



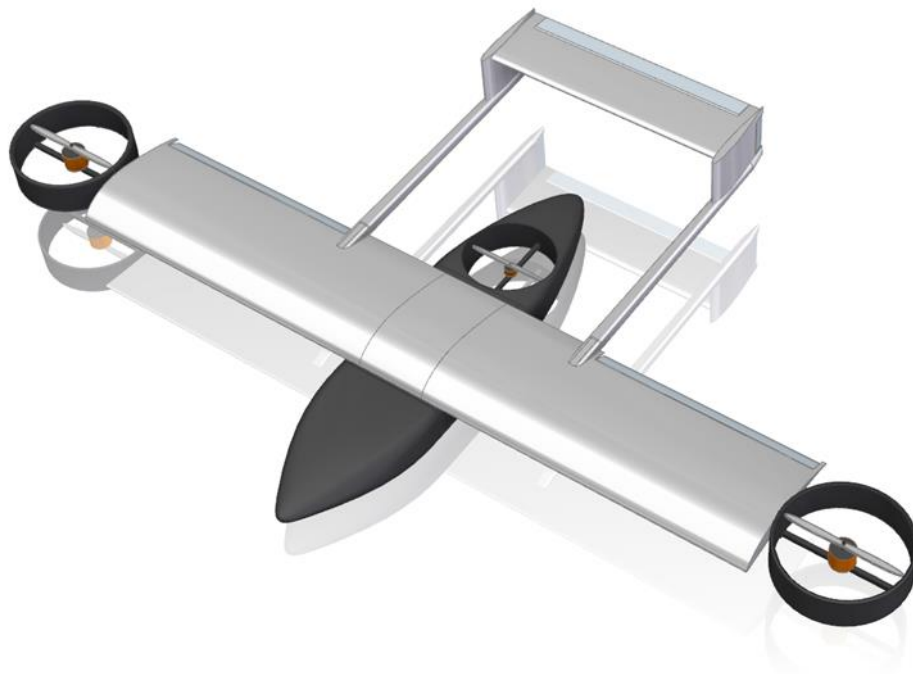
DEGREE PROJECT IN TECHNOLOGY,  
FIRST CYCLE, 15 CREDITS  
STOCKHOLM, SWEDEN 2021

# Conceptual Design of a Small Size Unmanned Air Vehicle

Part B: Flight Performance and Flight Mechanics

Arastoo Bayati

Peter Reinders



**Authors**

Arastoo Bayati (arastoo@kth.se) and Peter Reinders (petrei63@kth.se)  
Vehicle and Mechanical Engineering  
KTH Royal Institute of Technology

**Place for Project**

Stockholm, Sweden

**Examiner**

Gunnar Tibert  
Vehicle Engineering and Solid Mechanics  
KTH Royal Institute of Technology

**Supervisor**

Raffaello Mariani  
Vehicle Engineering and Solid Mechanics  
KTH Royal Institute of Technology

# Abstract

This report summarizes the task of conceptually designing an UAV suited for agricultural observation of Swedish farmland. The design of the UAV was divided into two parts. This report focuses on the flight mechanics, performance analysis, and cost analysis of the UAV, whereas the other part centers around the aerodynamic performance. Therefore, some elements, such as the wing selection, will not be subject to discussion in this report. A set of different requirements were posed, such as having a flight time longer than two hours, being able to between 5-10 m/s, able to perform vertical take-off and landing, fly at a maximum of 100 meters, and weighing less than 5 kg. By using different sources of literature, reasonable assumptions, and Matlab analytics, a UAV was designed that met all constraints demanded. The cost analysis yielded a result that was reasonable, which overall makes this conceptual UAV a realistic product that could be manufactured using the project design.

**Keywords:** UAV, VTOL, Flight mechanics

## Sammanfattning

Denna rapport sammanfattar uppgiften att konceptuellt utforma ett UAV som lämpar sig för jordbruksobservation av svensk jordbruksmark. Utformningen av UAV delades in i två delar. Denna rapport fokuserar på flygmekanik, prestandaanalys och kostnadsanalys av UAV, medan den andra delen kretsar kring aerodynamiken. Därför kommer vissa delar, t.ex. En uppsättning olika krav ställdes, såsom att ha en flygtid längre än två timmar, kunna mellan 5–10 m/s, kunna utföra vertikal start och landning, flyga på högst 100 meter och väga mindre än 5 kg. Genom att använda olika litteraturkällor, rimliga antaganden och Matlab-analys utformades en UAV som uppfyllde alla krav på begränsningar. Kostnadsanalysen gav ett resultat som var rimligt, vilket sammantaget gör denna konceptuella UAV till en realistisk produkt som skulle kunna tillverkas med hjälp av projektdesignen.

**Nyckelord:** UAV, VTOL, Flygmekanik

# Acknowledgments

This report has been written by Arastoo Bayati and Peter Reinders. Almost all of the work has been done together by zoom meetings and discussions back and forth, with the exception of a few subjects that have been divided among us (cost analysis for Arastoo and V-n diagram for Peter). There was also a strong cooperation between the main workgroups. Adrian and Johanna have been very good partners. This shared ambition towards a common goal has yielded a good quality thesis project. A special thanks goes to Raffaello Mariani, the supervisor of this project, who has guided us in this endeavour.

