



Albatross Tampere
Preliminary Design Report
New Flying Competition 2020

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List of abbreviations and Symbols

The next list describes several symbols that will be later used within the body of the document

ρ	Air density
C_D	Drag coefficient of the aircraft
C_L	Lift coefficient of the wing
D	Drag force
L	Lift force
S	Wing area
S_2	Cross sectional area of the aircraft
U_∞	Undisturbed air speed
ACC	Air Cargo Challenge, an aeronautical engineering competition for students
AoA	Angle of Attack
BEC	Battery Eliminator Circuit, a voltage regulator between a battery and other electronics
CG	Center of Gravity
CNC	Computer Numerical Control, an automated control of machining tools
ESC	Electric Speed Controller, a component to control electric motors
FDR	Final Design Report
NFC	New Flying Competition, an aeronautical engineering competition for students
PDR	Preliminary Design Report
PLB	Payload block defined by the organizer. Weights 2 kg and size is 1100mm×250mm×150mm
VTOL	Vertical Take-Off and Landing
XT-90	A battery connector

1 Introduction

Team Albatross Tampere consists of students of Tampere university and Tampere university of applied sciences. Our supportive association Euroavia Helsinki ry is a club for aeronautical and space engineering students. Team members are engineering students for aerospace, electronics and physics and we all have common interest in aviation. Our team of five members are familiar with drones and fixed wing RC-planes.

Albatross Tampere was founded on November 2018 for joining Air Cargo Challenge 2019 -competition in Stuttgart. We were the first Finnish team ever to participate in ACC and we learned a lot from there. We heard about the New Flying Competition there. We finally got a team in December 2019 and applied to NFC.

We are putting all our knowledge on this competition and acquire new skills for winning the first prize. This is the second time we have joined a design-build-fly type competition, but our first one, the ACC in 2019, showed us the level of these competitions and the other student teams.

2 Considered configurations

The task is to design an energy efficient VTOL aircraft. We thought and studied different ways to engineer a VTOL aircraft. We excluded helicopters and airships and focused on multi-rotor aircraft that could be energy efficient and can carry the large payload block (PLB). Energy efficiency requires aerodynamic design and the benefits of fixed wing aircraft on cruise flight. [1]

One of the first considered solutions was the tail-sitter type aircraft (**Figure 1**). Because it takes off and lands on its tail, there wouldn't be a need for any extra retractable or tilting motor mechanism like in many other types of VTOL aircraft. The problem was, that the competition rules state that the PLB must be horizontal relative to the ground. In a tail-sitter configuration this would have been solvable by putting the PLB in a round tube inside the wing spar, but that would have increased the size of the aircraft excessively.

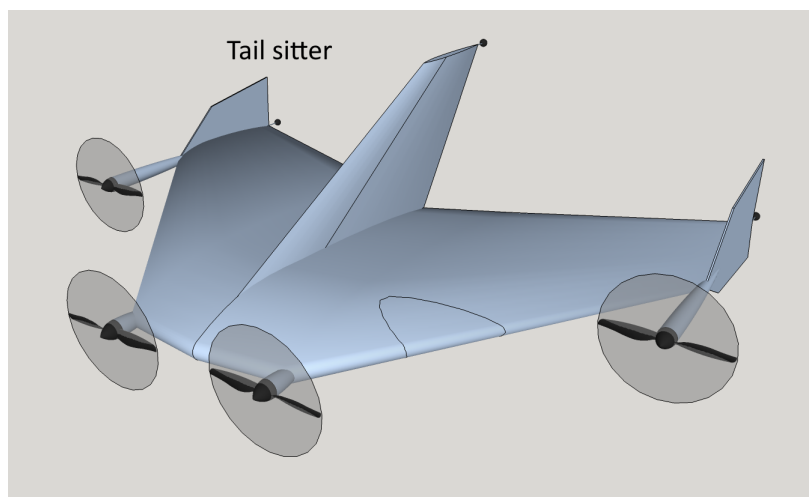


Figure 1: The tail sitter concept

We knew that a flying wing configuration (**Figure 2**) would ideally be more aerodynamically efficient than a conventional aircraft. To make it smaller than the tail sitter configuration the PLB should be positioned lengthwise. Most natural way to implement the vertical take-off capability would have required a tilting rear rotor and embedded lift fans in the wings. The size of the PLB and lift fan results that the root chord of the flying wing would be very thick that increases drag. Also embedding the lift fans inside the wing would reduce the effective wing area and break the airflow in an aerodynamically very sensitive part of the airfoil. Proper flight stability of a flying wing is also a challenge that we felt we'd rather not need to undertake.

