AirCargoChallenge 2022

Technical Report

Team #15

Team Albatross

Technical Report

TEAM ALBATROSS, TAMPERE UNIVERSITIES

1 INTRODUCTION

This Technical Report explains the outline for the project management of the competition team Albatross. Additionally, the design of the competition aircraft is explained with specific information about aerodynamic and structural design and a prediction of the payload the aircraft can carry.

The design of the ACC competition aircraft began by exploring different configuration variations. After analysing the most promising variations against limiting factors, such as buildability, a rough force calculation was done using OpenVSP. The final concept was chosen, also considering the preference to build an unconventional aircraft. Therefore, The Team decided to build a blended-wing aircraft. Optimisation of the concept was continued using OpenVSP.

The project has been, at the same time, motivating and stressing. The Team has learned a lot about the designing process of a UAV, and the theoretical knowledge has finally been put to use. When the Team has not been able to meet physically, the project has put stress on many. However, now it seems that the process is flowing. If the fearless concept corresponds with the design, the result could be a success.

2 PROJECT MANAGEMENT

This chapter explains the outlook of the project management of the competition team Albatross. The 7-person Team has experienced changes in its composition due to the elongation of the competition. The composition of the Team is explained in this chapter. Further, the financial budget and time schedule are introduced.

2.1 TEAM COMPOSITION

The composition of the Team Albatross has evolved during the competition. All of the members are students from Tampere University, and most of them study Mechanical engineering. However, there are a couple of Aeronautical engineering master's students and students from electrical and automation faculties. We all share the same passion for aviation. Currently, the Team has seven members:

- Otto Harrikari (Team leader),
- Aaro Huuhka,
- Lauri Pitkäjärvi,
- Akseli Arola,
- Lauri Mäntypuro,
- Sami Vapola and
- Jouka Ahponen.

The Team was originally divided into groups, where each of the groups had an individual leader. The groups were for:

- Construction,
- Technics,
- Modelling,
- Promotion,
- Mechanics and
- Aerodynamics.

Further in the process, the teams merged due to changes in the team competition. Currently, the positions vary depending on the expertise in the task. Two of the team members participated earlier in the competition, and those two are experienced model aircraft builders. Their expertise is utilised in the building process. Aerodynamics has been the task mainly of the aeronautical engineers.

We have experienced challenges in the organising also induced by the covid. Most of the students were capable of joining the competition during the second or fourth year of their five-year studies. Due to the prolongation of the competition, most have been writing their thesis during the final moments of the competition.

2.2 Financial budget

The participation of the Team Albatross to Air Cargo Challenge is financed through the local association EUROAVIA Tampere. This project's income consists of two sources: funds leftover from Team Albatrosses New Flying Competition 2019 participation due to our withdrawal from the event, and support from EUROAVIA Tampere. Tampere University, Dunderberg Foundation, QOCO Systems Ltd and Kelluu Ltd sponsored the NFC participation, and they all approved that the remaining funds can be used in ACC2021.

Income:

Remaining NFC2020 funds	3100 €
Support from EUROAVIA Tampere	750 €
Total income:	3850 €

Expenses are composed of participation fees, building costs and travel expenses. These amounts are still estimates because, for example, flight tickets have not been purchased yet. On building, components like servos and AXi motor can be taken from our previous ACC plane, which saves money.

Expenses:

Building	1000 €
Travel	2000 €
Participation fees	1750 €
Total expenses:	3850 €

So our budget is well balanced. EUROAVIA Tampere can easily support the missing 750 €, because our association's general financial situation is also good.

2.3 Time schedule

The project began in September 2019. The Team held biweekly meetings for the outlook of the process until spring 2022, when the meetings were held weekly. Autumn 2019 was used to organise the project. When the Team was divided into groups, the groups continued working alongside the biweekly/weekly meetings. The Team continued working actively until the 2021 competition was postponed. A lack of motivation was noticeable, and the Team then decided to return to action in autumn 2021, when the design of the prototype started. Designing and production of a hot-wire cutter caused a delay in the process and the

3 Structural analysis

The aircraft is an unconventional blended wing aircraft. However, the structural analysis is performed on the same principles as a conventional aircraft. The length of the septagon-shaped body of the aircraft is 650 mm, and the width is 400 mm. The body will be mainly carbon fibre coated and supported with balsa wood.