<b>1 Introduction.....</b>	<b>2</b>
1.1 Problem and goal.....	2
1.2 Ethics and sustainability .....	3
1.3 Limitations.....	3
<b>2. Method .....</b>	<b>4</b>
2.1 Initial weight estimation.....	4
2.2 V-n diagram .....	5
2.3 Pitch.....	5
2.4 Battery sizing, endurance and range.....	8
2.5 Control surface sizing, statistical method .....	8
2.6 Climb and glide ratio .....	10
2.7 Power requirements .....	11
2.8 Turn rate and turn radius .....	11
2.9 Cost analysis .....	12
<b>3. Results.....</b>	<b>13</b>
3.1 Initial weight estimation.....	13
3.2 V-n diagram .....	13
3.3 Pitch.....	13
3.4 Battery sizing, endurance and range.....	14
3.5 Control surface sizing .....	15
3.6 Climb and glide ratio .....	15
3.7 Power requirements, .....	15
3.8 Turn rate and turn radius .....	15
3.9 Cost analysis .....	17
3.10 Conclusions .....	18
3.11 Further work .....	18
Appendix A.....	19
<b>References.....</b>	<b>20</b>

# 1 Introduction

Although agricultural spending is relatively low in Sweden (0.3% of GDP), the need for scanning vast farm territory is still a need to be met. One approach to meet this demand is by using an unmanned aerial vehicle (UAV). The subject of this project is the design of an UAV, capable of vertical takeoff and landing. The UAV will be in the lower weight category (between 0 kg and 25 kg approximately). The design will be based on relevant calculations with regards to aerodynamics and performance. Different software tools will be used to complement analytical work. Open-source software such as xflr5 [8] can be an important tool to evaluate flight mechanics properties. This type of simple aircraft design is a popular course in many universities as it tests problem solving in multiple parts of the aircraft.

## 1.1 Problem and goal

The main mission of the aircraft is surveillance, with an autonomy of a minimum of two flight hours in autonomous flight mode. The aircraft should be optimized for endurance, not speed, and the design cruise speed should be between 5m/s to a maximum of 10m/s. The aircraft should have VTOL (Vertical Take-Off and landing) characteristics to allow operations independent of paved runways, from both land and water. The operational altitude is sea-level, with a maximum altitude of 100m. The maximum wingspan is 2m, and take-off weight should not exceed 5kg. The payload consists of one GoPro High Resolution camera, which must fit inside the aircraft. In order to comply with the sustainability effort at KTH and in Sweden, the aircraft must be electrically powered. Hybrid propulsion systems, such as battery and fuel cells or battery and solar cells, will be considered.

The specific goals for this sub-project group is analyzing the performance and evaluating the flight mechanics. The following goals were specified by the supervisor:

### Performance analysis

- Climb and glide rate.
- Turn rate and turn radius.
- Range and endurance
- V-n diagram
- Power-to-weight ratio
- Power available and required.
- Flight Mechanics Analysis
- Roll, pitch, and yaw static moment coefficients
- Sizing of horizontal and vertical tail
- Preliminary sizing of control surfaces (ailerons, elevators or canard, rudder)
- Analytical approach

- Low-fidelity (xflr5) validation
- Cost analysis
- A maximum wingspan of 2m.
- Fly altitude interval of 0 to 100 meters.
- Cruise speed between 5 to 10 m/s.
- Equipped with GoPro camera
- 2 Hours flight time minimum
- Maximum weight of 5 kg

## **1.2 Ethics and sustainability**

This UAV is made for agricultural surveillance, which is a harmless purpose. However, one might be able to use this for illegal surveillance. The risk of this happening is evaluated to be low, since there are cheaper, lower class UAVs more suitable for spying on humans (this relatively long range drone is excessive for that purpose). Another real threat is attaching bombs to this drone, but again unlikely since this mission requires larger UAVs.

The UAV replaces the need for humans to drive around in cars to survey land and therefore is a more environmentally sustainable choice. The materials of the drone are carbon fiber and Styrofoam. The CO<sub>2</sub> emission related to the production of Styrofoam is 4.25 kg of CO<sub>2</sub> per kg Styrofoam [1] and 53.34 kg CO<sub>2</sub> per kg carbon fiber [2]. For the weights assigned to the UAV that equates to a total of approximately 21.3 kg of CO<sub>2</sub>. This is relatively low, the carbon emission of a Big Mac is around 4 kg, so producing 5 big macs (regular lunch for the authors of this paper) would be the same.

## **1.3 Limitations**

The scope of the project is the conceptual design. Some advanced components of the design are left out, such as control systems and software in order to fit the scope of the project (it would require considerably longer time if those areas would have been included). There are no economic specifications given.



## 2. Method

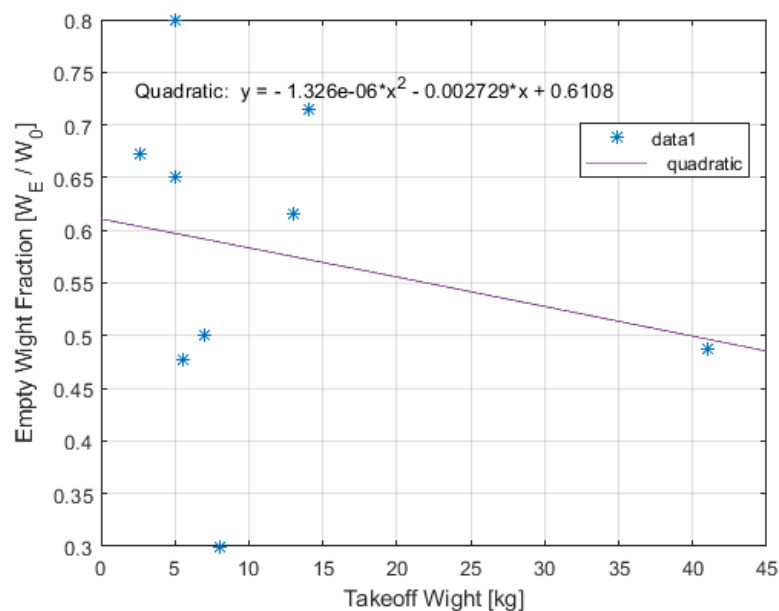
The following sections will describe the methods and analytical tools that have been used in this project.

