a *mirror* to obtain the whole structure. However, for some reason it did not work properly, probably due to some constrains on the guides or the *sketches*.

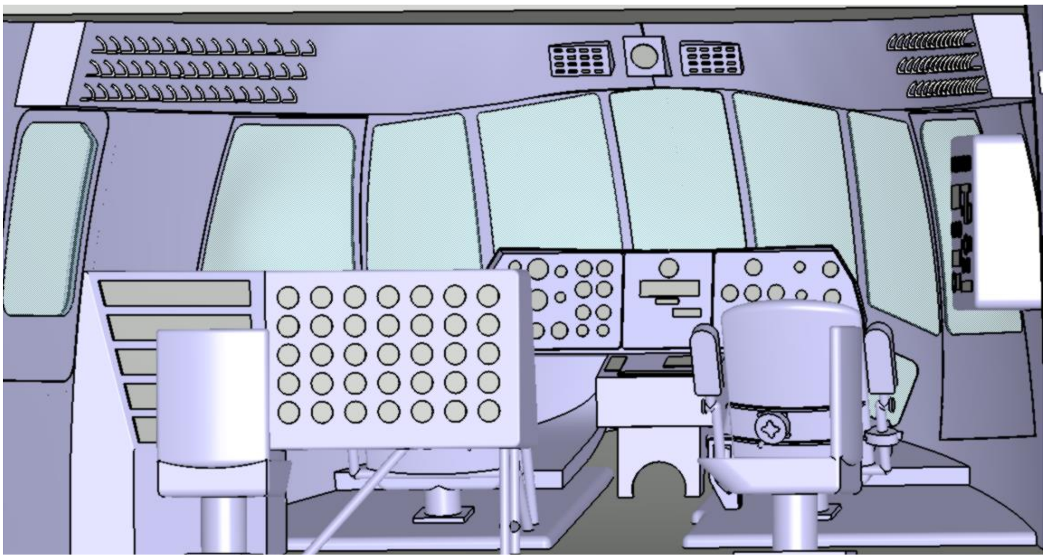

Illustration 67: Ceiling control panel

To do the indicators there has been used the command *pad*. The switches design, however, have not been that easy to model. As the disposition of the switches has an irregular curvature, it has been necessary to create a line to *project* over the desired surface, then, a *equidistant point* command was applied to crate several positions. Finally, it was used, as it was previously explained in other sections, a *user pattern* on a switcher created with a *pad* and the set of points designed.

4.2.2.8. Wall to corridor and back side of the stairs

At this point, the whole lower floor has been modelled but for the corridor. The first thing that has been created is the wall that separates the corridor and the cockpit itself, moreover, there has been done a hole with the command *pocket* where the door should be placed. In this section, it has also been modelled what would be the back side of the stairs that lead to the second floor, which occupy most of the width of the corridor, what can be contemplated in the photographs. In order to do this, the stairs have been created with a simple *pad*, even though at this point there were no stairs on the other side, the modelling of them would be done some steps later.

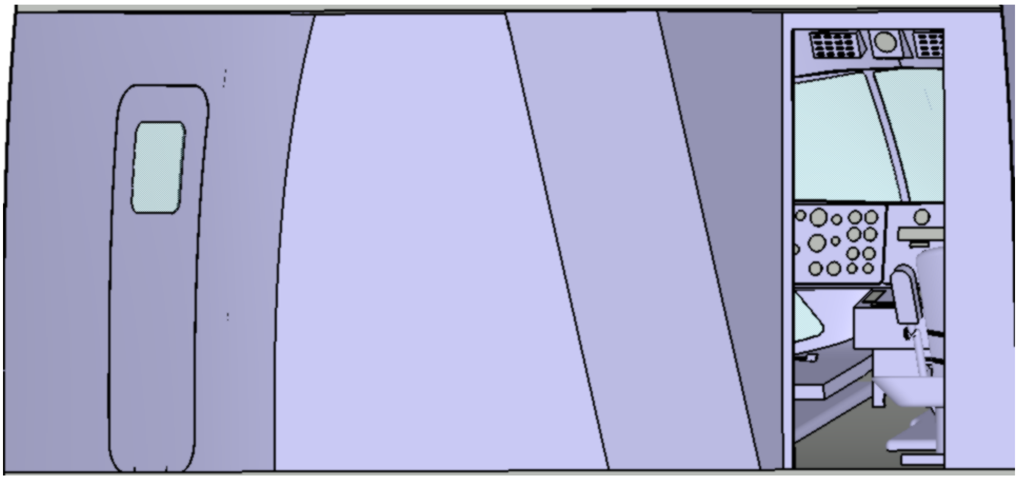

Illustration 68: Back side of the stairs and wall cockpit-corridor

4.2.2.9. Corridor benches

Both sides of the corridor have a bench each and have a back attached to a wall. One of them has the back attached to the wall that connects the corridor and the cockpit, the other one is attached to the wall that leads to the main fuselage.

The modelling process of the benches has been extremely simple, using only a *pad* with the desired *sketch*.

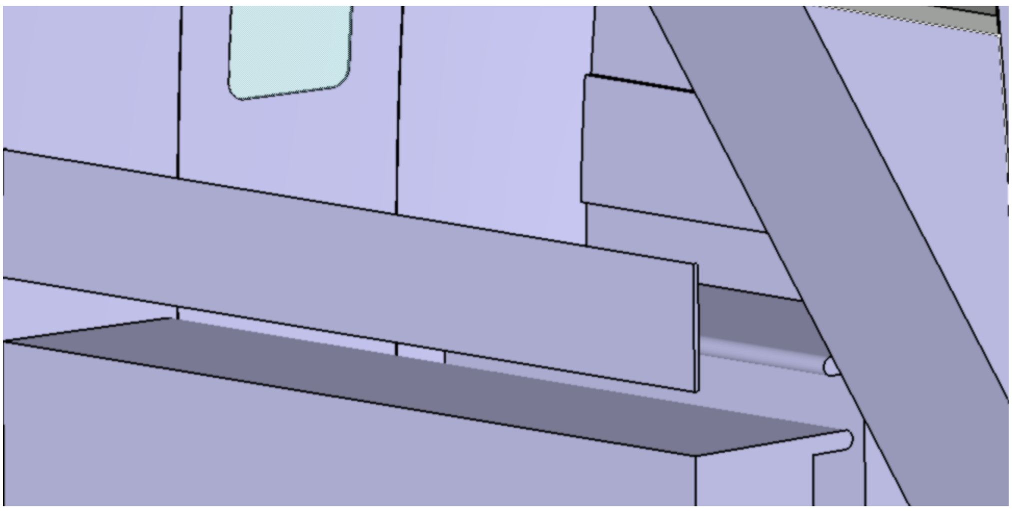

Illustration 69: Corridor benches

4.2.2.10. Corridor to fuselage wall and door

To finish with the corridor design, it has been necessary to create a wall that would correspond with the opposite side of the wall created in the fuselage, which, if it is remembered, left a hole in the area of the door. For this reason, as it was previously said, it is in this section when the door is going to be designed.

The modelling of both the wall and the door have been done with the commands *pad* and *wall*, the same way that it has been done so many times until this point.It should be mentioned that the door contains a window, so the respective material application has been carried out.

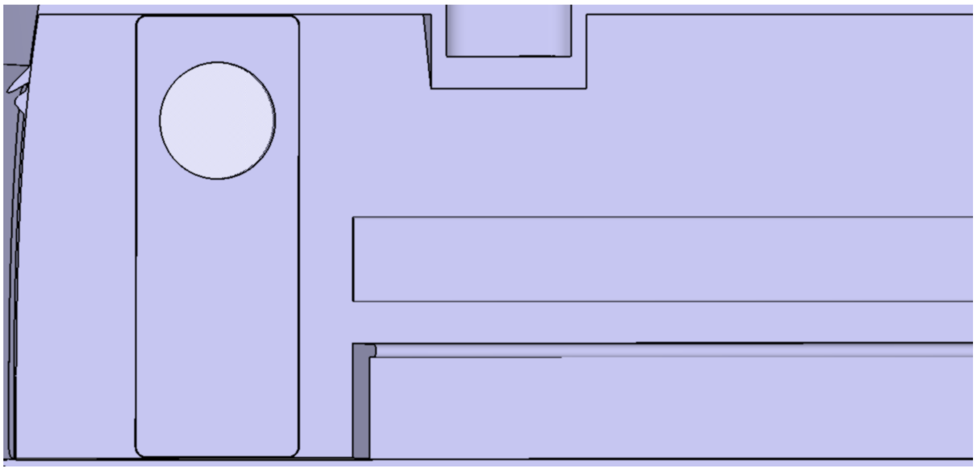

Illustration 70: Corridor to fuselage wall

4.2.2.11. Stairs

The stairs that communicate the first and the second floor of the cockpit have been modelled by using a *pocket* in the solid previously created to design the back side of the stairs. At the end of the stairs there is some kind of security structure around the contour of the floor, to model such structure, there have been used the commands *pad, pocket, rib* and *edge fillet*.

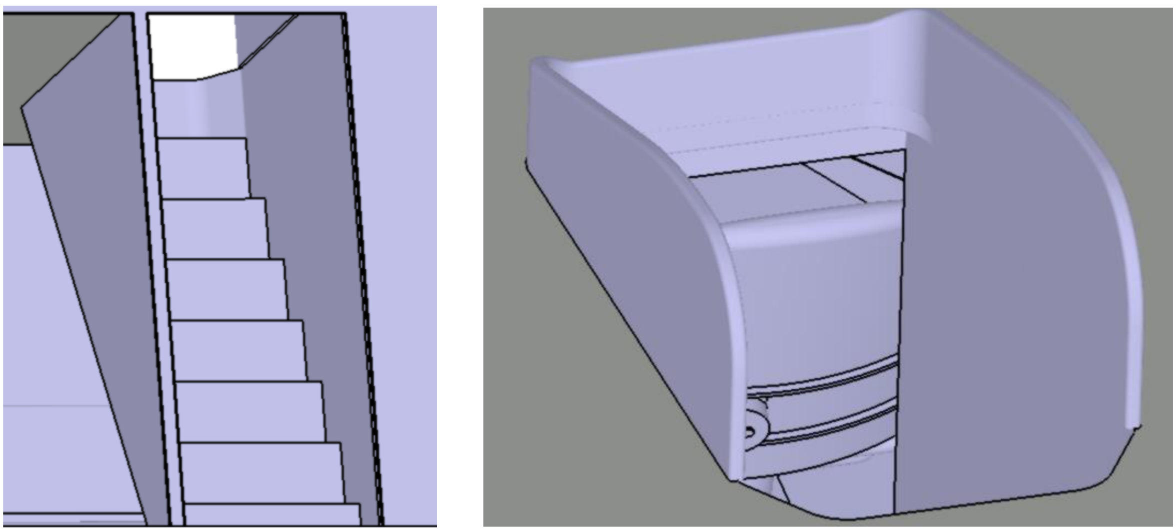

Illustration 71: Stairs modelled

Before explaining the modelling of the elements inside the upper floor it should be mentioned that, as it was previously explained, the modelling of the seats and the panel attached to the wall will be avoided, as the design methodology is the same followed in previous sections.

4.2.2.12. Side structures and binocular system

The first thing that can be found once in the upper floor are two big structures, which occupy a great area of the floor, and a binocular system attached to the left structure. Both structures have been modelled with *pads* and *edge fillets.* The binocular, on the other hand, has been designed by using *pads, pockets* and *multi-sections solids,* in order to obtain the desired geometry.

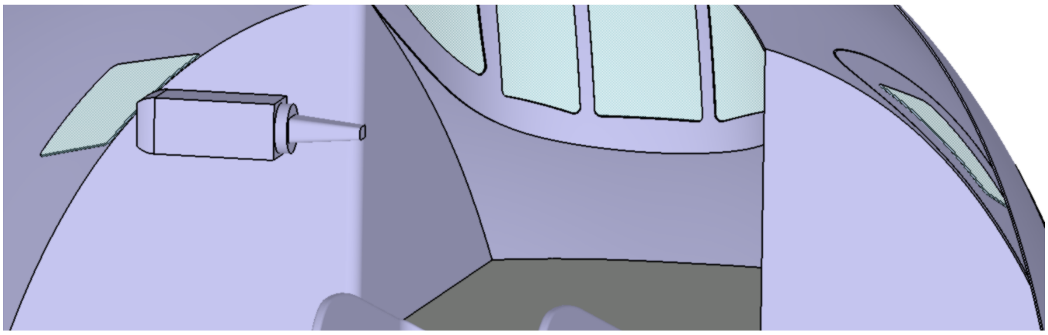

Illustration 72: Binocular system

4.2.2.13. Upper floor control panel

As well as it was done with the lower floor, it has been created a main control panel. In order to do so, there have been defined three planes, related to the attitude of the three sections that compose the control panel. With the three planes created, the task has been to design a *sketch* with the correct geometry and apply on it a *pad up to next*. Once the main geometry of the three divisions of the panel has been created, there have been modelled several *pads* on it to simulate the indicators, as it had been done in previous sections with the lower floor panels.