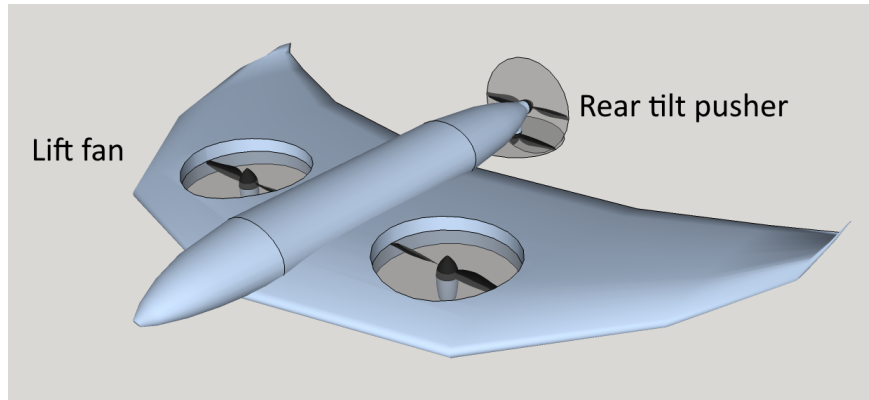


Figure 2: The flying wing concept

We looked at a few configurations for a conventional aircraft to obtain a VTOL capability (**Figure 3**). We are somewhat limited by the maximum continuous current of circa 90 amps deliverable through an XT-90 connector, and thus also by weight and reasonable propeller size. Therefore all our concepts included a tilting or retracting rotor and their number varied from three to five. We finally concluded, that three motors are enough and they would weight less than a four or five motor system. To reduce air resistance we abandoned the idea of fixed lift rotors supported by pylons. We considered retractable motor pylons that would hide inside the fuselage but the mechanisms required would be quite heavy and would also require too much space inside the fuselage, thus making it difficult to fit the payload. We wanted to utilise all the motors so that none of them would be dead weight during the flight task so we finally ended up with the tilt-wing pusher configuration.

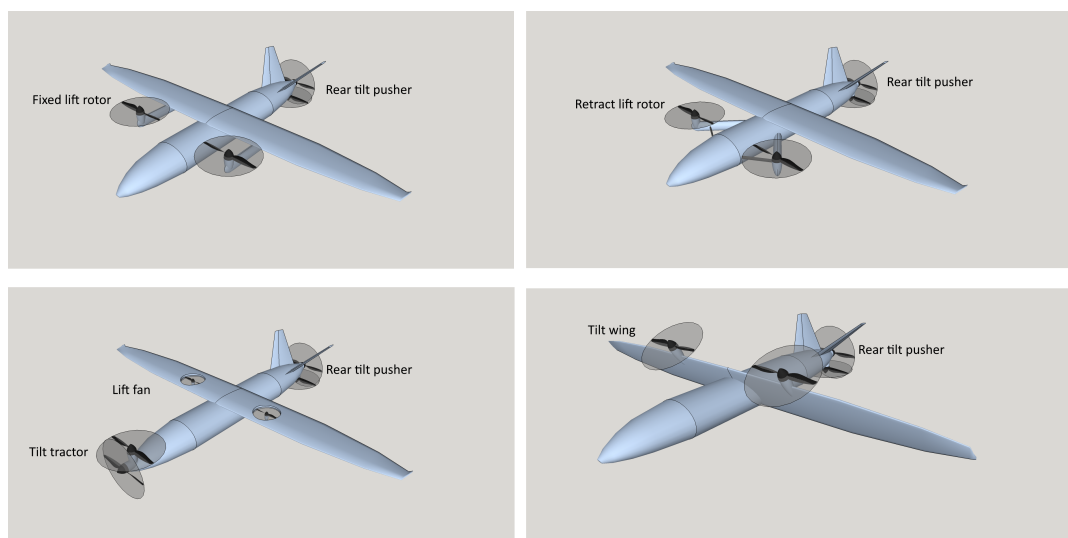


Figure 3: Various conventional aircraft configurations

One of the advantages of the pusher tilt-wing is that the rear motor could handle most the cruise flight alone and as such it could be optimized for lower thrust and higher pitch speed than the wing motors so that it would be more suited for cruise while still providing enough lift during take off for stabilization purpose. All the motors will be available for all phases of the flight and the high thrust wing motors will, for example, aid with completing the loop maneuver. It also makes the transition between cruise flight and hovering very smooth and simple. Unlike a tilt-rotor configuration there is no need for flaps and there is only a single rotation mechanism for the whole wing instead of one per rotor. Also the wing is not blocking the lift rotor airflow. During the transition between the flight modes the wing will confront very high angles of attack (AoA) and might stall, so the flight controller will have to counter that with the lift generated by rotors. [2]