The most stressed parts, wings and tail booms are supported by carbon fibre tubes. The stress calculations are provided below.

3.1 Wings

Balsa wood ribs transmit the load in the wings to the main load-carrying components of the wings, carbon fibre spars. The wing loading was modelled with OpenVSP, and it presented the lift coefficient Cl times the local chord c per the mean aerodynamic chord Cref = 0.331 mm as the function of the distance from the centerline Yavg.

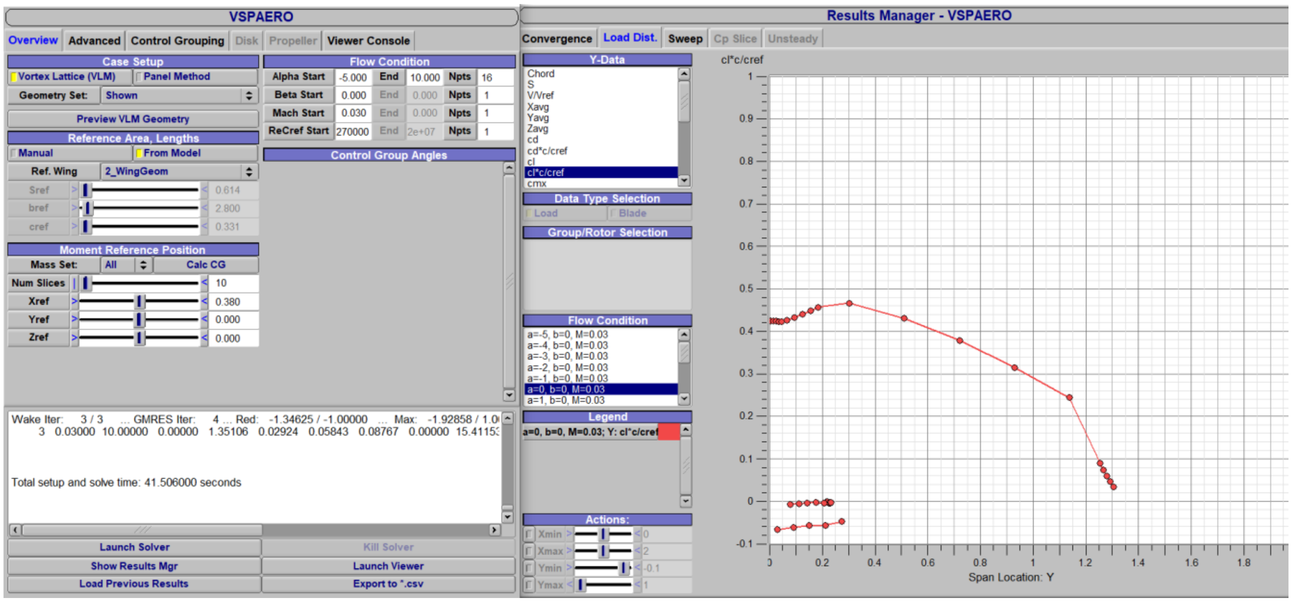


Image 1: OpenVSP settings and the spanwise Cl values used for structural analysis.

The moment at the wing root was calculated with a Riemann-sum. The function is presented below:

$$M_x = \sum_{i=1}^{n} f(x_i^*)\Delta x_i,$$

where the wing was divided into n spanwise parts and the x_i^* presents the distance from the wing root. The function to be summed is the lift times the distance from the root:

$$f(x_i^*) = L \cdot x_i^*$$

The lift calculated for a spanwise part was calculated with a general lift formula:

$$L = C_L \frac{1}{2} \rho V^2,$$

The C_L represents the coefficient of lift. The values for the coefficients were exported from OpenVSP. Standard atmosphere density $\rho\ = 1.225\ \frac{kg}{m^3}$ and a conservative speed of $V\ = 20\ \frac{m}{s}$ was used in the calculation.