The following image shows the panel fully designed, as well as the two seats and the lateral panel modelled, whose modelling has been avoided this time.

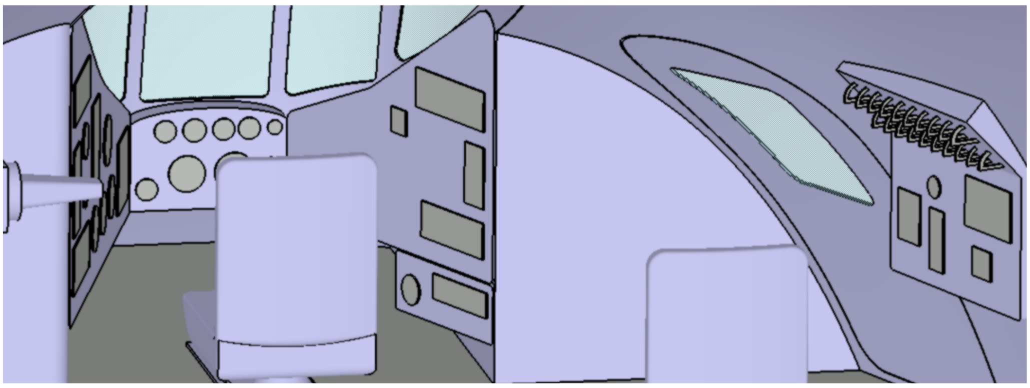

Illustration 73: Upper floor main control panel

4.2.2.14. Shelf rack and ladder

Attached to the wall that connects the cockpit and the fuselage, there is a structure that looks like some kind of shelf rack. As its shape or its size is something that does not appear in any photograph, its measures have been estimated.

The shelf rack has been designed as simply as possible, with a *pad* and a *pocket*.

Finally, the last element to be designed in the upper floor is a ladder. Although it does not appear in the photographs, it can be seen in the poster and, as there is a hatch, there must be a ladder that leads to it.

The ladder has been modelled with one *rib* to define the vertical rods, and one *pad* and a *user pattern*, which has been created following the already explained procedure, to create the horizontal rods.

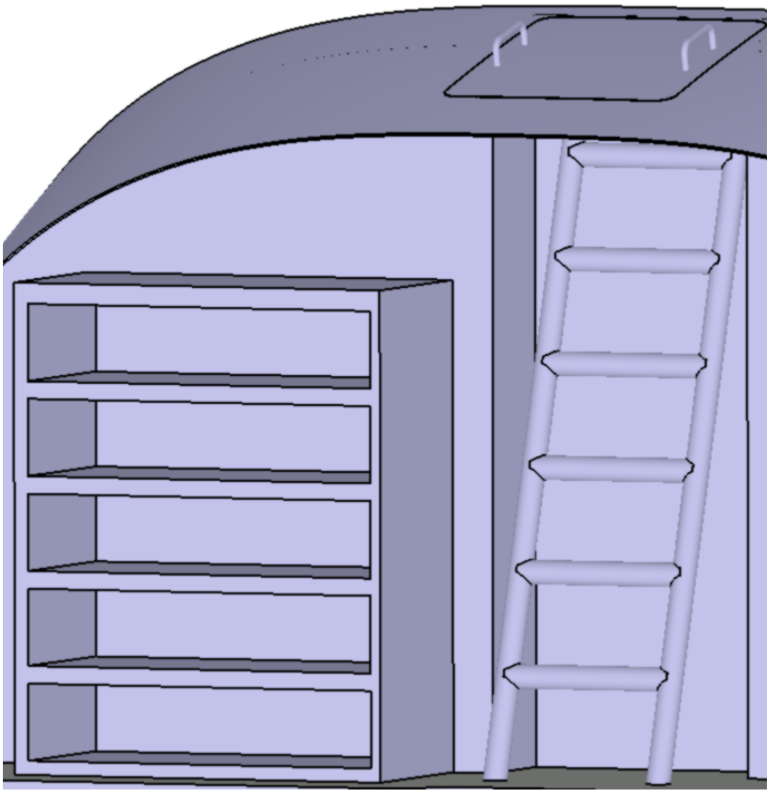

Illustration 74: Shelf rack and ladder

4.3. Tail

The third section modelled includes the tail structure of the aircraft and the stabilizers. As well as it did happen with the nose, the only geometrical imposition that must be already set is the shape of the first profile of the tail, which must coincide with the constant profile of the fuselage, in order to make a successful assemble in future steps.

The order of design will be the same followed on previous sections.First at all, it will be modelled the outside of the tail, after it, all the elements will be created, and the stabilizers modelling will be carried out as the last step of this section.

The tail and stabilizers correspond to the section inside the green rectangle seen in the image below.

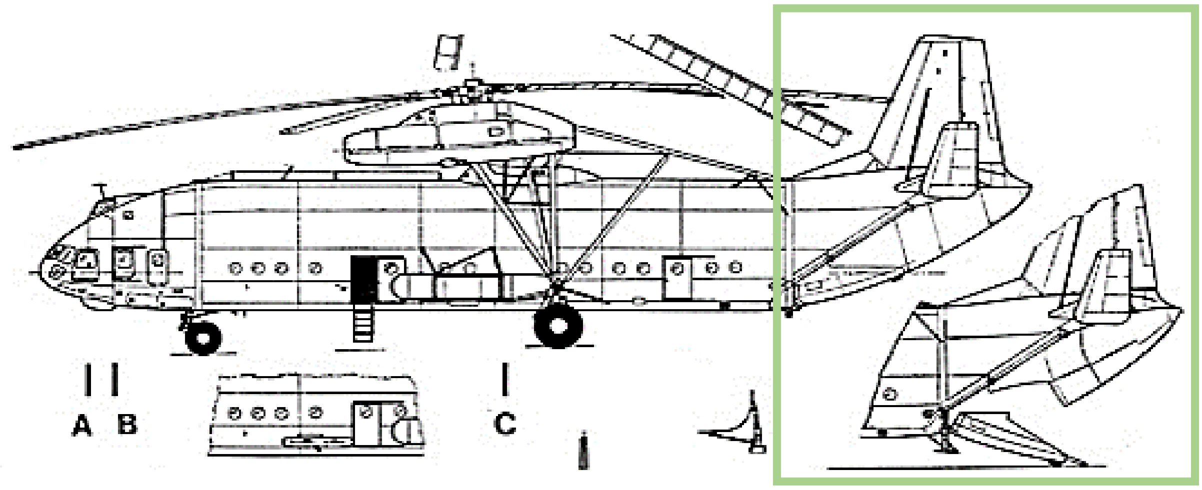

Illustration 75: Tail pointed out in blueprints

4.3.1. External modelling

Before beginning with the explanation of the modelling, it should be realized that there cannot be found the profile of any section belonging to the tail, which implies that only the height and width can be measured using the blueprints, as there is no way to know the proper curvature of the different sections along its length.

Therefore, in this section there have been used only five *sketches* to define the tail for two main reasons, the first one is that, as it was proved in the nose modelling, sometimes less is more, especially if the accuracy taking measures from the blueprints is not the optimal. The second reason is that the curvature had to be extrapolated from the initial imposed section, to a final section with a way different curvature, what implies that the curvature of every new *sketch* created had to be estimated, so the more estimated data, the higher chance of creating a wrong surface.

Surprisingly, after doing only a few changes in two of the initial *sketches*, the result was highly accurate.

On the next images there can be seen the actual tail, the *sketches* employed and the resulting surface, created with the command *multi-sections surface*. It is worth to mention that the tail can be opened, being composed by two side gates (which open symmetrically) and a floor gate. The opened configuration is shown in a photograph below too, however, it has not been modelled in this project, as there have not been crated any animations.

Illustration 76: Mi-12 real tail

Illustration 77: Mi-12 with open tail gate

Now, the mentioned *sketches* and the consequent geometry are illustrated below.

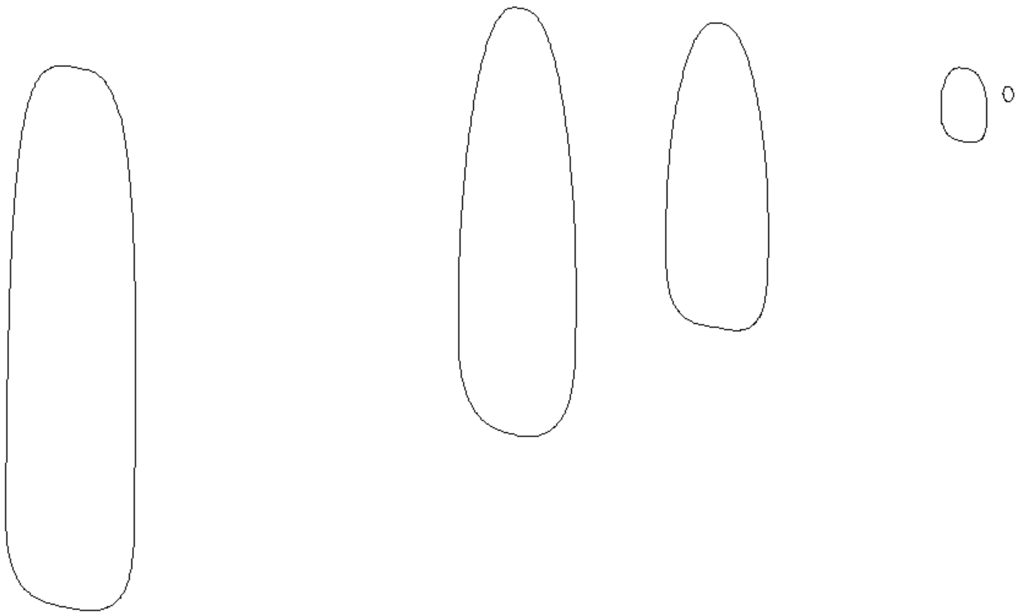

Illustration 78: Tail sketches

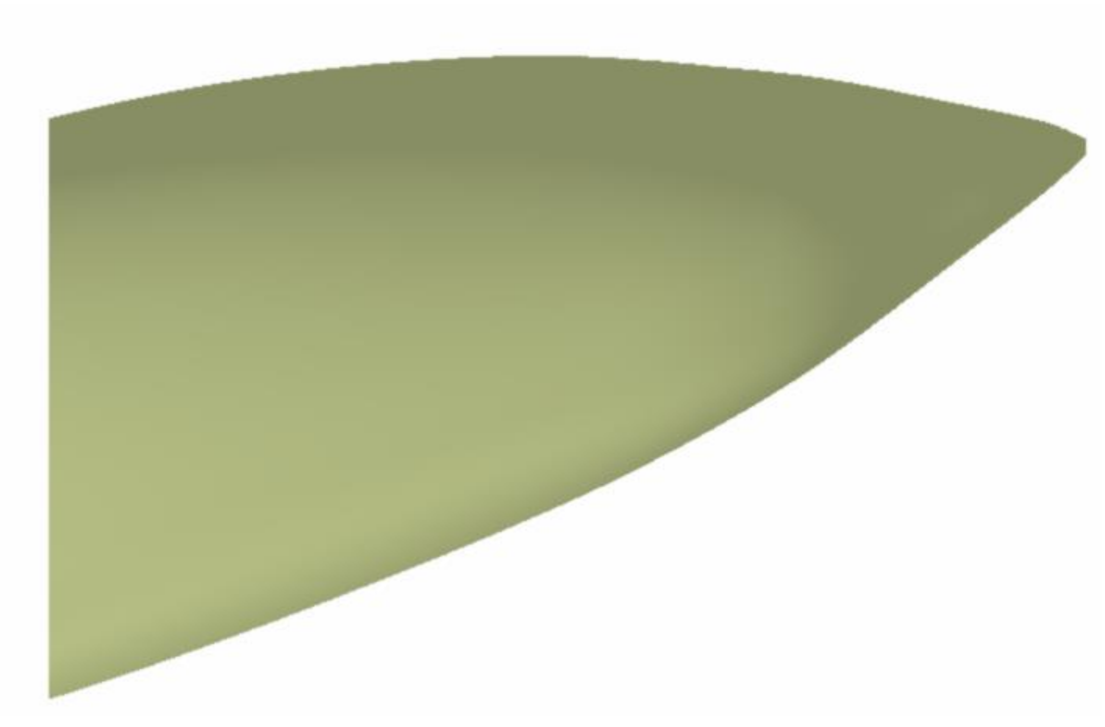

Illustration 79: Tail multi-sections surface

The only problem found with this procedure was that, as it can be observed, the geometry is not close at the tip of the tail. Doing so has not being an easy task, as many procedures have been tried, all of them with poor results. However, at the end there has been found a solution that solves the problem smoothly. The process consists on making two *sketches,* one in the "YZ" plane and the other one in a plane parallel to the plane "XY" that passes through the midpoint of the hole that is desired to be closed.