The tilt-wing design is not very unusual - it is quite simple to build and it is very scalable. First successful tilt-wing aircraft demonstrator was Vertol VZ-2 in 1957 [3]. The VZ-2 and many of its manned successors suffered the mechanical complexity of having a tilting wing and two sets of controls for hovering and cruise flight. With modern flight computers and electric motors our radio controlled aircraft will be easy to control. With the conventional airframe it will be naturally stable in cruise flight.

3 Chosen concept

Our chosen concept for the NFC2020 task is a tilt-wing aircraft with tilting pusher rotor. The airframe is conventional high wing monoplane with a V-tail. The tilting wing has two fixed rotors that rotate in opposing directions. These lift rotors are close to the center of gravity (CG) so they are responsible for the most of the lift in take-off and landing phases of the flight. The rear pusher motor is used in the hover flight mode to stabilize the aircraft but its main function is to provide propulsion in horizontal flight. Usually in tilt-wing aircraft the wing rotors provide the thrust in all flight modes, but in our case we want energy efficiency. The lift rotors are large and they will be optimized for maximum static thrust, so they would be inefficient in cruise flight. We don't have capability to get small variable pitch propellers and using a compromise propeller would affect all flight modes negatively. The pusher rotor doesn't need to give much thrust during hovering so it can be optimized for efficient cruise flight.

The fuselage can be designed such that the efficiency of the pusher rotor could increase relative to usual tractor configuration [4]. We first thought that we could use folding propellers for the lift rotors but we are limited by the availability of suitable counter-clockwise rotating folding propellers. Attempting to manufacture one would be a safety concern and getting one custom made for us would be way out of budget so we will probably have to settle for fixed propellers. To minimize air resistance and weight we will use very low landing gears with fairings and a tricycle configuration.

3.1 Weight and center of gravity

The longitudinal center of gravity of the aircraft will be at the center of the payload, which will also dictate the position of the wing relative to the fuselage in such a way that the center of lift is either in the same place as, or just slightly behind of, the center of gravity. The length of the nose and tail boom at this design stage are easily adjustable such that we should not need to add

any extra weights in order to achieve this goal. The approximate center of gravity is illustrated in appendix 5. Our estimate for the weight of all the electronic components necessary for the aircraft is 2 kilograms and the payload is also 2 kilograms, so we will be targeting an all up weight of 7 kilograms, which we are confident that is achievable.

3.2 Thrust loading

The design of the wing will have a tubular carbon fiber main spar as much forward of the center of lift as possible. This tube will act as the axis of the tilting mechanism and thus determine how far forwards of the center of gravity the motors will be placed. Our current version of the design has this distance at 50 mm. We will be using motors and propellers that will provide 44 N of static thrust each so in order to counteract this, the rear motor will have to be able to provide 4.4 Nm of torque around the center of gravity. This will be achieved by a motor and propeller combination that provides at least 4.4 N of static thrust at a distance of one meter behind the center of gravity.

3.3 Wing, wing loading and empennage

The current wing design has a span of 3000 mm and root chord is 300 mm. It will have ailerons to control roll in cruise flight. With partly tapered shape and excluding the fuselage the wing area is around 63 dm². In horizontal flight the wing loading is close to 110 g/dm² so it is close to a big scale RC plane. The airfoil is not decided yet, but it should work with Reynolds number of $3 \cdot 10^5$ and has a thickness of 8%. The Reynolds number comes from velocity goal of 70 km/h and the length of the chord.