### 2.1 Initial weight estimation

The weight of an aircraft is of great importance to its performance. To get an estimation of the weight a statistical method is used. This method relies on data of earlier UAVs for the empty weight fraction method that is used here [1,2,3]. Table 1 is taken from Ivan Willis Rasmussen, PhD [6]

**Table 1**

	Joker 3 UAV	LT Modular UAV	T-8	X401 Whirl- wind	X601 Photo- grapher	GY- SMS- 1000	iFly U20	Iflyer Big White 2	Jincheng 1 UAV
Empty Weight (kg)	3,25	20	4	1,75	3,5	2,65	2,4	10	8
Max take off weight(kg)	5	41	5	2,6	7	5,55	8	14	13



**Figure 1 Empty weight fraction. Statistical input**

The compilation of statistical data is complete. The use of equation (1) and (2) will yield equation (3) Gundlach [1]. Now the iterative process can be initiated so an estimation can be calculated.  $PF$  is the power fraction and  $BF$  is the battery fraction.

$$W_{TO} = W_{struct} + W_{Subs} + W_{Prop} + W_{PL} + W_{Energy} \quad (1)$$

$$EWF = P_1 M_{to}^2 + P_2 M_{to} + P_3 \quad (2)$$

$$M_{to} = \frac{M_{UL}}{(1-EWF-PF-BF)} \quad (3)$$

## 2.2 V-n diagram

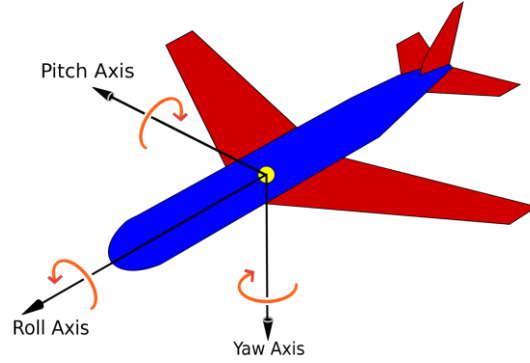
The V-n diagram is used to determine the safety limits in which the aircraft will operate. The load factor is denoted  $n$  and is taken from table 14.2 in Raymer [2]. With the use of equation (4) the diagram in figure (10) in section 3.2 is plotted. This shows the boundaries where the aircraft can fly safely regarding to its structural limits. The stall speed of the aircraft is dependent of  $C_{Lmax}$ . This speed is the slowest speed the aircraft can fly. To calculate the stall speed Equation (5) is used Anderson [4].

$$V^* = \sqrt{\frac{2n_{max}}{\rho_{\infty} C_{Lmax}} \frac{W}{S}} \quad (4)$$

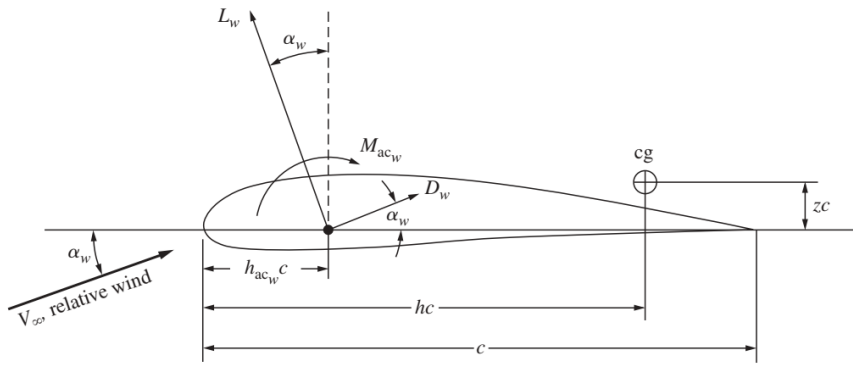
$$V_{stall} = \sqrt{\frac{2W}{\rho_{\infty} S C_{Lmax}}} \quad (5)$$

## 2.3 Pitch

During flight, an aircraft will rotate about its centre of mass. By defining a 3D coordinate system, it is possible to define the rotations of the plane. This is shown in figure 2. The pitch axis is perpendicular to the aircraft centreline (parallel to the wings), the pitching motion is therefore an up/down movement of the aircraft. This motion is caused by turning the elevator of an aircraft. The elevator work in pairs and a change in an angle of the elevator causes downward deflection, and increased lift is generated. The change in lift causes the airplane to rotate about its centre of gravity.