In these *sketches,* there have to be created the curves whose curvature are desired for the closure surface to have. Of course, both curves must coincide in one point and be tangent to the surface, having a similar look to the following ones.

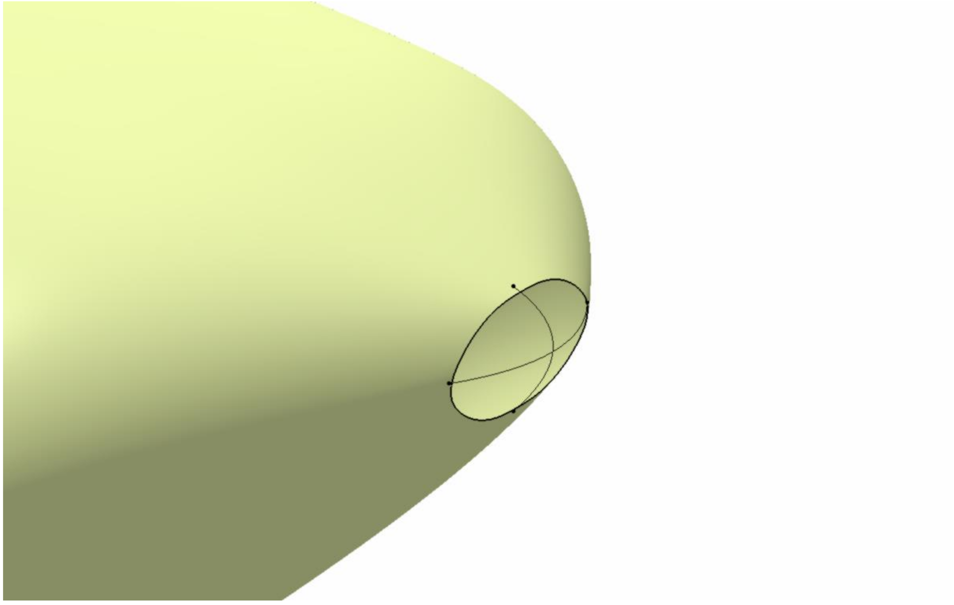

Illustration 80: Closure surface sketches

Once this has been done, it is time to use the command *fill* four times, one for each of the four divisions that can be observed, what would create a surface adapted to the imposed curvatures, leading to the result seen on the next image.

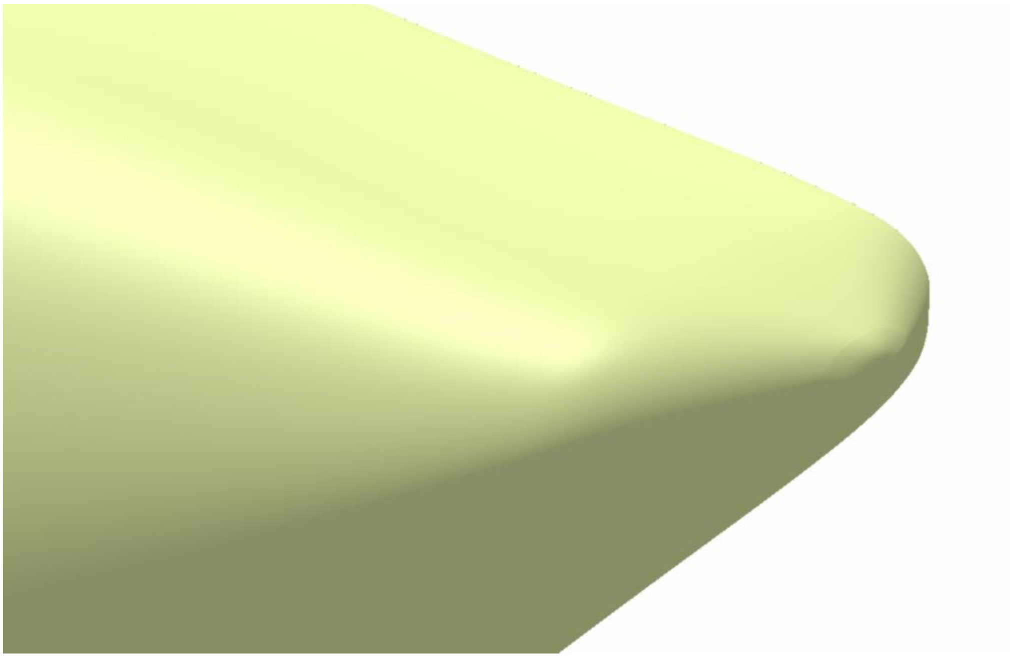

Illustration 81: Closure surface

Finally, it is the time to apply some thickness to the generated surface with the command *thick surface*, leading to the geometry contemplated below.

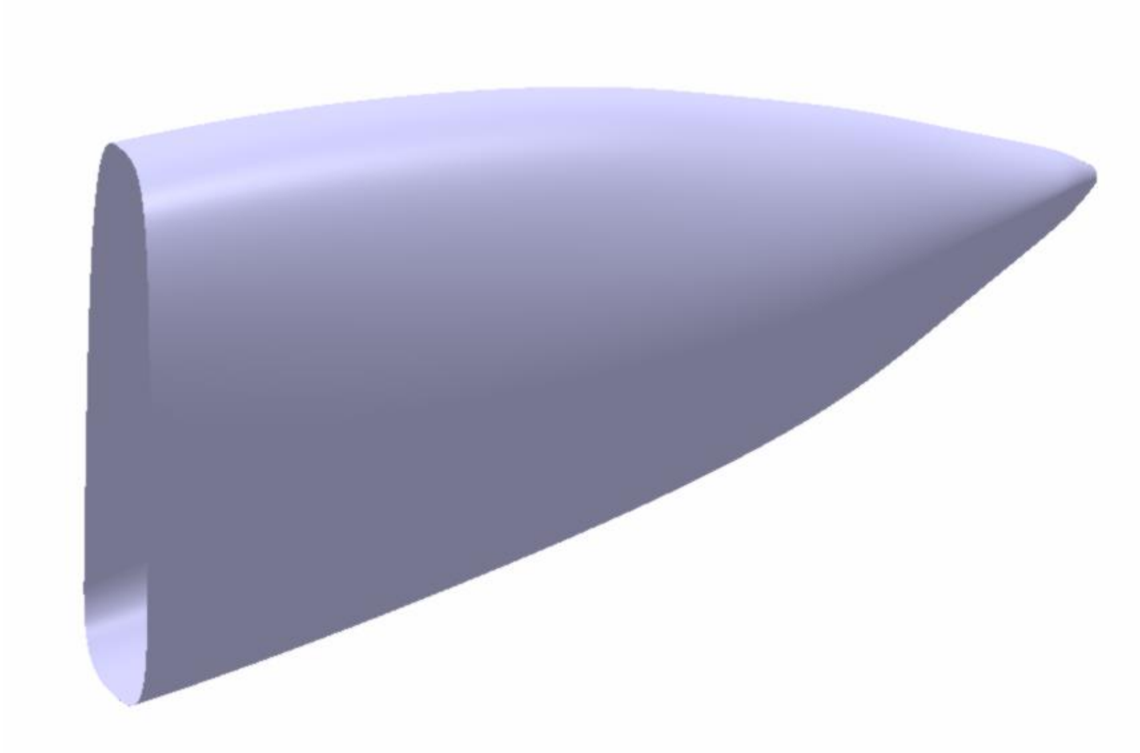

Illustration 82: Modelled tail external geometry

4.3.2. Internal modelling

The internal modelling of the tail has been done in the most accurate way with the poor information available, as there are barely no photographs which show the inside of the tail properly, being the image shown below the one that shows it clearer.

Illustration 83: Real inside view of the tail

As it can be seen, it has been especially difficult to keep a great level of detail with the elements of the inside of the tail, as there are many areas that cannot be seen, like the ceiling or the sides of the tail, and because of the high distance and the darkness, the accuracy of the visible elements is probably not the optimal.

However, the rest of the elements which cannot be seen have been estimated, trying to generate a model as accurate as possible. In the image below it is shown the final result of the modelling of the tail, in order to overview it.

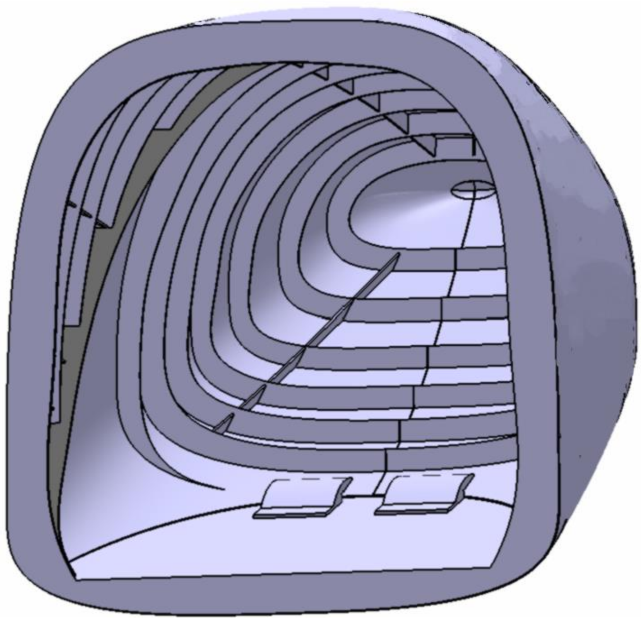

Illustration 84: Modelled inside of the tail

4.3.2.1. Floor

From the starting point of the internal modelling, the empty geometry of the tail, the first step has been to create the floor.

To define as accurately as possible the dimensions, the length and inclination of the floor has been determined equalizing it to the length of the opened gate shown in the blueprints. Although it might be possible that the lengths of the floor and the gate are not exactly the same, or the measurements are not the exact ones, it is a good approximation to the reality.

The floor has been created using a *pad*.

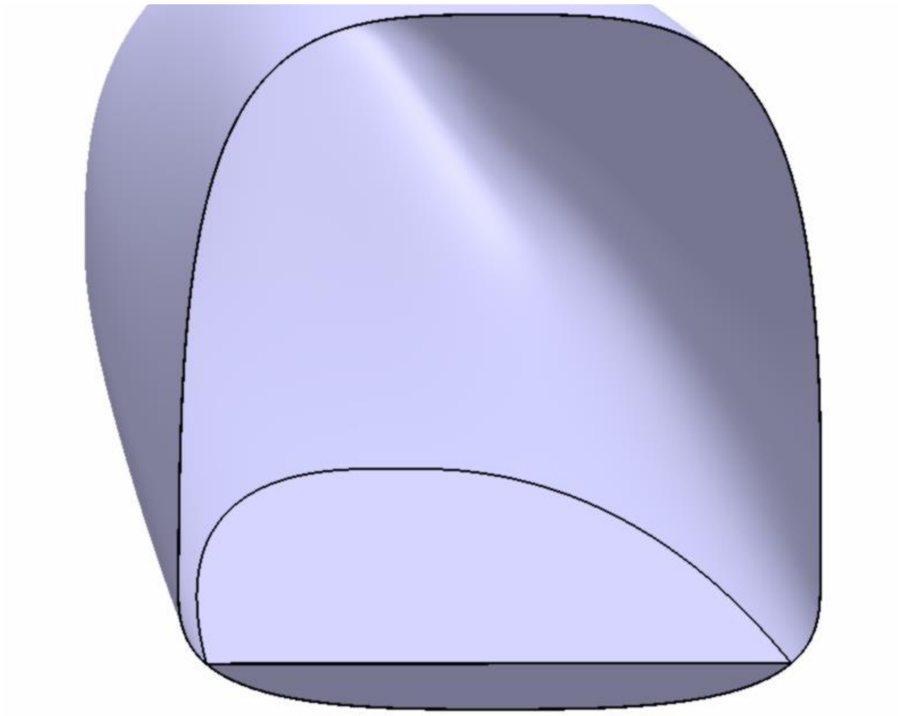

Illustration 85: Tail floor

4.3.2.2. Side gates formers

As it can be seen in the photograph, there seems to be an oblique former which separates the side gates from the floor gate. Behind that oblique former, there are several formers that cover the whole contour of the side gates, but for the first one.

All these side gate formers have been modelled in this section. This time, as the curvature of the tail is too strong, it has been impossible to create the formers with *pads*. Instead, for each former there have been used two planes, with an offset of 20 mm and 30 mm in some cases (which are the estimated widths of the different formers). On these planes it has been created a *sketch* on each, in which it have been obtained the intersections with the internal geometry of the tail and then there has been defined the shape of the rest of the former. Finally, it has been made a *multi-sections solid* joining both *sketches*.