The wing does not need to work in low speeds like during the take-off, so it is sufficient to just design it for cruise speed. If we ignore the moment and the lift of the tail empennage, according to the lift equation the desirable lift coefficient is about:

$$C_L(\alpha) = \frac{2L}{\rho U_\infty^2 S} = \frac{2 \cdot 7 \text{ kg} \cdot 9,81 \text{ m/s}^2}{1,22 \text{ kg/m}^3 \cdot (19,44 \text{ m/s})^2 \cdot 0,63 \text{ m}^2} \approx 0,47. \quad (1)$$

This is just a suggestive value for the design. Assuming the cross sectional area of the aircraft is about 0,16 m² (fuselage of 300mm diameter and about 30 mm thick wing), and the needed thrust to overcome the drag in speed of 70 km/h is around 20 N, the drag coefficient is:

$$C_D(\alpha) = \frac{2D}{\rho U_\infty^2 S_2} = \frac{2 \cdot 20 \text{ N}}{1,22 \text{ kg/m}^3 \cdot (19,44 \text{ m/s})^2 \cdot 0,16 \text{ m}^2} \approx 0,54, \quad (2)$$

The premise of the wing design seems promising. The scale of drag coefficient is very easy to get smaller and the desirable wing coefficient is possible to obtain for example with SD7003 or E178 airfoils when the AoA is 2-3 degrees [5]. Another useful feature of our tilt-wing design is that the AoA could be adjusted in proportion to the airspeed. The tilting mechanism will use a worm drive driven by a small step motor.

The empennage will be a V-tail because it is lightweight and aerodynamic. It will include the control surfaces for yaw and pitch. Based on our experience in ACC it will have symmetric airfoil and at start 370 mm length and 240 mm root chord. While planning them we need to take into account the pusher rotor so they won't collide.

4 Cost estimate

The budget estimation of Albatross Tampere consists of the building costs, the travel costs and the application fee. The needed components for the aircraft are not settled yet, but their cost can be assumed from the price ranges of known online store catalogs. The list of needed components are listed in a table below:

Item	Amount	Single price [€]	Total price [€]
Control servo	4	20	80
Cruise rotor and ESC	1	130	130
Flight controller	1	40	40
Lift rotor and ESC	2	150	300
Power distribution with BEC	1	30	30
Landing gear motor	1	10	10
Micro controller	1	10	10
Propulsion battery	1	60	60
Rear motor tilting servo	1	30	30
Receiver	1	10	10
Avionics battery	1	10	10
Tiltwing mechanism	1	60	60
		Sum:	770

The building costs also include the building materials, that are also unspecified at this stage. With the help of our sponsors and based on last year ACC project the materials will probably cost around 550€. In addition we are going to build prototypes and a CNC hot-wire foam cutter. Prototyping might cost 300€ and the self made CNC foam cutter approx. 280€, so the total cost for the building costs is 1900€.

The traveling cost depends on the number of members and the time of the trip. Our team has currently six members. Because Hamburg is relatively close to Finland, we will probably travel with a ferry and one or two cars. That also defines that our aircraft must fit in a car for transportation. The ferry prices from Helsinki to Travemünde for six people and a car is around 1000€.

The application fee for the competition is well known and it is 1750€ for us with six members. Our total budget is then:

Expense	cost [€]
Building	1900
Traveling	1000
Application	1750
Sum:	4650

The application fees are mostly handled already with the grant of 1500€ from our university. We have already contacted some local companies who have promised to help with carbon fiber parts. We are looking for more sponsors and we will seek a grant from the Dunderberg foundation. If needed we could try to cut expenses from building costs and traveling.

5 Project schedule

After this PDR our team has a lot of time until the submission of final design report (FDR) on 31st of July 2020. Our project time will include planning of the aircraft, fundraising and building. We will use two or more months for designing the aircraft to be structurally strong and aerodynamic. We can start already with construction of the CNC hot wire foam cutter that we will need for building prototypes and the final aircraft. During February or March when we obtain the needed components we will build an "iron bird" hovering demonstrator that just has a simple frame and fixed motors to test the lifting power and flight control system. In the same time we will build a "foamy bird" to test the aerodynamic design in horizontal flight. The prototypes will be ready in March or earlier and so we could get the final tilt-wing aircraft ready in the end of June.

After we submit the FDR in July our team will continue the test flights of our aircraft to tune its flight to be as efficient as possible. During summer we will decide the traveling method to Hamburg.