The result of the calculation showed that the moment in the wing root is $M_{x,root}\ = 25.13$. The moment in the centerline of the aircraft is not much greater, resulting in $M_{x,0}\ = 25.41$.

The maximum bending stress of the spars can be calculated with the following formula:

$$M_b = \frac{R_m \cdot I}{y},$$

where the R_m is the ultimate strength of the carbon fibre, I is the bending resistance of the profile, and y is the distance from the centre of the profile. The bending resistance for a circle profile can be calculated with the following formula:

$$I = \frac{\pi \cdot (R^4 - r^4)}{4},$$

where the R is the outer radius of the profile and r is the inner radius. The load is carried by carbon fibre spars, with an outer radius of 7 mm and an inner radius of 6 mm.

The manufacturer reported that the ultimate strength of the carbon fibre tubes used is 4900 Mpa. The maximum bending stress that the tube can withstand is then 607.51 Nm at the outer surface of the tube. The strength of the tube is well beyond the required strength.

3.2 TAIL

The tail is constructed in the same fashion as the wings. The balsa wood is considered to withstand the relatively light lift forces of the tail surfaces. However, the load for the tail booms are calculated. The forces caused by the tail surfaces are determined in the maximum lift condition, and the calculation was conducted as for the wings above. The maximum lift for the tail is calculated to be 8.08 N.

The length from the furthest point of the tail to the boom root at the wing is 750 mm. By using the lift formula above, the moment of the tail results in a moment of 6.0563 Nm. The carbon fibre tubes in the boom are similar to the tubes in wing spars. Therefore, the maximum bending stress for the tail boom is 607.51 Nm.

4 AERODYNAMICS

After studying the scoring formula of the flight competition, we chose to emphasise the rate of climb: The aircraft should be able to reach 100 meters or get very close to that altitude in 60 seconds. The aircraft's climb rate depends on the vehicle's excess of thrust, i.e. how large force is available to counter gravity after countering the drag. As the competition rules determine the powertrain, the aeroplane was designed accordingly to minimise drag. This way, we also hope to achieve high speed as well, the maximum payload being of secondary importance.

Many different concepts were presented and discussed, including conventional configuration, biplane, and tandem wing configurations. Finally, we chose to build unconventional aircraft with twin-boom configuration and inverted V-tail, pusher propeller, and wide central section blending into relatively high aspect ratio wing. This configuration was chosen as we believe it utilises available space within the 1500 mm tetragon very well. There is no need to spare space in front of the aircraft for a tractor propeller, so the nose can be stretched quite forward. This moves the aerodynamic centre forward, which allows us to place the centre of gravity forward, making the aircraft's tail more effective and thus reduces drag. An additional benefit is that the long nose provides much room to move equipment inside the aeroplane if the centre of gravity needs to be adjusted.

It is hoped that positioning the propeller directly behind the wing may positively affect the flow around the central section of the wing, but this has not been validated. The blended wing configuration is hoped to be efficient and have a high lift to drag ratio.

The wing was built to have as high an aspect ratio as possible and practical to minimise the drag. The span of 2625 mm gives it an aspect ratio of 11.2. As about one-third of the aircraft's wing area is in the central section, the effective aspect ratio is expected to be much higher. Finally, relatively large winglets are to be installed into the wingtips to reduce induced drag further. NACA 3516 airfoil was chosen as a result of the OpenVSP-analysis. This profile provided the best L/D ratio while having enough thickness to ensure rigidity and a manageable pitching moment. The wing is set at an angle of 1.75 degrees from the central section, which corresponds to about 3.75 degrees angle of attack when trimmed for level flight. The wing has a mild 3 degree V-angle to provide some roll stability.

The central section utilises EPPLER 503 -airfoil. This airfoil was mainly chosen for its low drag and appropriate shape to house the cargo and all the required equipment. It also has a relatively small pitching moment coefficient, which reduces the loading of the tail.