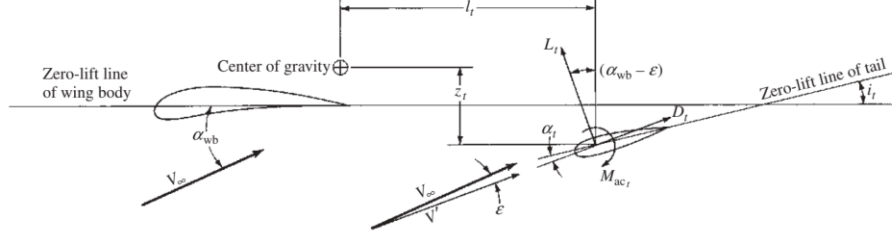
**Figure 2 The rotational axes of the aircraft [7]**



**Figure 3 Depicts the moment and forces acting on the airfoil [4]**

It is important to analyse the moments around the centre of gravity of the airplane, labelled  $cg$  as this will determine the stability of the aircraft. To get the total moment, it is needed to get the moment contribution from the wing, tail, fuselage. However, in order to better fit the scope of the project, only the moment contribution from the wings and tail will be considered. In figure 3, the zero lift line can be seen, which is the horizontal line with respect to the relative wind, at an angle of  $\alpha$ . This is the angle of attack. The chord of the wing is  $C$ ,  $hc$  is the distance behind the front edge of the wing to the center of mass. The aerodynamic center is placed at one fourth from the leading edge of the wing. The moment around the aerodynamic centre is labelled  $M_{acw}$ , and the corresponding wing lift and drag are  $L_w$  and  $D_w$ . Equation (6) [4] will give the moment of interest.

$$M_{cgw} = M_{acw} + L_w \cos \alpha_w (hc - h_{acw}c) + D_w \sin \alpha_w (hc - h_{acw}c) + L_w \sin \alpha_w zc - D_w \cos \alpha_w zc \quad (6)$$



**Figure 4 Depicts the moment and forces acting on the airfoil and wing [4]**

The effect of the tail is taken into consideration independently. In figure 4,  $V_\infty$  is the relative wind,  $V'$  is the relative wind at the tail, by an angle  $\epsilon$  inclined from  $V_\infty$ .  $L_t$  is the tail lift, and  $D_t$  is the drag. These forces are perpendicular to each other. From figure 4, equation (7) can be derived

$$M_{cgt} = -l_t[L_t \cos(\alpha_{wb} - \epsilon) + D_t \sin(\alpha_{wb} - \epsilon)] + z_t L_t \sin(\alpha_{wb} - \epsilon) - z_t D_t \cos(\alpha_{wb} - \epsilon) + M_{act} \quad (7)$$

$M_{cgt}$  is the moment given from the tail around the plane's centre of mass. By analysing Equation (7) [4] the first term on the right side is the  $l_t L_t \cos(\alpha_{wb} - \epsilon)$ , which is the dominating factor of magnitude. And some simplifications can be made within reason:

1.  $z_t \ll l_t$ .
2.  $D_t \ll L_t$ .
3. The angle  $\alpha_{wb} - \epsilon$  is small; hence  $\sin(\alpha_{wb} - \epsilon) \approx 0$  and  $\cos(\alpha_{wb} - \epsilon) \approx 1$ .
4.  $M_{act}$  is small in magnitude.

Using these approximations, the equation can be simplified to

$$M_{cgt} = -l_t L_t \quad (8)$$

By compiling the moments around the centre of mass, the pitching moment can be calculated using equation (8)

## 2.4 Battery sizing, endurance and range

This aircraft will be powered with electric motors. Battery sizing will have a great impact on the endurance and range of the aircraft. It is specified that the endurance is a minimum of two hours of flying time. The aircraft is required to take off and land vertically (VTOL). The take-off and landing are the most power consuming part of the mission legs so the battery must be able to deliver the amount of power needed.

In equation (9) there are two factors that are dimensionless ratios. The first is  $\eta_{Batt}$  and that dictates the efficiency of the battery. In this case a LiPo battery, (Lithium-Ion Polymer battery), is used, and the efficiency is 95 %. The second one is  $f_{Usable}$ . This factor is a ratio that describes the highest and the lowest voltage the battery cell can have. In LiPo cells the lowest voltage is 3.3 volts and fully charged it is 4.7 volts. If a load is put on the cell when the cell voltage is below 3.3 volts the cell will be damaged. The capacity is the ampere hours or Ah for short. Equations (9)(10) are used to determine the endurance [1].

$$Energy_{Batt} = Capacity \cdot Voltage \cdot \eta_{Batt} \cdot f_{Usable} \quad (9)$$

$$E = \frac{Energy_{Batt}}{P_{Batt}} \quad (10)$$

To determine the range of the aircraft is not a difficult task. When the battery energy for take-off and landing is taken into consideration the remaining energy is available for level flight. Equation (11) [1] is used for this task.

$$R = \frac{V_{cruise}}{E_{level\ flight}} \quad (11)$$

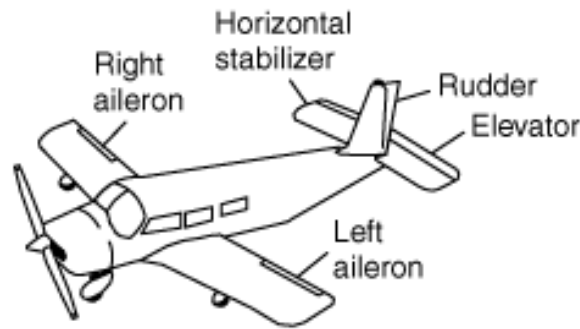
The power consumption is at its greatest during start and landing and equation (12) is used to determine the power. The used variables are T that stands for thrust and V which is the speed during start and landing. Important to point out is that there are two motors so  $P_{motor}$  must be multiplied by two. The efficiency  $\eta_{prop}$  is specific for the propeller that is chosen. Data for the propeller is listed in Appendix A.