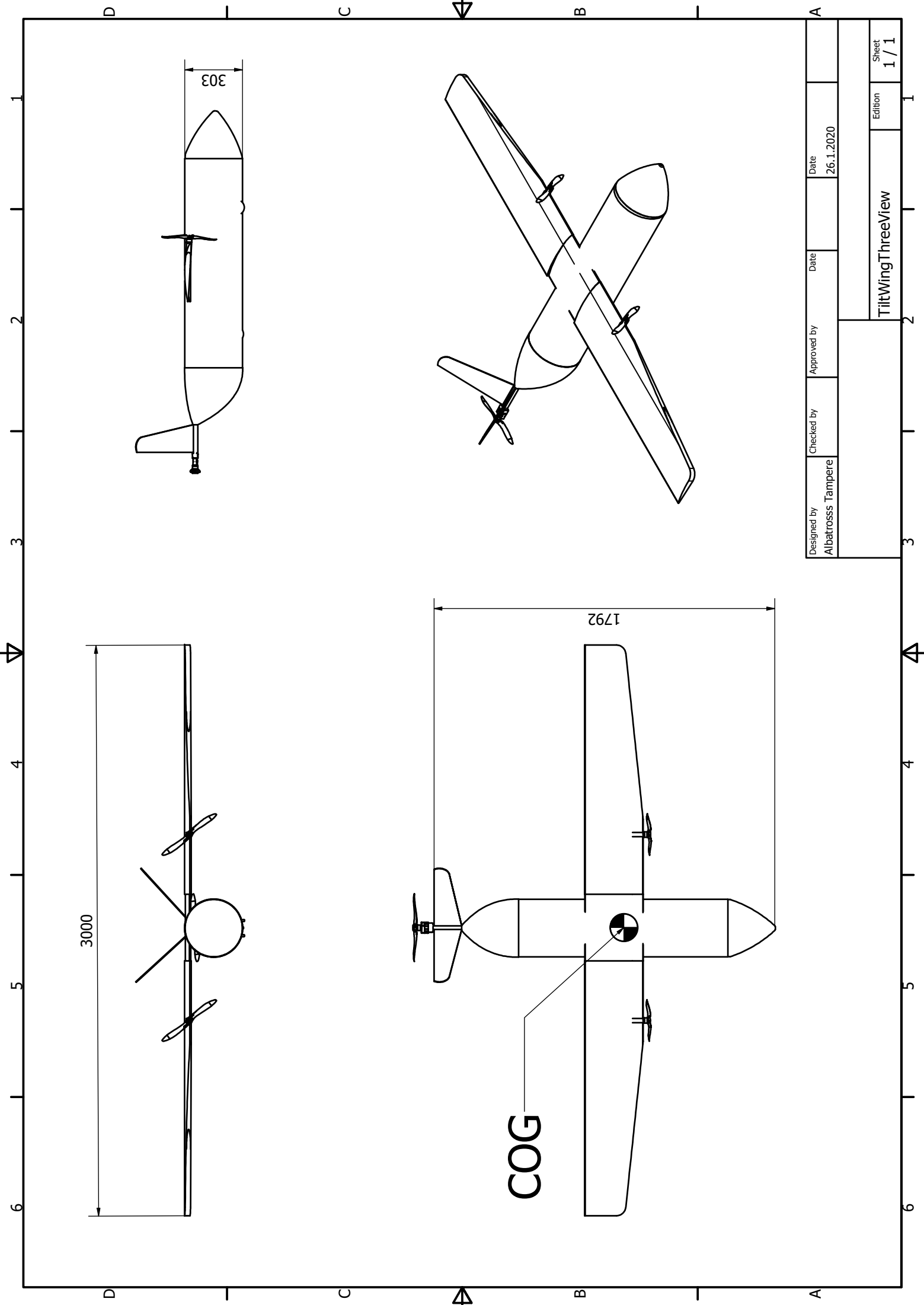
	January	February	March	April	May	June	July	August	September
Fundraising									
Planning									
CNC hot wire									
Iron bird									
Foamy bird									
FDR									
Final aircraft									
Test flights									
Competition									