The aircraft has an inverted V-tail at the end of a twin-boom structure. This layout provides clearance for the propeller in the chosen pusher configuration. The stabiliser's airfoil is an inverted NACA 0012. The stabiliser has a sweep angle of 25 degrees, and the angle between the left and the right stabiliser is 110 degrees. The booms connect to the wings at 303 mm from the centerline, and the tail is seated in between the booms.

We experimented with a more conventional configuration with a vertical stabiliser above or between two horizontal stabilisers. Still, after OpenVSP analysis, it appeared to perform poorly compared to the V-tail configuration. The sweep places the stabiliser as far back as possible within the allowed limits, thus making it more effective. In addition, we considered swept V-tail visually appealing. Inverting the tail rises it above the wing, thus reducing interference and drag.

An additional benefit of inverted V-tail is efficiency in yaw manoeuvres: When the conventional rudder or V-tail is offset left to make the aircraft yaw left, it will, due to its position above the centre of mass, also cause the aircraft to a slight bank to the right. Similarly, yaw to the right would cause the aircraft to bank left slightly, which usually needs to be compensated using ailerons. On the other hand, when an inverted V-tail is offset to the left, it would cause the aircraft to bank left and vice

5 PERFORMANCE

According to the OpenVSP -analyses, the aircraft has L/D ratio of about 18.2 with Cl = 0.5 and Cd_tot = 0.027 flaps up. Flaps down the values are approximately L/D = 18.9, Cl = 0.8 and Cd_tot = 0.045. Matlab & Simulink were used to estimate performance values. We expect the aircraft to reach a top speed of 16.0 m/s at level flight and climb to 95 m in 60 seconds with a mass of 2.85 kg. With an estimated empty weight of 1.85 kg this corresponds payload of 1.0 kg. The aircraft has a MTOW of 3.8kg with a take-off run of 40 meters, but it is unlikely we choose to fly with much more than 3.0 kg mass due to poor climb performance and sluggish turns.

6 STABILITY

OpenVSP was used to find the aerodynamic centre (AC) to show the aircraft's stability. AC, by definition, is a point along with the aeroplane's longitudinal axis where the pitching moment coefficient (Cm) does not vary with the angle of attack (AoA). OpenVSP analysis was run at different reference points along the aircraft's centreline until the point where the Cm is constant was found at 397 mm from the nose.