$$\eta_{prop} = \frac{TV}{P_{motor}} \quad (12)$$

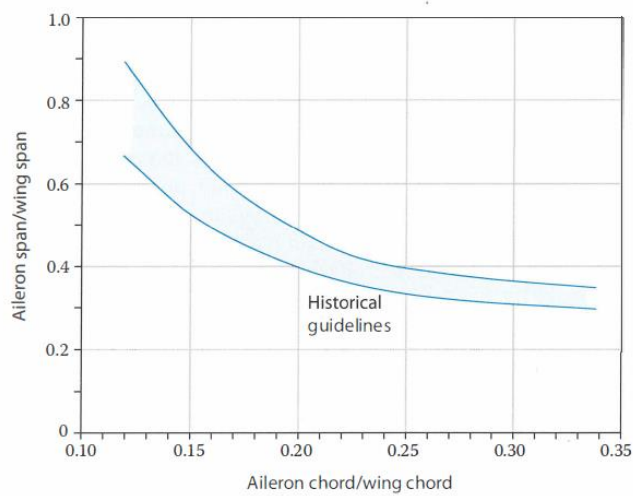
## 2.5 Control surface sizing, statistical method

Controlling the direction of the aircraft is essential and is done by the control surfaces on the aircraft. These are starting from the front of the aircraft ailerons, elevators and rudder. To determine the size of the control surfaces at this point

a statistical method is used [2]. In figure 5 the different control surfaces are shown



**Figure 5 Control surfaces of a plane**



**Figure 6 Statistical data for ailerons [2]**

**Table 2**

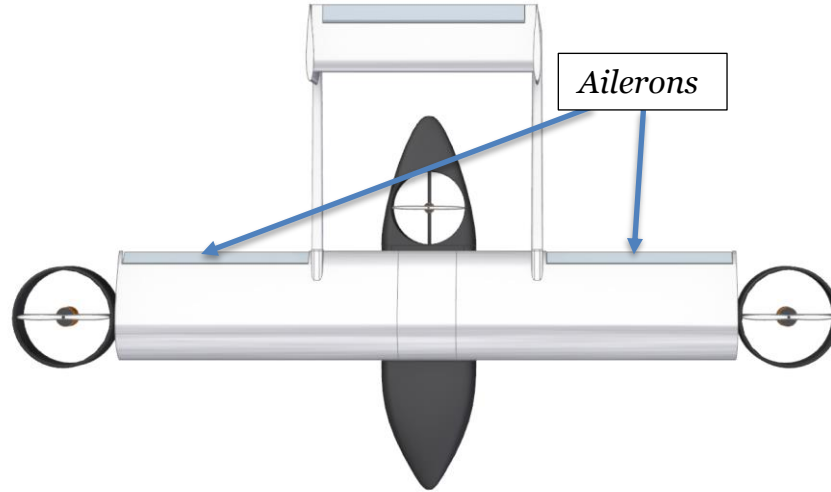
<i>Aircraft</i>	<i>Elevator <math>C_e/C_{Stabilizer}</math></i>	<i>Rudder <math>C_r/C_{Fin}</math></i>
<i>General aviation twin</i>	<i>0,36</i>	<i>0,46</i>

To get the initial sizing of the control surfaces the chord of the stabilizer and fin is used to get the chords of the elevator and rudder. The values from table 2 and equations (13) [2] will calculate the chords for the elevator and rudder.

To obtain the chord of the aileron a different approach is used. The span of the ailerons is limited by the aircraft configuration. The twin boom configuration leaves only the outer part of the main wing available for ailerons. Figure 7 shows the position of the ailerons. The diagram in figure 6 uses the ratio between the wing chord and wingspan and the ratio between the aileron chord and the wing chord. To derive the chord of the aileron, equation (14) [2] is used.

$$C_{Stabilizer} \times 0,36 = C_e \quad C_{Fin} \times 0,46 = C_r \quad (13)$$

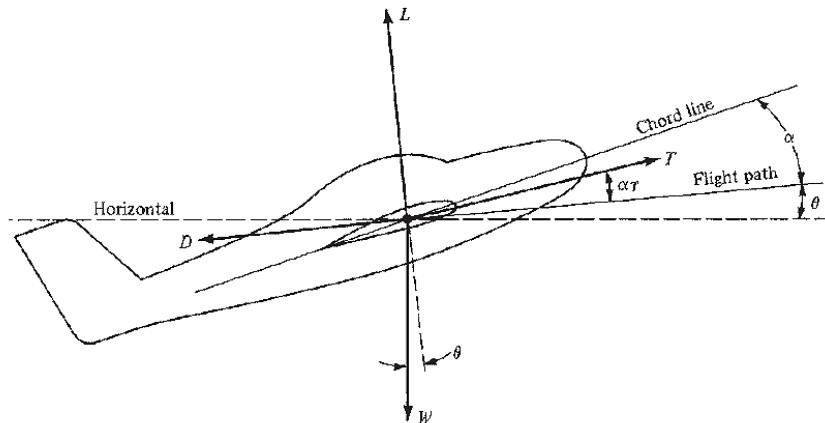
$$\frac{b_A}{b_W} = \frac{C_A}{C_W} \Rightarrow C_A = C_W \frac{b_A}{b_W} \quad (14)$$



**Figure 7 Aileron positions on the main wing**

## 2.6 Climb and glide ratio

The specifications stipulate that the cruising altitude will be no more than 100 meters. The climb angle will be between  $5^\circ$ - $10^\circ$  at steady climb and a maximum of  $20^\circ$  to avoid obstacles in the flight path of the aircraft if such an event should occur. The aircrafts climb is described with equation (15) [4]. Figure 8 depicts the forces involved in climbing.