This same procedure has been followed for each former, leading to the following result.

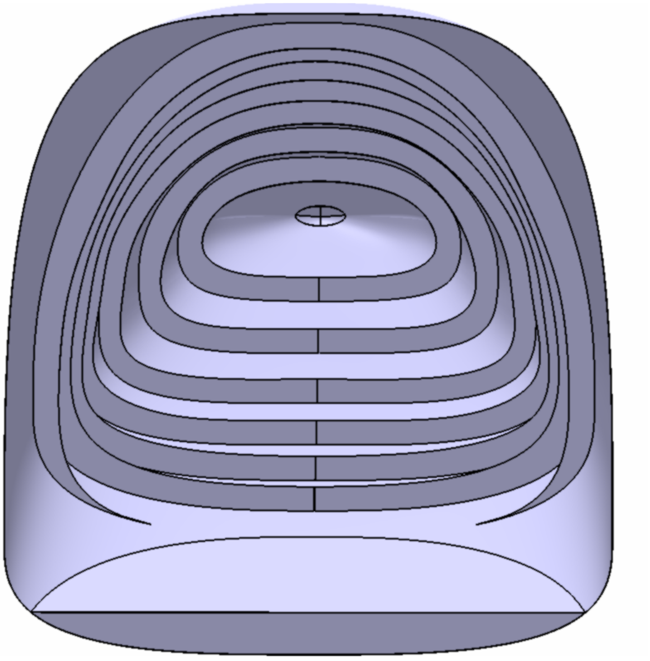

Illustration 86: Side gates formers

4.3.2.3. Oblique former

Now it is the turn to create the oblique former it was talked about in the last section. This will be carried out with the same procedure applied with the previous formers, by using the command *multi-sections solid.*

It has been applied a dark grey color to this former in order to differentiate it, and because that seems to be its color in the real tail.

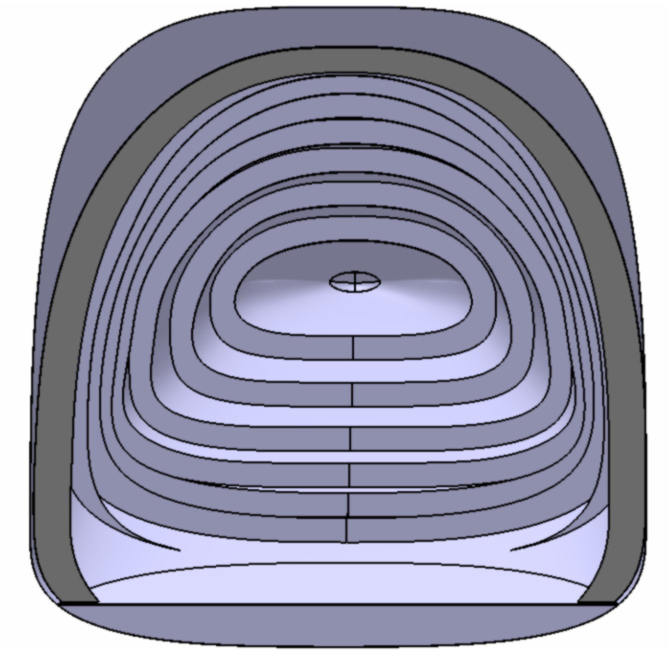

Illustration 87: Oblique former

4.3.2.4. Other formers

There are only a few formers left to be modelled, however, having a look at the photograph, it seems that the rest of the formers do not cover the whole surface until the floor, but that the extremes of the formers are set by the oblique former, which has been already created.

Taking this into account, the procedure followed to create these formers has been using *pads*, because the curvature at these lengths is low enough to provide the same resulting geometry, and the time and effort spent is much lower by using *pads* instead of *multi-sections solids*.

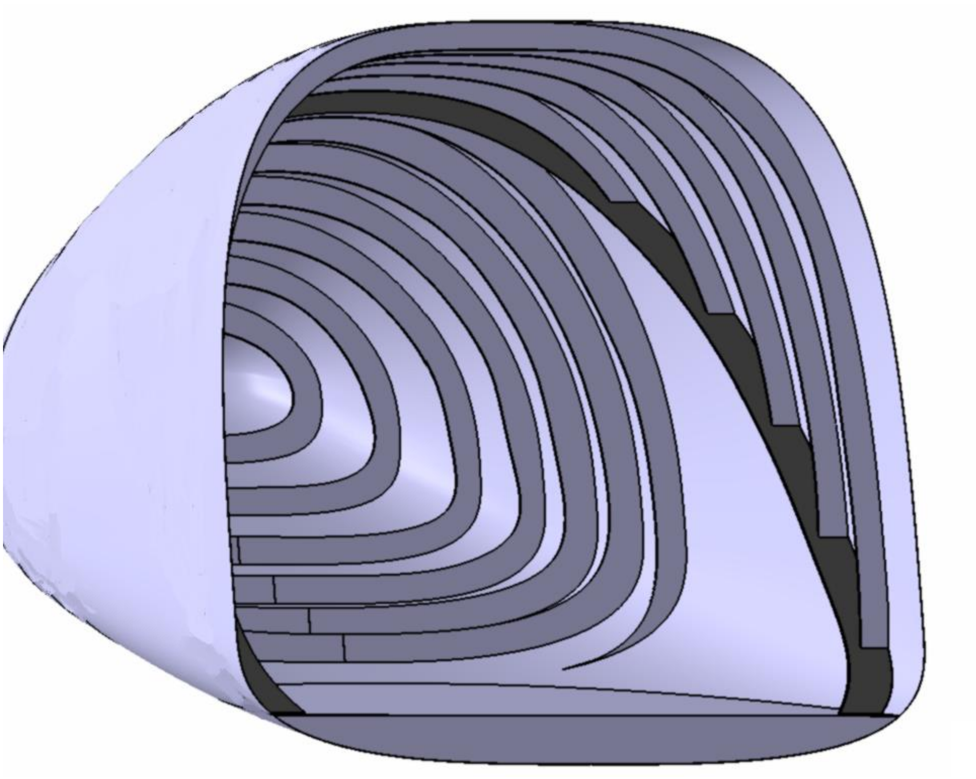

Illustration 88: Tail with all formers

It is worth to mentions that all the formers crated until now, the ones that belong to the side gates and those created in this section, have been modelled in planes parallels to the plane “XZ”, which are perpendicular to the aircraft axis. This fact, of course, has been an assumption, but as it was said, there is not accurate enough information about the inside of the tail to know the inclination of the formers properly. For the same reason, it has been also assumed that the inclination of the oblique former corresponds with the contour of the side gates.

4.3.2.5. Ceiling structure

Attached to the ceiling, there can be found a solid structure at the beginning of the tail. Such structure has been modelled with *pads* in order to facilitate its creation. Although the curvature of the ceiling is anything but constant, there has been created a first thin *pad* that would define the down side of the structure, afterwards, the top side of the geometry created has been applied another *pad up to surface* in the “Z” axis direction.

The result is the one shown in the next image.

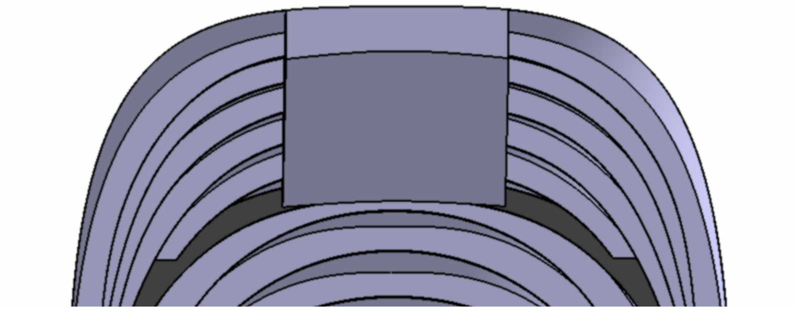

Illustration 89. Ceiling tail structure

4.3.2.6. Side gates longerons

On the photograph there can be seen two longerons attached to the down side of the side gates area, however, it has been assumed that there are two more longerons attached to the ceiling, in line with the ceiling structure defined.

To model the longerons, it has been created a line from the former that defines the starting point of the longerons, to the former that marks the final point of them, parallel to the “Y” axis, and it has been projected on the desired points of the surface. Once these curves over the surface have been obtained, the longerons have been created by modelling a *sketch* with the shape of the longeron profile, and using a *rib* on such *sketch* and the projected line. Two of the longerons have been created this way, the other two have been generated with the command *mirror*.

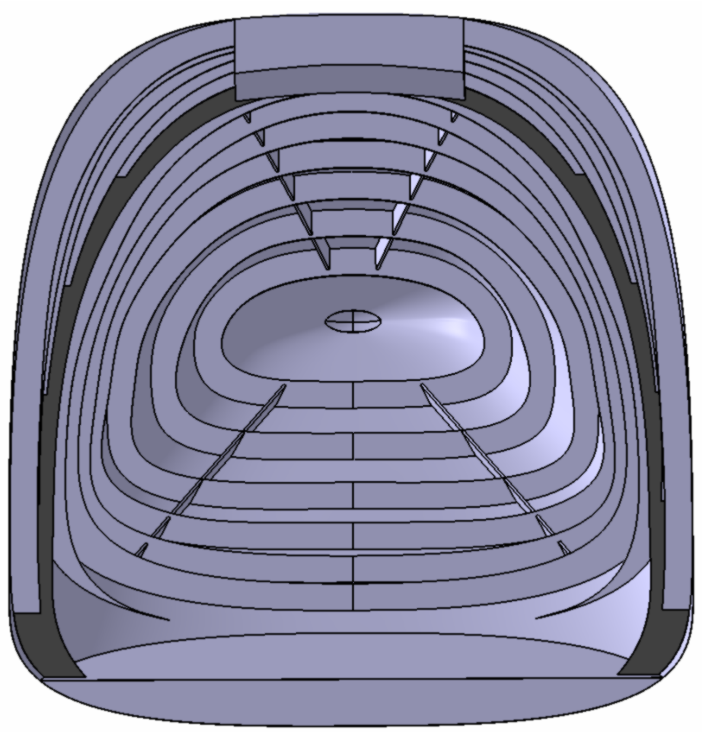

Illustration 90: Side gates longerons

4.3.2.7. Other longerons

The rest of the longerons have been modelled in the exactly same way that the previous ones, creating a line, projecting it and doing a *rib* with the desired *sketch*. In that case, the ending point is set by the oblique former.

The right side longerons have been generated with the command *mirror*.

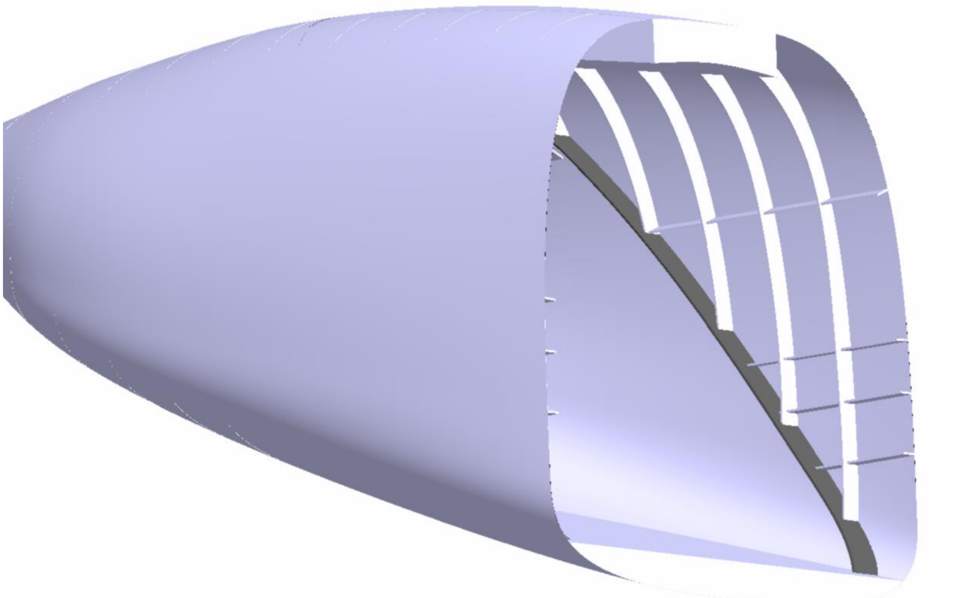

Illustration 91: Tail with all longerons

4.3.2.8. Tail to fuselage former

It can be observed that in the plane that separates the fuselage from the tail, there is a bigger former, as it was not modelled as a part of the fuselage, it will be designed here. It has been created with a *pad*.