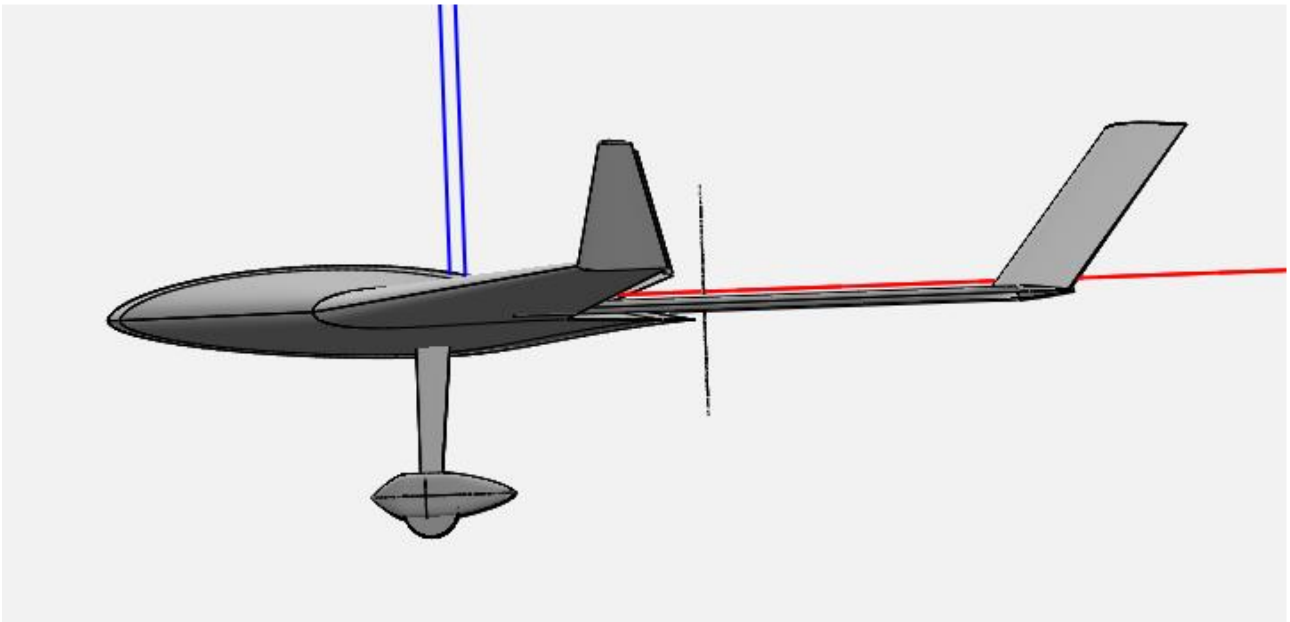


Image 2: locations of CoG (the blue front line) and AC (the rearmost blue line) at the aircraft's longitudinal axis.

The aircraft's mean aerodynamic chord (MAC) is 330 mm. We consider the acceptable stability margin for the aircraft to be about 5–10% of the MAC, which is 17–33 mm, which means that the centre of gravity (CG) must lay at 17–33 mm in front of the AC at all circumstances. To show that the aircraft is stable at this range of CG locations, images 3 and 4, taken from OpenVSP analysis, are provided here.

As can be seen from the images, the aircraft would pitch down when the AoA increases and pitch up when AoA decreases. The equilibrium point is at 0 degrees for CG at 5% and –2,7 degrees for CG at 10%. Should we fly at CG set to 10%, we may always trim the elevator to provide a nose-up pitching moment, thus manually setting the equilibrium point to 0 degrees. Note that the Alfa angle used in OpenVSP analyses is set so that it is the angle between the flight path and the aircraft's x-axis. It means that when the aircraft is trimmed for level flight, AoA is 0. The actual AoA of the wing is greater than this.