**Figure 8 Shows the forces involved in climb [4].**

$$\sin \theta = \frac{T-D}{W} \quad (15)$$

The glide ratio is a good indicator on how far the aircraft flies in unpowered flight. This marks how much the aircraft will drop in altitude for every meter travelled horizontally. It can be viewed as a benchmark of how efficient the plane is with respect to aerodynamics.

## 2.7 Power requirements

To determine how much power will be used, the power to weight ratio and the available power required are the tools used to obtain this. The power to weight ratio is divided into three parts. The start, landing and level flight. In the start phase the power to weight ratio must be greater than one since it is a VTOL aircraft, and the take-off is vertical so thrust must overcome the weight of the aircraft. When landing the power to weight ratio is just below one. Both the start and landing are heavy consumers of power, and it will have a great impact of choice of power source. Power required will take into account the required power in plane flight. The altitude the aircraft will fly at is no greater than 100 meters, so the variation of the air density is neglected. The aircrafts drag at sea level is the only factor that must be considered.

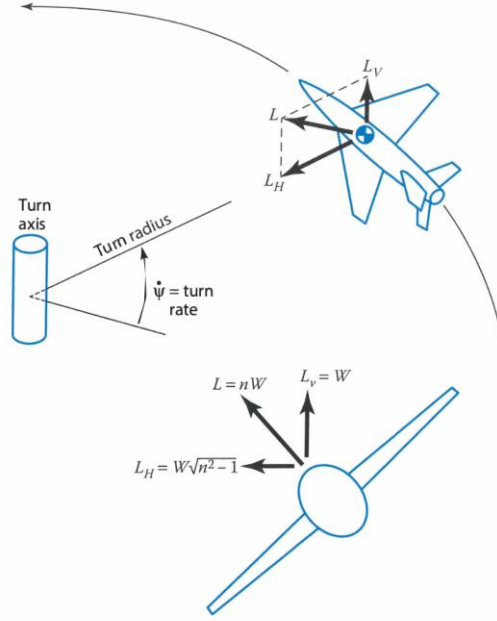
## 2.8 Turn rate and turn radius

Turn rate of an aircraft shows how fast a plane can turn. Different types of planes have varying requirements, for example fighter jets must have a high rate of turn so that they can outmanoeuvre enemies. Whereas surveillance aircraft can have a lower rate of turn since it will not engage in combat. The UAV designed for this project does not have any particular demands posed with regards to rate of turn since it is not optimized for agility but for endurance and efficiency. However, it is important to analyse the turn rate to see that it is within reasonable boundaries. Equation (16) [2] shows how the turn rate is calculated. When turning, the wing is tilted so that the horizontal part of the lift exerts a centripetal force that drives the turn. Observe that the aircraft weight is denoted  $W$ , the load factor is  $n$ , and the speed is  $V$ . The turn rate is normally expressed as degrees per second, however equation (16) [2] gives radians per second so one must multiply by 57.3 for the correct conversion.

$$\dot{\psi} = \frac{W\sqrt{n^2-1}}{(W/g)V} = \frac{g\sqrt{n^2-1}}{V} \quad (16)$$

In figure 9 the physics of turning is demonstrated. Note the force of lift being directed to the centre, aligned with the turn radius.





**Figure 9 Depicts the motion of the plane when turning [2].**

Figure 9 shows the turn radius, which is another important piece of information that describes the manoeuvrability of an aircraft. A lower turn radius equates to a higher agility as the aircraft will not require the same amount of distance to turn. There are no specific requirements, with regards to the turn radius, for the UAV in this project as it is not relevant for the purpose. The turn radius is evaluated with equation (17) [2] to establish if it is within reasonable limits. Equation (17) [2], which is similar to the turn rate equation (16) [2], has been used to evaluate the turn radius.

$$R = \frac{v^2}{g \tan \phi} = \frac{v^2}{g \sqrt{n^2 - 1}} \quad (17)$$

## 2.9 Cost analysis

For the cost analysis multiple methods were used. For the material and hardware costs, different sources were used to gather the costs. The cost of labour is more difficult to calculate since this is a conceptual design. There is little data on how long it will take to manufacture, what tools will be needed, what exact components and adhesives etc. To answer this question, an interview was conducted with a consultant at the KTH Mechatronics department Lars Hässler. He has experience in managing start-up's both in Sweden and abroad and he also engaged in KTH prototype, a company tied to KTH that specializes in producing prototypes for companies.

### 3. Results

The following sections will present the results of this project.

#### 3.1 Initial weight estimation

The initial weight yielded 1,52 kg and that correlates well with the cad model that gave the weight of 1,0 kg. The aircrafts total take-off weight is approximately 3,5 kg which is less than the maximum weight of 5 kg the specifications stated.