Figure 4: Project schedule

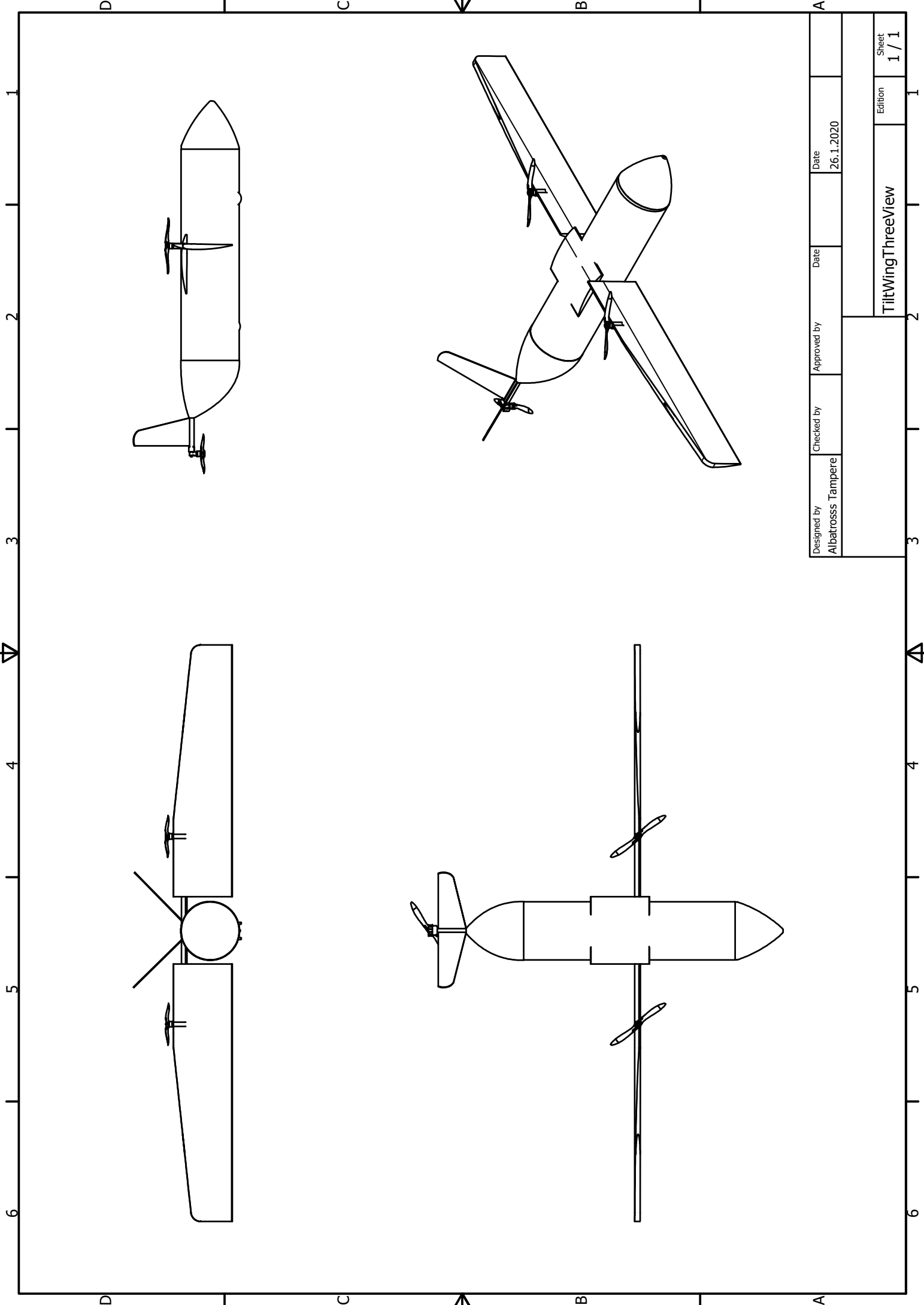
Appendices

3-view of the base line concept in horizontal flight.

3-view of the base line concept in vertical flight.



Designed by		Approved by		Date		Date			
Albatross Tampere						26.1.2020			
TiltWingThreeView				Edition		Sheet			
						1 / 1			



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Albatross Tampere						26.1.2020		1 / 1	
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								TiltWingThreeView	
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References

- [1] Neues Fliegen e.V. Competition task nfc 2020. <https://www.newflyingcompetition.com/downloads/>, 2019. NFC 2020 Competition Task.pdf.
- [2] D. Finger, Carsten Braun, and Cees Bil. A review of configuration design for distributed propulsion transitioning vtol aircraft. 10 2017.
- [3] Smithsonian National Air and Space Museum. Vertol vz-2 (model 76). <https://airandspace.si.edu/collection-objects/vertol-vz-2-model-76>, 2019.
- [4] Thorsten Lutz, Peter Funk, Andreas Jakobi, and Siegfried Wagner. Calculation of the propulsive efficiency for airships with stern thruster. 1 2001.
- [5] Airfoil Tools. Airfoils sd7003 and e178. <http://airfoiltools.com/>, 2020.