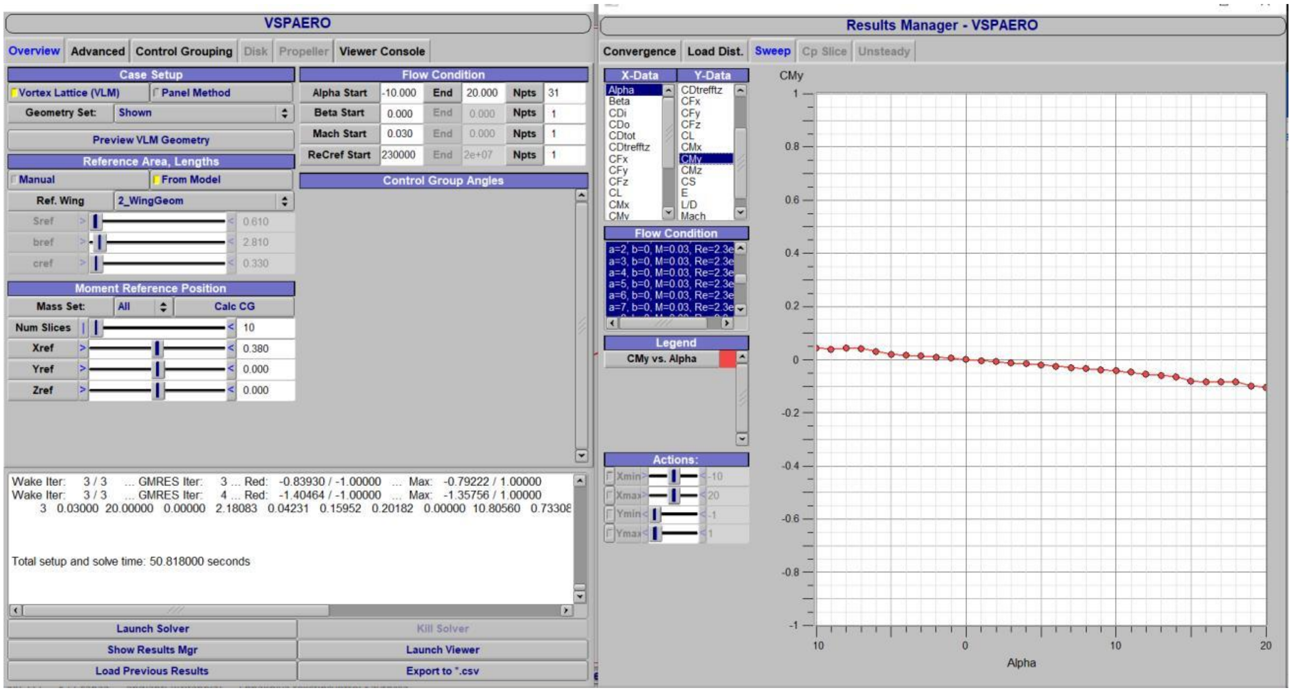


Image 3: Cm at the function of AoA at CG = 5% (380 mm from the nose).

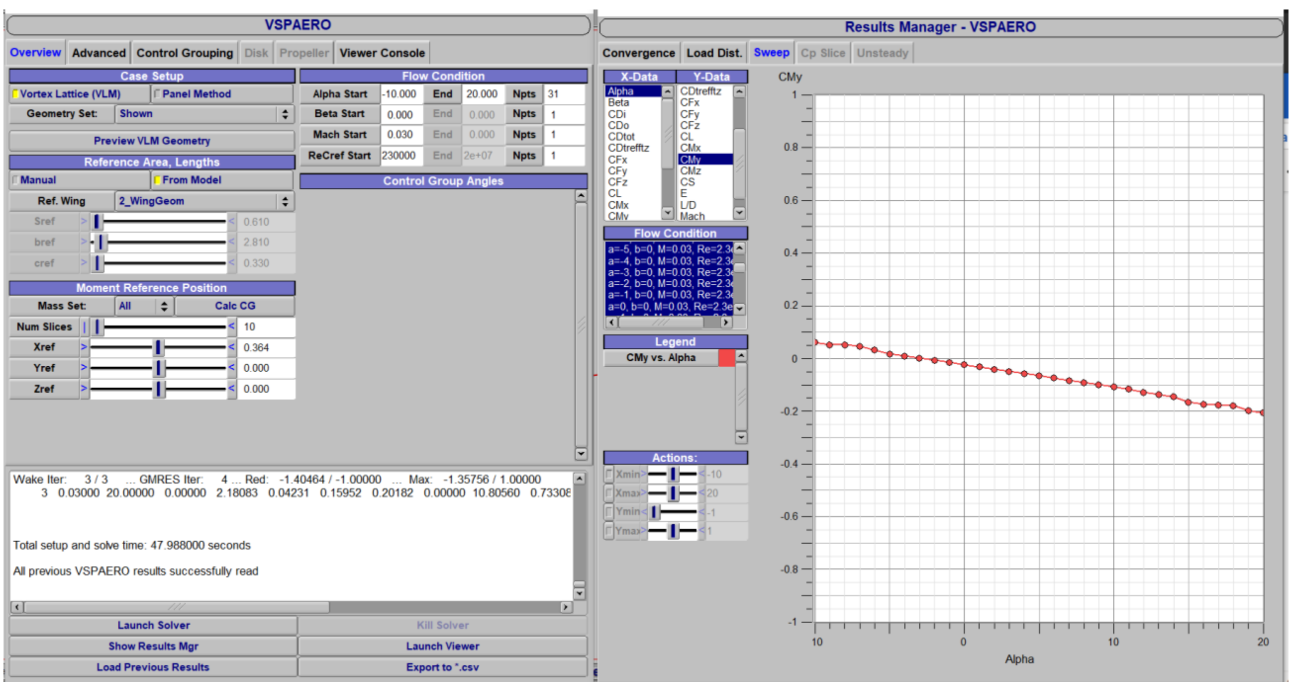


Image 4: Cm at the function of AoA at CG = 10% (364 mm from the nose).