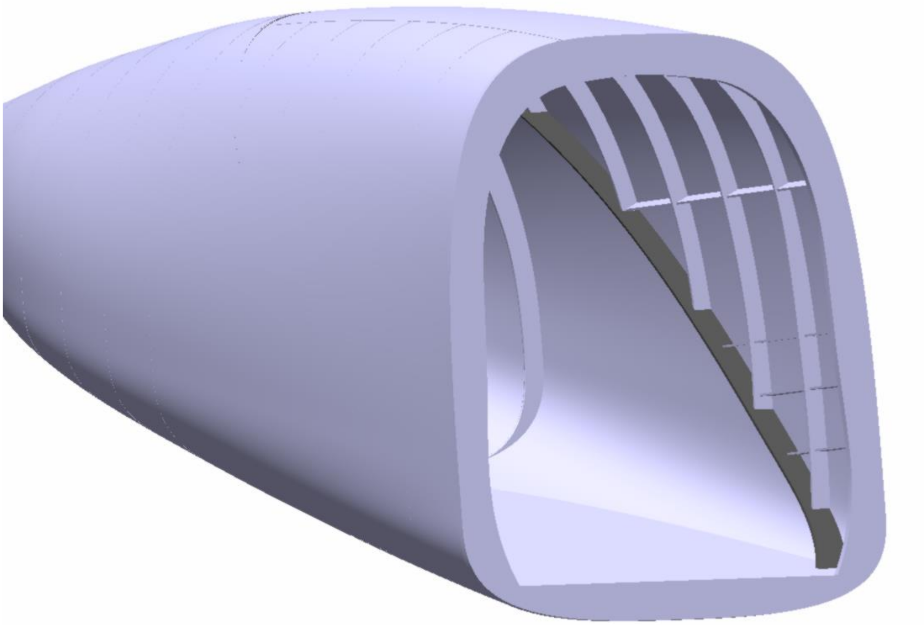

Illustration 92: Tail to fuselage former

4.3.2.9. Sliding platform

Finally, it has been modelled the platform which can be seen at the end of the floor. It is a sliding platform that relies on the floor when the gates are open. Its main task is to act as a ramp for the vehicles to be able to enter the fuselage. It has been created with the commands *pad* and *pocket*. The other sliding platform has been done with a *mirror*.

It is worth to mention too that, although there will not be animations in this project, there have been applied some *pockets* of 1 mm along the curves that would define the contour of the gates, its use is merely descriptive.

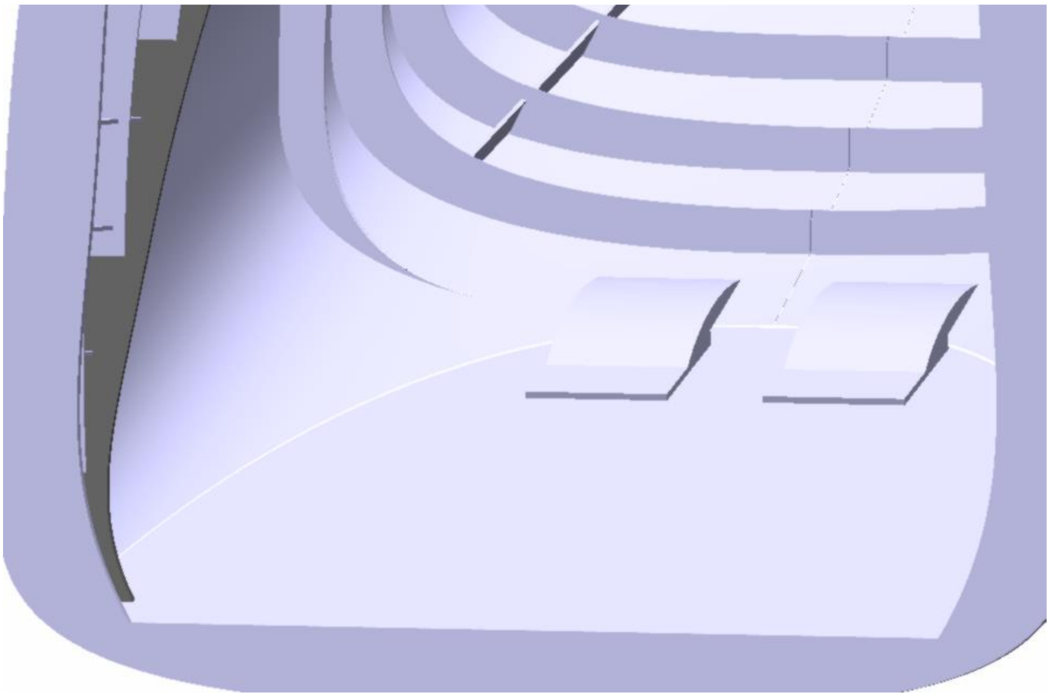

Illustration 93: Sliding platform

With this, there have been defined all the elements inside the tail.

4.3.3. Stabilizers

Once again, to model the stabilizers it has been firstly used the module *generative shape design*, therefore, by creating *sketches* with the desired profiles and projecting them on the surface of the tail with the command *project*, there have been defined all the extremes of the stabilizers attached to the tail. If there are created, on the required positions, more *sketches* that define the opposite side of the stabilizer and some other which define some guides, there can be easily some *multi-sections surfaces* to obtain the stabilizers.

This way, having generated the respective projections, *sketches* and *multi-sections surfaces* for each stabilizer, as well as having used the command *fill* to close the open profiles, the obtained result is shown in the following illustration.

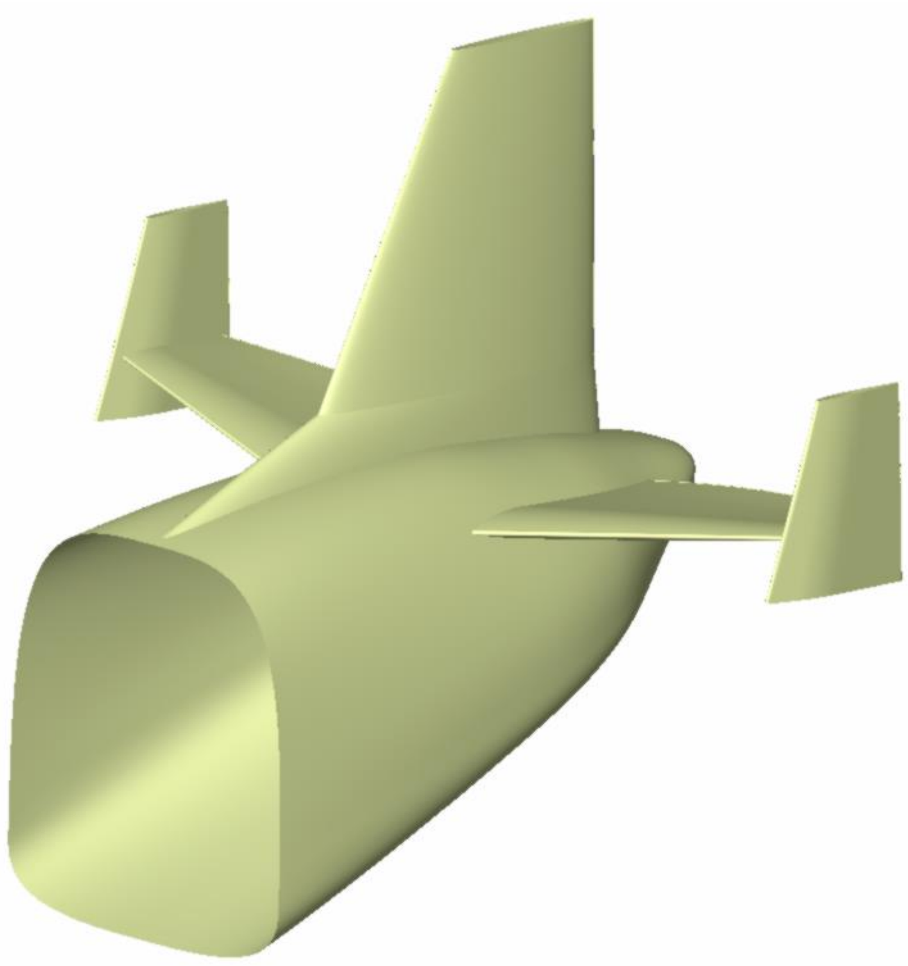

Illustration 94: Stabilizers surfaces

Once this surface has been achieved, the last task is to give the new obtained surfaces some thickness, what can be done in the module *part design* with the command *thick surface*, apply some curvature to the edges generated by using *edge fillet* and there have also been used some *mirrors*, as these operations were only applied on one side.

The final result then of the complete tail with its stabilizers is the one see on the image below.

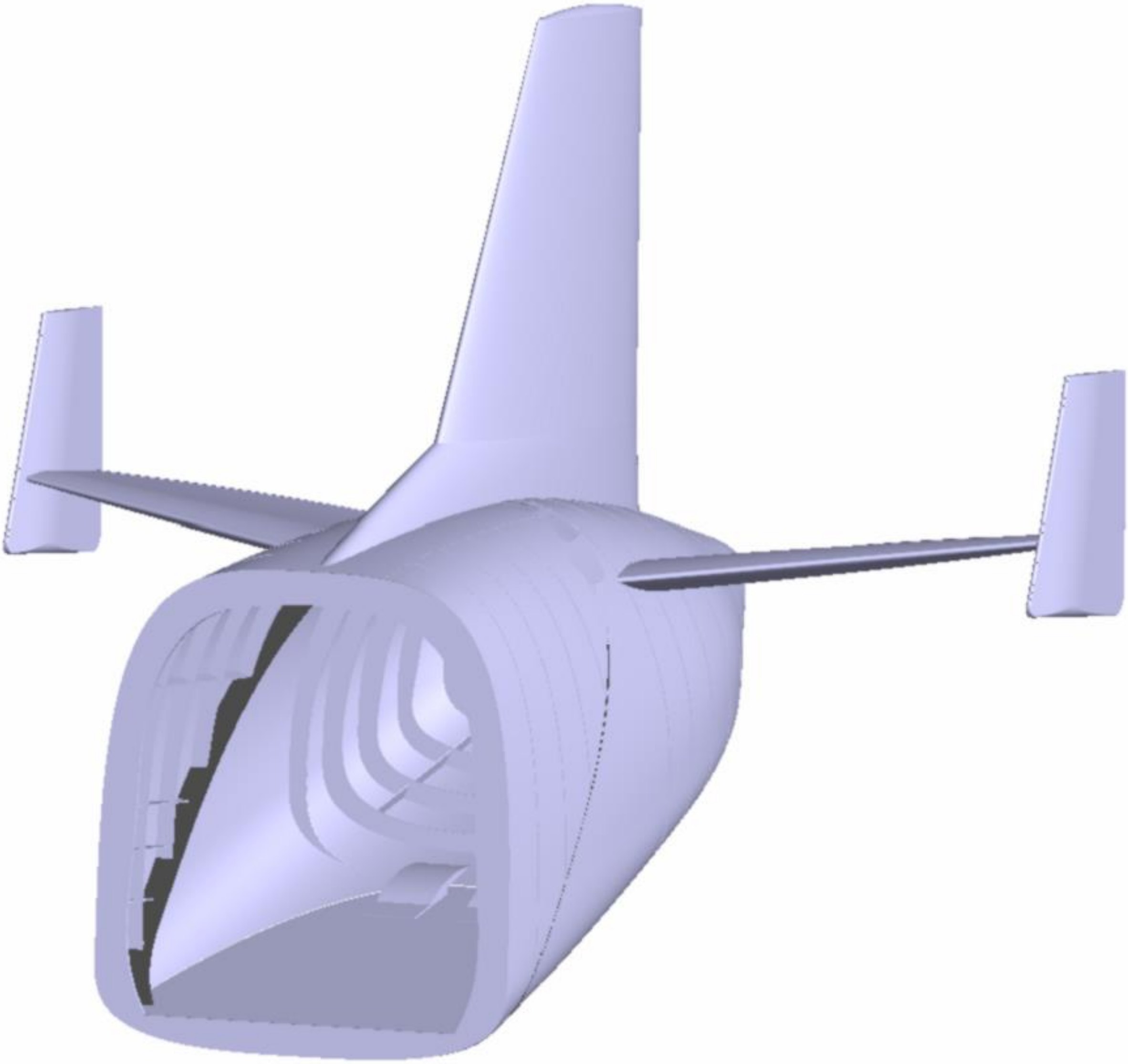

Illustration 95: Tail fully modelled

4.4. Wings, rotor systems and other structures

In this section there will be modelled any other external element that can be observed in the image below, from the wings to the landing gear.

Illustration 96: Mi-12 photograph

In this case, if it was required to define the area that is going to be modelled in the blueprints, it would be everything inside the red perimeter.