#### 3.2 V-n diagram

Figure 10 shows the limits the aircraft can fly whit safety. The lowest speed is 2,2 m/s. Below that speed the aircraft will lose lift and fall out of the sky.

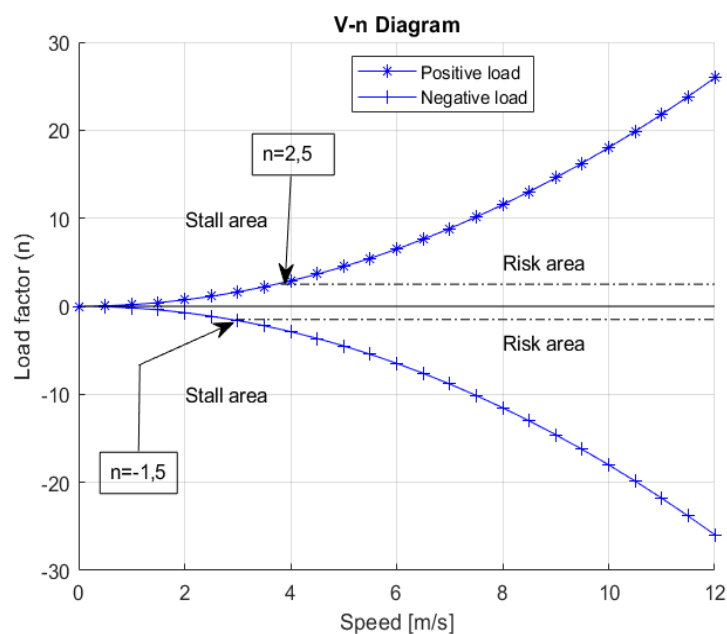
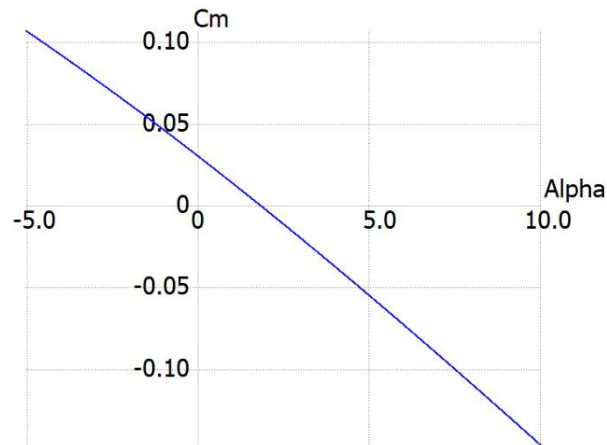


Figure 10 V-n diagram

#### 3.3 Pitch

After the plane had been modelled in XFLR5, a graph was extracted depicting moment coefficient with respect to the angle of attack.



**Figure 11 depicting the moment coefficient with respect to the angle of attack.**

The slope is negative, as can be seen in figure 11, meaning that for higher angle of attacks the coefficient becomes more negative. If the moment coefficient is negative that means the plane would be tilted forward and avoids stalling, the moment coefficient should therefore be negative, which it is in our case of 5 degrees.

Note that at approximately 2 degrees no moment is induced. For an angle of attack of 5 degrees, a pitching moment of -1.1703 Nm is yielded. This is a reasonable pitching moment coupled with a reasonable coefficient.

### **3.4 Battery sizing, endurance and range**

For level flight 30W is required. For takeoff and landing 1.2kW. This yields 60Wh for flight and 20Wh for takeoff and landing. Total Energy is 80Wh.

The battery must have the capacity of a minimum of 5,4Ah and a voltage of 22V.

The chosen battery is GensAce Tattu 10000mAh 6S 15-30 C LiPo.

This yields an endurance of 4.2h of flying time, and specifications states a minimum of 2h flying time so there is a good reserve if it is needed.

### 3.5 Control surface sizing

Table 3 shows the sizing requirement of the control surfaces of the aircraft.

**Table 3**

	Span (m)	Cord (m)
Ailerons	0,45*	0,054
Elevator	0,54	0,0648
Rudder**	0,119	0,054
*There are two ailerons on the main wing. one on each side of the fuselage. **There are two rudders. This because the twin boom configuration of the aircraft.		

### 3.6 Climb and glide ratio

It was determined that the glide ratio was 15.36. This is a reasonable figure, which equates to the plane moving 15.36 meters for every meter lost. A comparison to similar aircraft has not been conducted due to lack of data but to get an indication a comparison was made with other aircraft. In comparison a Boeing 747 has 15.5, Rutan Voyager closer to 27. None of these aircrafts are related to each other very closely, but it indicates around what values the glide ratio should be.

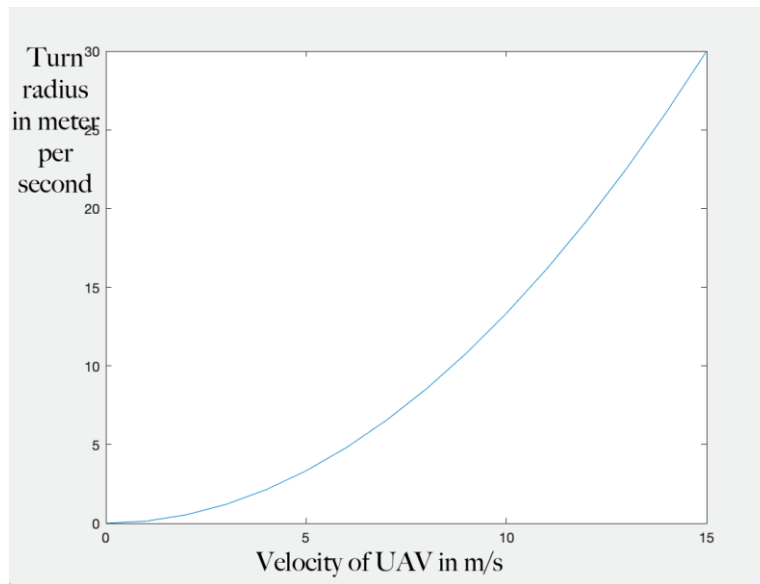
The climb rate was evaluated to be 1.04 m/s vertically for an angle of attack of 5 degrees. This is also a reasonable value for this rather small aircraft.