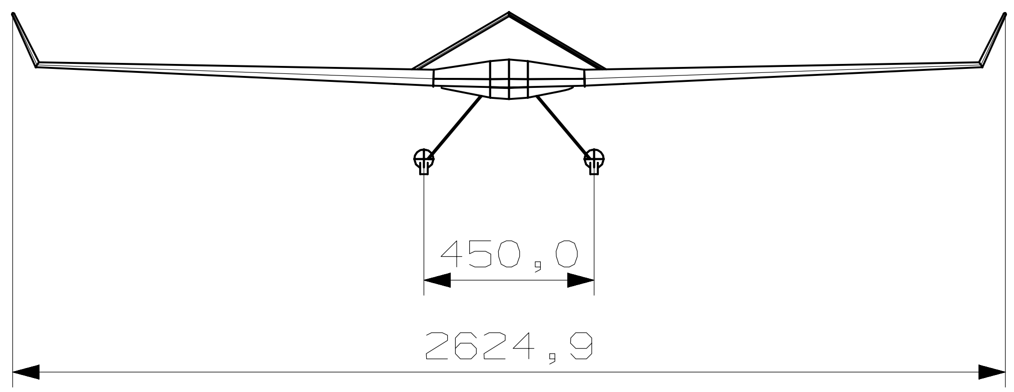
As our aircraft will have quite a large internal volume, there will be enough room to adjust the cargo location and the powertrain to make sure that it lays at the desired location. Moreover, the full-scale prototype we are working on will prove the stability empirically in addition to the OpenVSP analysis.

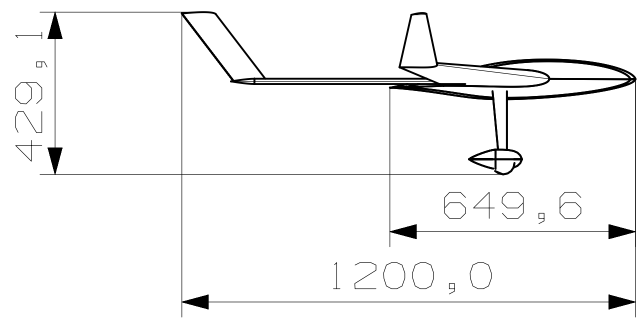
7 OUTLOOK

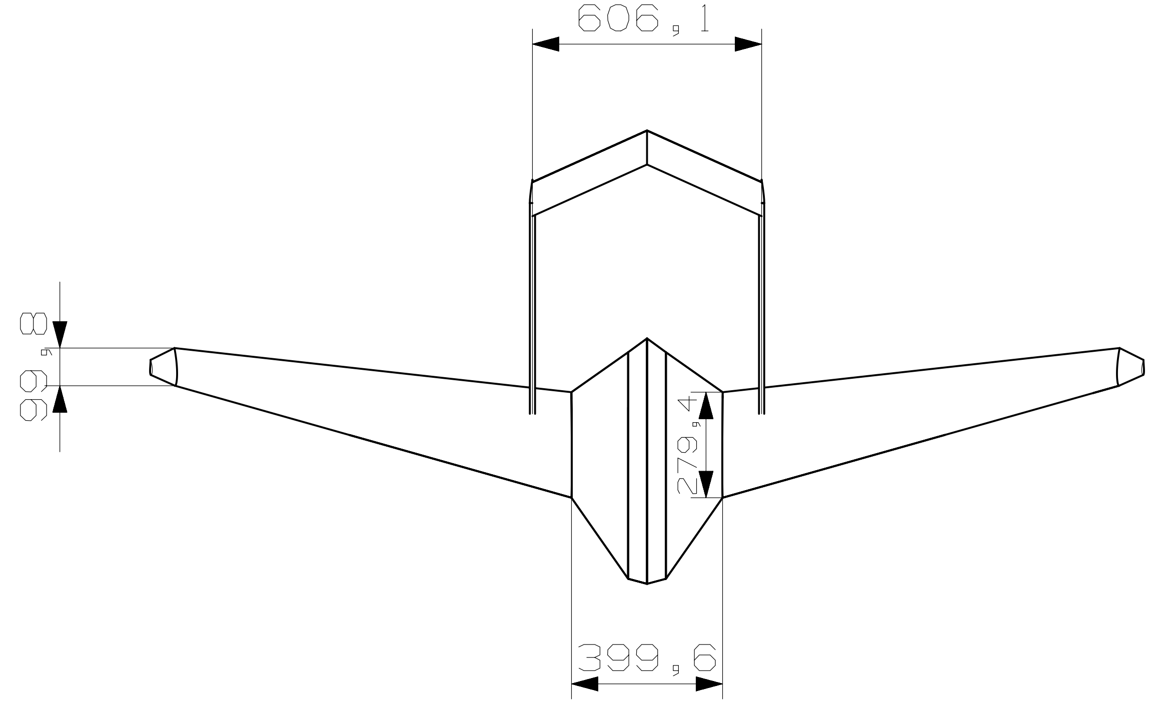
The project has been a learning tool for the Team Albatross members. While many members have not built aircraft before, most of us are happy if the concept flies as designed. The aim is not high, but if the courageous choice to build an unconventional aircraft pays divided, the advantage could raise the Team Albatross to high points. At the same time, the Team is aware that many of the design areas could be more optimised.