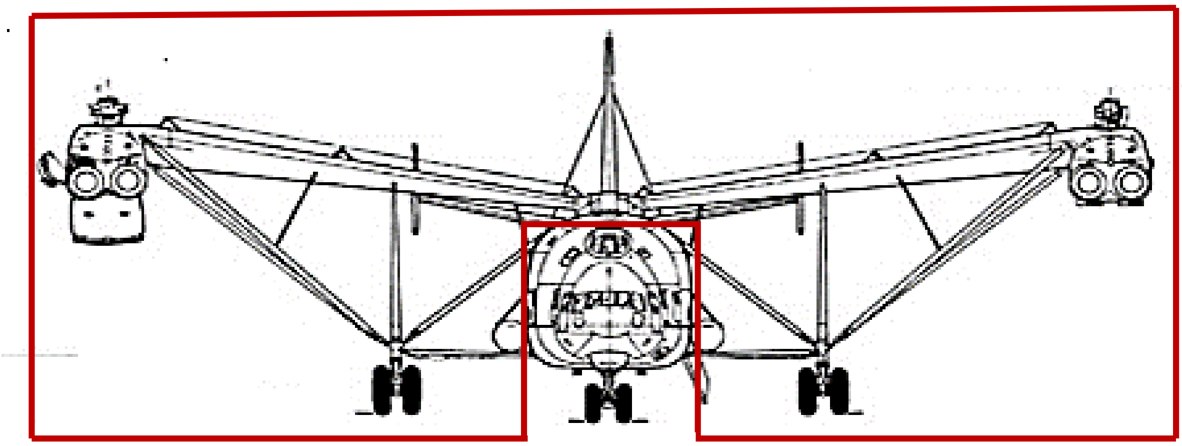

Illustration 97: Outer elements pointed out in the blueprints

As well as it happened with all the previous sections, once all the elements of this sections have been created, the objective is to assemble them with the fuselage, for this reason, any geometry created, must be generated being conscious of the fuselage shape. In order to do so, the first thing done it has been to create the surface that defines the outside of the fuselage.

4.4.1. Wing box

With this starting point, the first task has been to create the wing box, which is attached to the top of the fuselage. Making use of the blueprints, the first step taken was to define the shape of the wing box in a *sketch* in the "XY" plane and *project* it on the upper side of the fuselage. Then, as it was done with the closure surface of the tail, there have been created two curves defining the lateral and the front projection of the wing box. After that, there have been generated four *fills* with the obtained curves, leading the procedure followed to the following result.

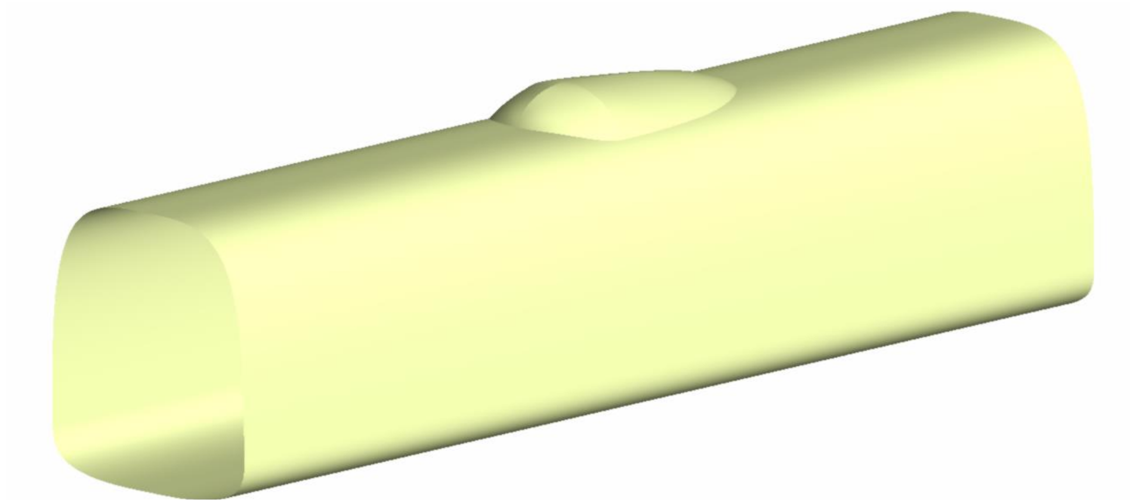

Illustration 98: Wing box surface

In this case it cannot be used the command *thick surface*, because if it was done, the solid generated would go through the fuselage. For that reason, what has been done is use the command *split* on the fuselage surface, with the projection previously created, keeping both sides, then, use the command *join* on the obtained surface and the four surfaces that defined the wing box. Once these operations have been done, the wing box will have been defined like a fully closed surface, so now, it has been used the module *part design,* specifically the command *close surface* to make a solid from the surface.

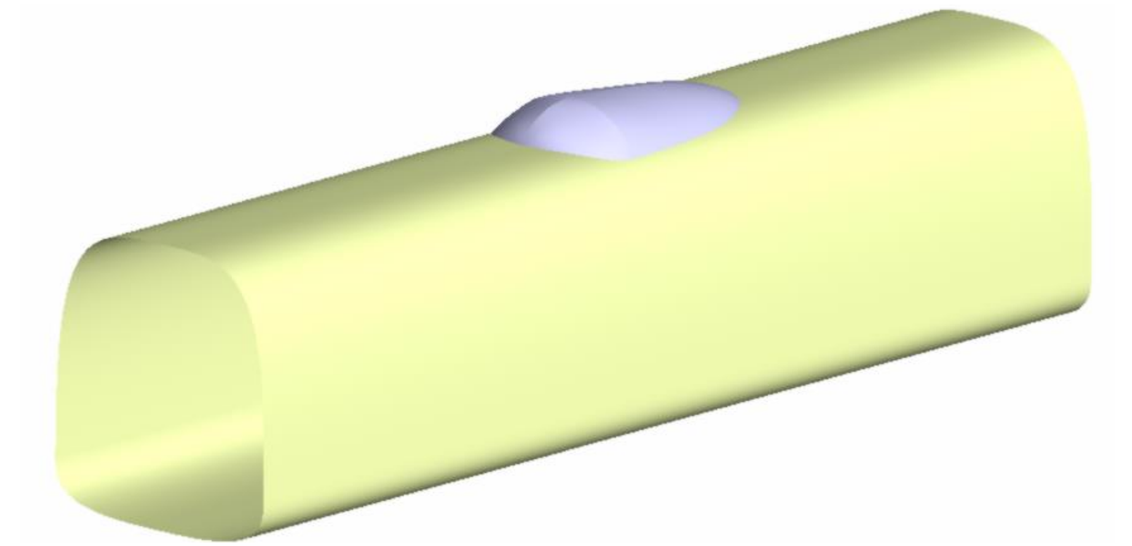

Illustration 99: Wing box

4.4.2. Engines

The next element modelled have been the engines. In this section it will be explained the design process of one engine, having been the other one modelled in an analogue way, as it could not be done with mirrors.

First of all, the engine has been divided in two parts, one of them is some cylinder with an elliptic section and variable size of the profile along its length, the other one is the structure that links the wing and the engine.

To create the first mentioned part, there have been created a *sketch* with the profile, and two more with one guide each, afterwards, it has been used the command *sweep* with the profile type "*explicit*" and the subtype "*with two guide curves*", the *sketches* and the resulting surface are shown on the following images.

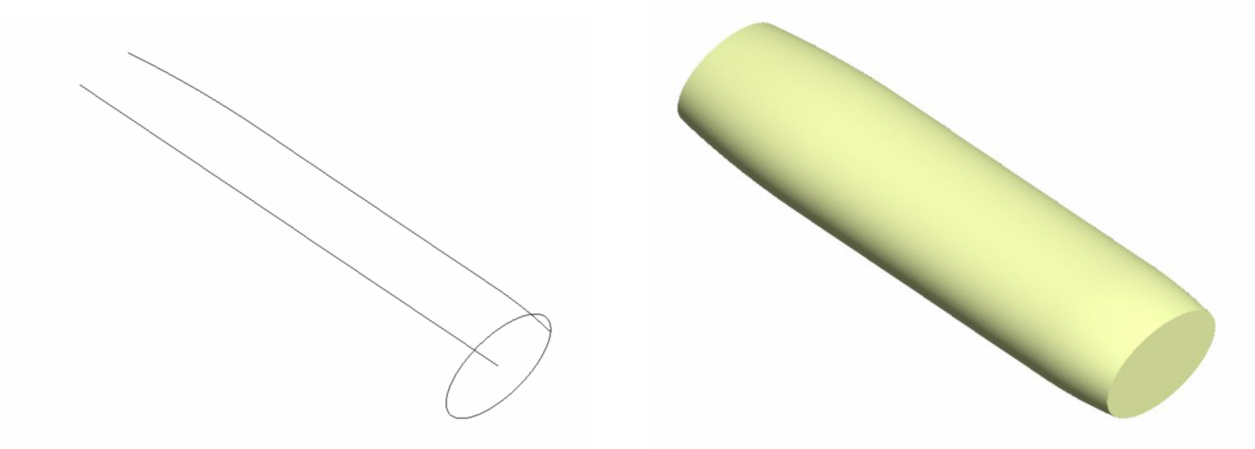

Illustration 100: Engine sketches and surface (1)

To generate the second part of the structure there have been created three guides, two of them are the lines defined by the sides of the already created surface, the last curve is contained in the vertical plane of symmetry of this same surface and it will have the exact shape of a wing profile (profile of which will be talked in future sections), but a size a little bit higher. Once the three guides have been created, it is going to be generated a *sweep* with the profile type "*circle*" and the subtype "*three guides*", obtaining the following result.

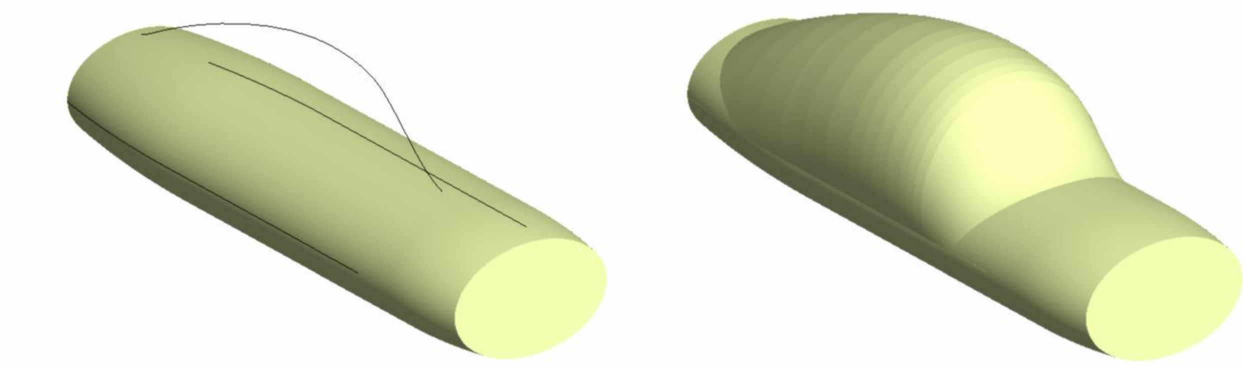

Illustration 101: Engine sketches and surface (2)

Finally, to make a solid from the designed surfaces, the first one has been closed, as it has already been done, with the commands *fill* and *join*, and then it has been applied a *close surface* on the generated geometry. With the second surface it has simply been applied a *thick surface*.

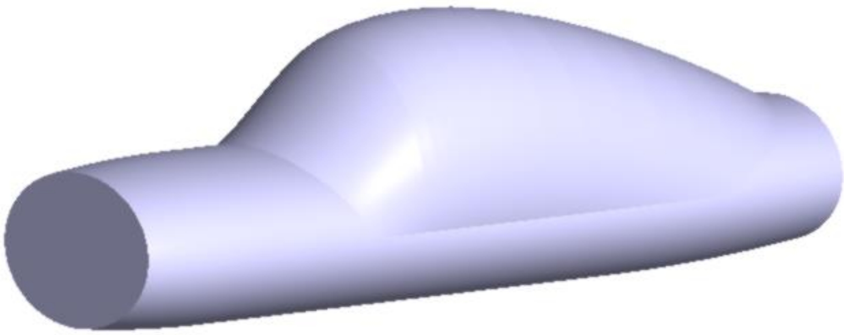

Illustration 102: Engine solid

4.4.3. Wings

Regarding the wings, the only available information about the shape of its profiles was the section shown in the blueprints.

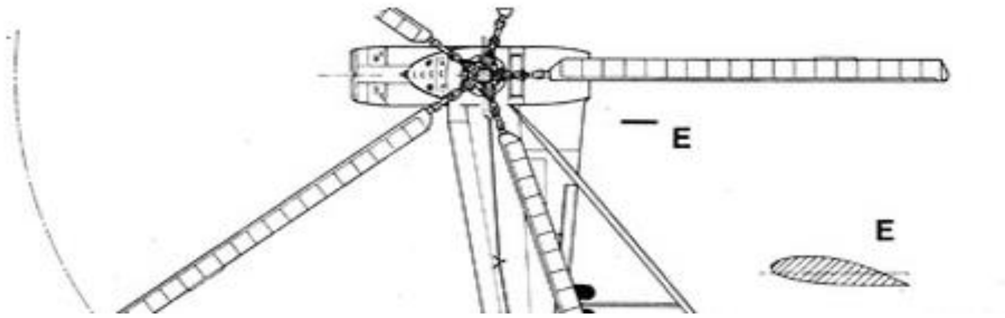

Illustration 103: Wing profile blueprint

However, despite it seems that this information is more than enough, if it is taken into account that the measures taken from the blueprints are never exact, and being aware that it is almost impossible to simulate an irregular profile such as that in CATIA, the result is that the profiles created were quite far from the one shown in the blueprints, no matter how many tries were made.

For this reason, after a process of research, another method was applied.

There is a web on the net (whose name has been mentioned in the section "references") which contains the data of many aircraft profiles. It has been found out that the wings in the aircraft Mi-12 have a NACA4421 modified profile, however, as it has not been possible to find a modified profile, it has been decided that the most similar profile to the real one is the NACA4418. The data of any profile consist on two columns, one with the X coordinates and the other with the Y coordinates of a set of points.

In order to be able to use these files, there has been downloaded a program called "Profscan", which can represent this type of files and, what is more, it can generate a .DXT file out of them, which is compatible with CATIA.

By doing this, it has been possible to generate the exact shape of a NACA4418 profile in CATIA and use it to model the wings.

Illustration 104: NACA4418 profile

It is worth to mention that it has been assumed that there is no torsion along the wing, as the angle of attack of the profile has been designed to remain constant.

Once the desired profiles have been obtained, the next task is to *project* this profile, with the desired sizes, on the engine and the wing box, and create a *multi-sections surface* using such projections and some guides to obtain an accurate surface.

Finally, with the surface obtained, it is applied the command thick surface to obtain a solid wing.

With all this processes completed, the resulting geometry is the following one.

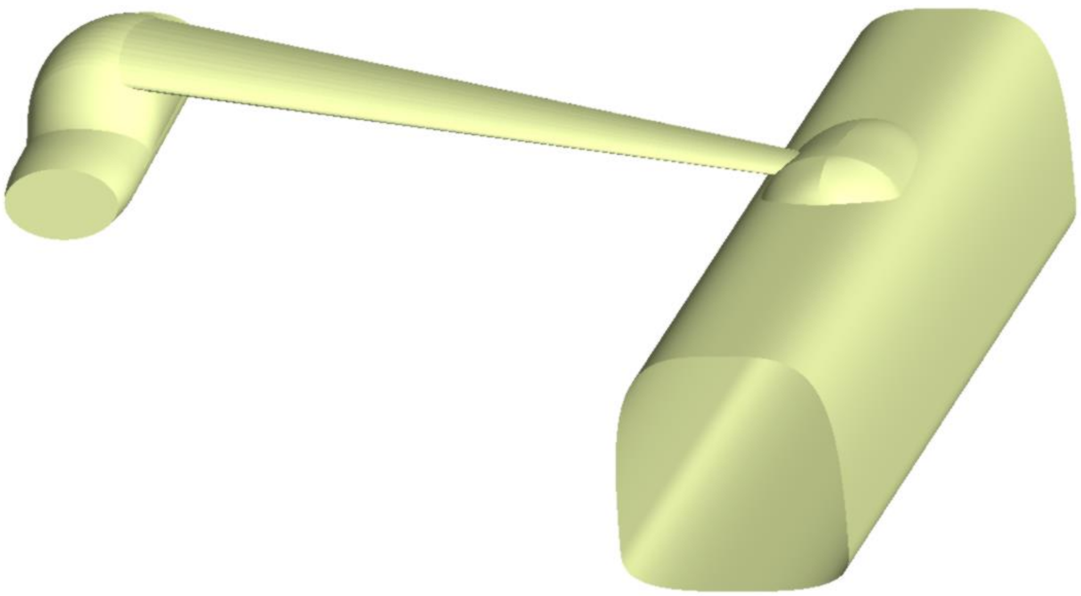

Illustration 105: Wing surface

And now, adding a thickness to such geometry, and seen all the solids created together, the following image represents the obtained result.

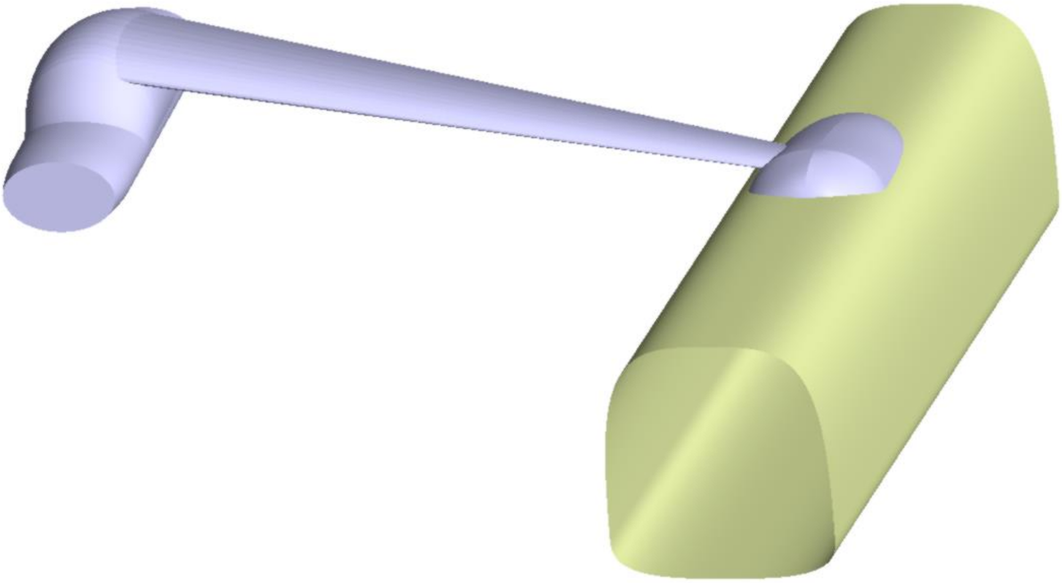

Illustration 106: Solid wing

4.4.4. Engine details

In this section it will be used the module *part design* in order to generate the air intakes, the nozzles and other details of the engines.

In order to create the air intakes and the nozzles, there are going to be applied a set of *pockets*, which will be painted in black color. To generate the surface of the nozzle, it has been done with a *rib*, and the resulting geometry has been painted in dark blue. The shape around the intake has been simulated by doing a *slot*, and the geometries on the back of the engine have been modelled with *pads*.

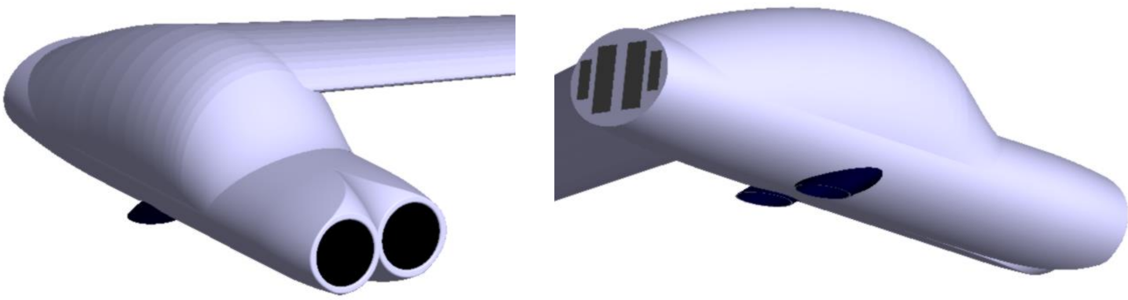

Illustration 107: Detailed engine

4.4.5. Rotors

The first thing that has been designed of the rotors is their connection to the engine. It is composed by a set of rods, a wide one in the middle (the rotor mast) and five small rods around it (the control rods). All these rods have been modelled with *pads*, and such elements are attached to the hub, which has also been created with a *pad*, and that is supposed to connect the engine and the rotor blades.

The beginning of the rotor blades has been modeled like a cylinder with a *pad* and reproduced with the command *circular pattern.*

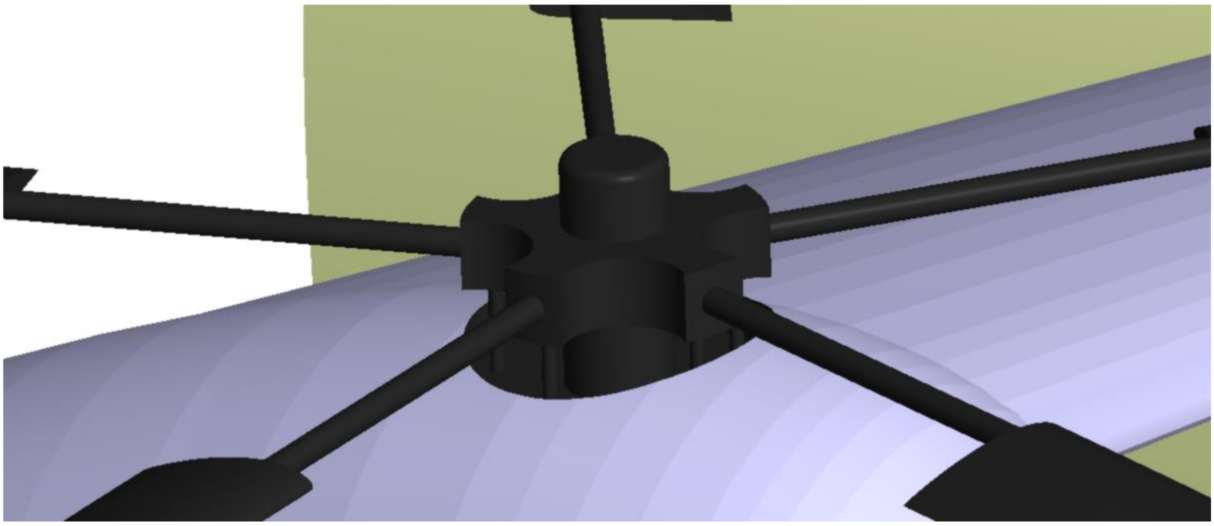

Illustration 108: Rotor

There are some things worth to be said before explaining how has been generated the rotor blades.

First at all, as well as it was done with the wings, the rotor blades have been designed with a NACA profile, but the profile chosen has been the NACA4415, and again, the angle of attack remains constant along the rotor blade length.

Illustration 109:NACA4415 profile

The exposed NACA profile applied to the rotor blade looks like it is shown in the next image.

Illustration 110: NACA4415 section

Moreover, although only one side of the aircraft is being explained due to the symmetry of the helicopter and all the previously created elements can be *mirrored*, it has not been done with the rotors for two reasons, the first one is that, as it can be seen in the blueprints, the length of the rotor blades is higher than the distance from the rotor to the symmetry plane of the aircraft, what implies that, if the rotors were symmetrical, the rotor blades would crash. The second reason is that, as it was explained mentioned in the general information about the Mi-12, one of the rotors rotates clockwise and the other one anti-clockwise, and the rotor blade profile has a leading edge and a trailing edge, so the orientation of the profiles of one rotor is the opposite to the orientation found in the profiles of the other.

However, although all these facts have been taken into account in the modelling of both rotors, there will be only explained the creation of one of them, as the procedure is analogue in the other one.

Finally, in the blueprints it can be observed that the rotor blades have a certain curvature, in order to model that, it has been created *sketch* with such curvature, and it has been applied a *rib*, with the NACA4415 profile as the chosen section to *rib*, and the created *sketch* with the defined curvature as the guide.

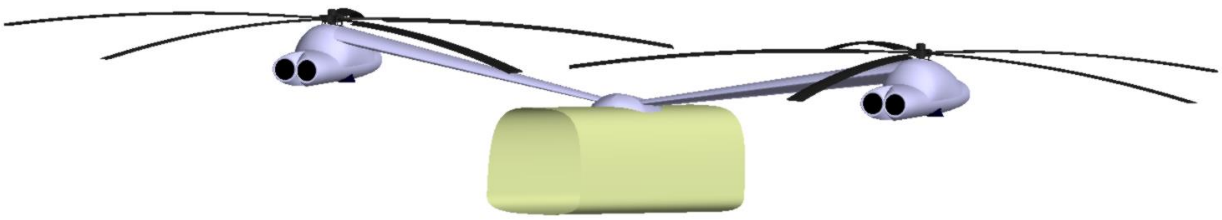

Illustration 111: Rotor (2)

4.4.6. Landing gear and rods

The landing gear has been modelled with the exactly same method applied and explained for the wheel of the nose, which consists on using a few *pads* and a *rib,* so there will be no further explanations in order to avoid redundancies.