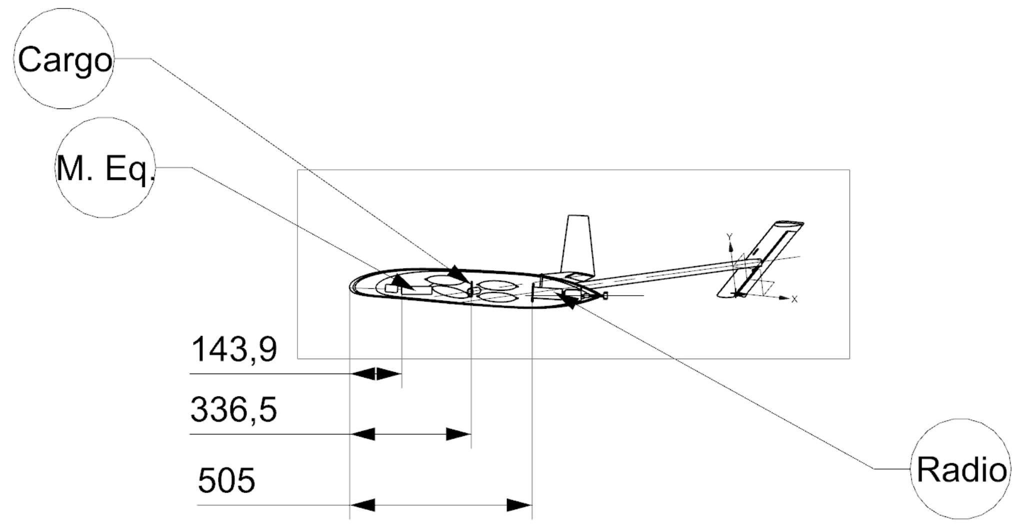
The aircraft's aerodynamics is several times iterated, and the simulation models provide excellent values for the lift and drag. However, the design program, OpenVSP, has its weaknesses, and the Team is somewhat uncertain whether the simulation presents realistic values. The prototype, now in the construction phase, shows a lot of the aircraft's stability.

If the prototype succeeds, the Team should have well time to build the final product as the production of the final product has been determined. Yet, The Team is still lacking moulds for the carbon fibre coating of the body, and the manufacturing process is new for everybody. Therefore, there are still challenges ahead.









[1]	[WING]	[NACA 3516]
[2]	[BODY]	[NACA 3516]
[3]	[V-TAIL]	[NACA 1514]

ALL DIMENSIONS IN MM

Tampereen yliopisto
Tampereen ammattikorkeakoulu

TEAM ALBATROSS

FIRST ISSUED		TITLE
DRAWN BY	Otto Harrikari	Main dimensions of the ACC competition vehicle
MODELLED BY	Aaro Huuhka	
DESIGNED BY	Akseli Arola	

SIZE	DRG NO.	SHEET REV
A3	ACC3.7_stp	A
SCALE 1:20		SHEET 1 OF 1