Regarding the rods, there can be found several rods connecting the landing gear with the fuselage, the wings, the engines or even the rear side of the fuselage.

However, there are mainly three kind of rods, and all of them have been defined in a similar way.

First at all, to create all the rods, there have been define two points for each rod, one at each endpoint of the rod to be designed. Once the two points have been created, it is time to generate a line which has those points as endpoints. Now, depending on the kind of rod required, there have to be one (in the middle of the line), two (in both endpoints) or three (in the three mentioned positions) planes.

For the rods of the type 1 (1 plane), there will be no variation on the size of the profile along the rod, so it will be modelled with a single *pad* up to both surfaces. For the type 2 rods, the rod will be wider in one extreme and thinner in the other one, so for this kind of rods there have been designed two different profiles, one at each endpoint (and each one with a different size), and it has been applied a *multi-sections solid* to them. Finally, the third type of rods is a mixture of the other two, most of the rod has a constant section, but it gets thinner in the endpoints. To recreate these rods, it has been modelled a profile in each plane, being the one of the middle larger than the others, it is applied a *pad* to the bigger profile, mirror extended and up to a certain distance from the endpoints, now it has been used the command *multi-sections surface* to join the resultant extremes of the *pad* with their respective endpoint *sketches.*

Once the landing gear and the totality of the rods have been modelled, the result is the following one.

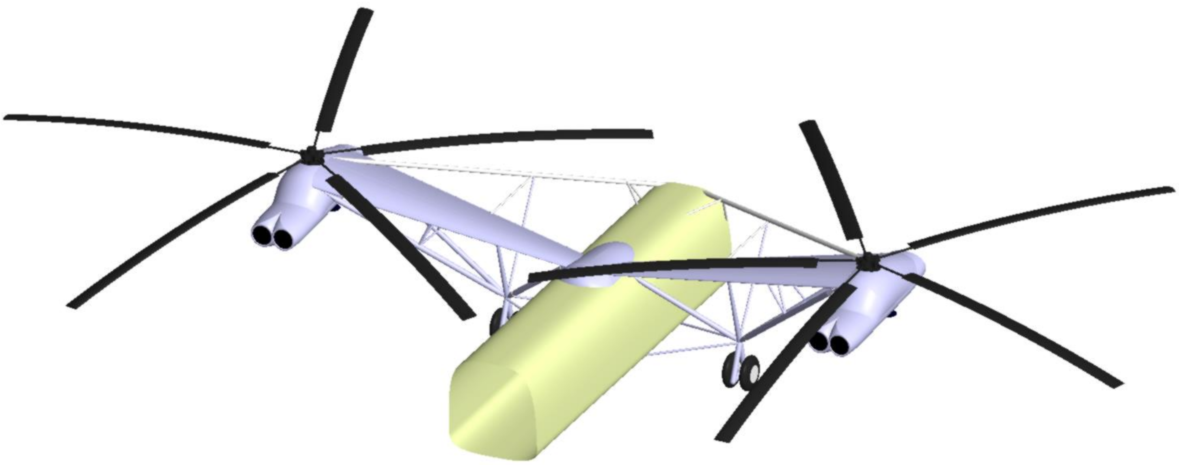

Illustration 112: Landing gear and rods

4.4.7. Fuel tanks

The only remaining elements to be modelled are the fuel tanks.

The fuel tanks have been modelled with a *pad* and some *edge fillets*, regarding the rods that join the fuel tank and the fuselage, each of them have been designed like it was explained in the previous section, and all of them are “type 1” rods, using the same nomenclature.

It is worth to mention that the connection from the fuel tanks to the engines has not been modelled. The fuel tanks are connected to the fuselage, so the fuel transport system is probably inside the body, and it is one of the areas that has not been modelled due to the lack of information. A photograph of a fuel tank can be seen below.

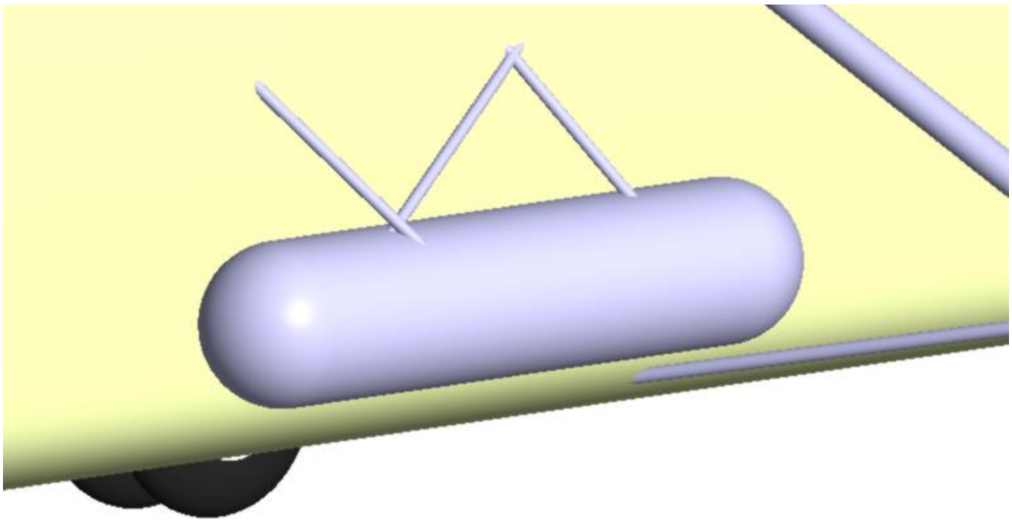

Illustration 113: Fuel tank

Therefore, the final result, with all the details and outer structures included, can be seen in the next image.

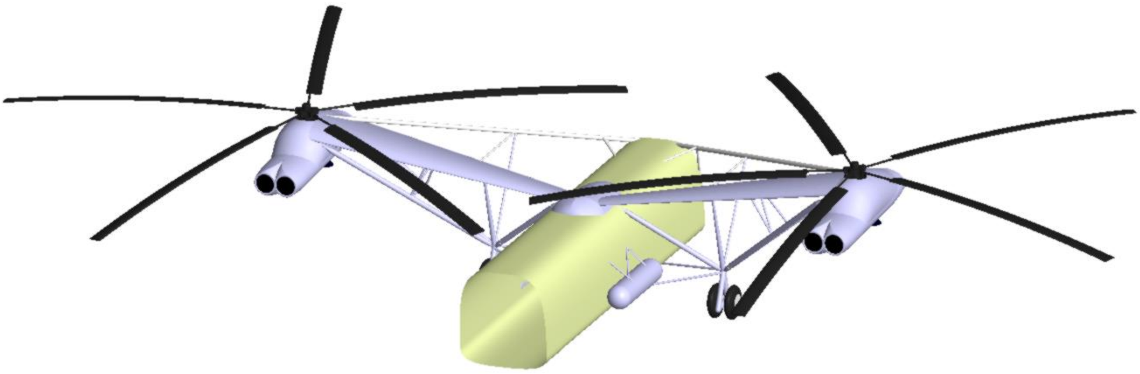

Illustration 114: Outer systems and structures

4.5.Mi-12 assembly

By this point, all the parts in which the aircraft has been divided are completely modelled, both externally and internally, and with a great level of accuracy. It is time then to create a *product*, what will make it possible to join the different *part designs* previously created.

In order to do so, the first part called from the library has been the fuselage, and its position has been fixed because, as it was said, the whole aircraft has been built around the body. Afterwards, the rest of the parts have been added to the fuselage, imposing *contact* and *parallelism constrains* between them and the fuselage, not allowing any kind of displacement.

Illustration 115: Front view of the aircraft

Illustration 116: Back view of the aircraft

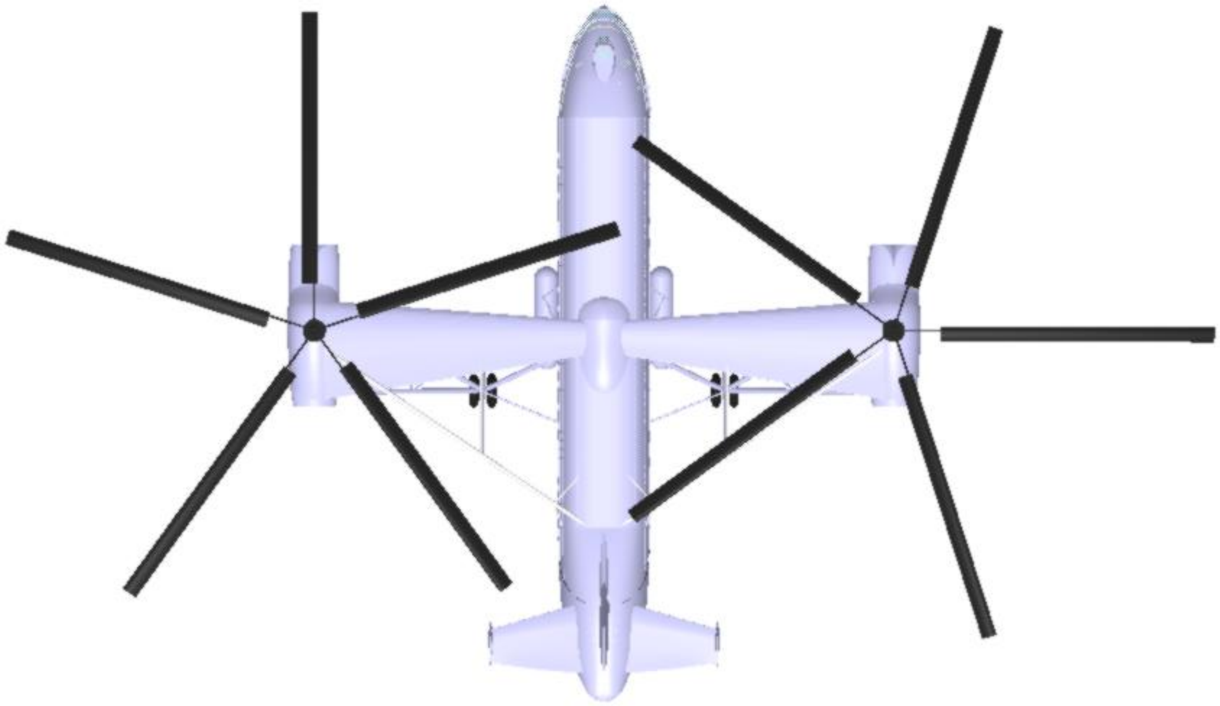

Illustration 117: Plant of the aircraft

In the next images it has been put the created model of the Mi-12 in different backgrounds, in order to see how it would be in the reality if the 3D model was manufactured.

Illustration 118: Rendered image 1

Illustration 119: Rendered image 2

Illustration 120. Rendered image 3

5. Conclusions

One of the main difficulties found during the creation of this project has been the low number of blueprints whose accuracy and detail level was enough to allow their users the possibility to obtain in a detailed way the main geometry of the elements. For this reason, as it has been explained during the project, many times it has been necessary to make some assumptions or approximations by using low quality photographs or even paintings which can be found on the net.

Another difficulty has been the use of some modules that have not been widely explained during the degree. For example, the main structure of each part and most of the wings and engines have been modelled with the module *generative shape design*, however, it has been both a disadvantage and an advantage because, although it has been necessary to spend a great deal of time to learn how to use these modules properly, at the end of the project, the experience gained is quite notable.

As improvement proposals, it could be suggested the implementation of some animations in the moving parts of the aircraft, which are the rear gate, all the doors, the rotors and the flaps and spoilers. Also, as it has been mentioned many times along this project, because of the lack of information, there has not been modelled anything under the floor of the aircraft, neither some of the helicopter systems such as the hydraulic system, the electrical system or not even the inside of the engine so, if it was able to access to such information, it would be advisable to model those parts too. Finally, although it is not a modelling proposal, it would be interesting to make an aerodynamic and structural study of the model by using some different softwares.

At last but not least, it is worth to mention that every personal goal self-imposed during the project implementation in terms of gaining experience in the use of CATIA and related to the level of detail of the final result has been satisfactorily accomplished, so it can be concluded that the time spent has been worth it and the overall balance is positive.

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Illustration 7: https://www.the-blueprints.com/blueprints/helicopters/mil/76287/view/mil_mi-12_homer/

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Illustration 76: https://commons.wikimedia.org/wiki/File:Tail_Gate_of_Mil_Mi-12_(8911208511).jpg

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