### 3.7 Power requirements,

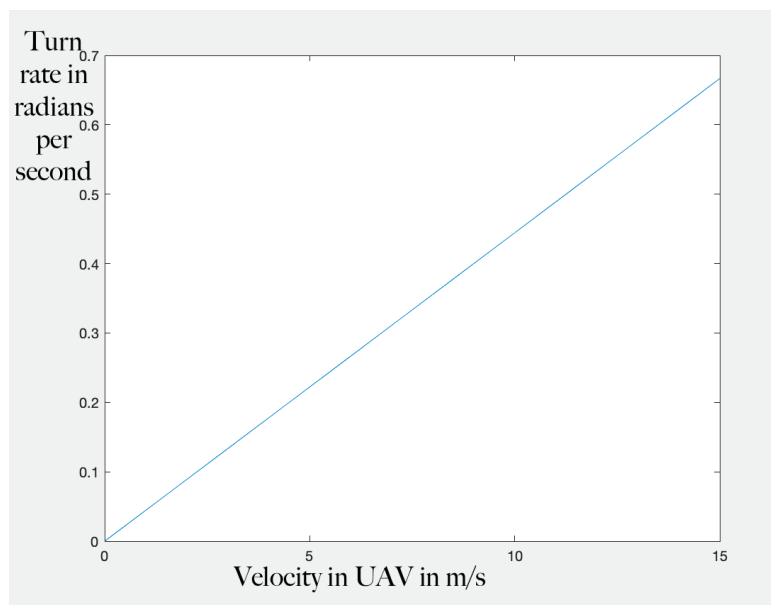
The start and landing are the most power consuming phases and will require 1,2 kW of power. When in level flight the power consumption will be in the region of 30-40 Watts.

### 3.8 Turn rate and turn radius

Figure 11 and figure 12 were constructed depicting the turn rate and turn radius for different velocities.



**Figure 11 depicting turn radius with respect to velocity.**

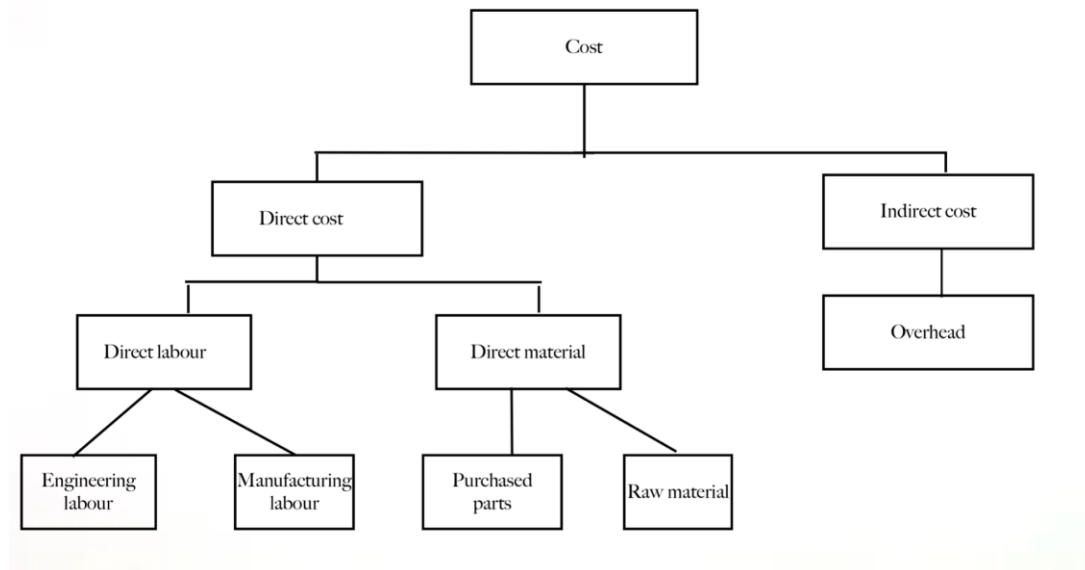


**Figure 12 depicting turn rate with respect to velocity.**

The turn rate was determined to be 30.55 degrees per second, and the turn radius at 13.33 meter Both values where obtained at 12 m/s. The turn rate is somewhat elevated, however considering the relatively small size of this UAV it is reasonable. The turn radius is also plausible. Although no demands were put for these measures, they fall within reasonable limits for operating this drone.

### 3.9 Cost analysis

The interview with Hässler gave an approximation for the different costs. The most strenuous task was determining the cost of labour involved in manufacturing this aircraft, Hässler thought the first working prototype of the plane might take a full time employee about a month to manufacture, if the blueprints are available. The cost of hiring someone skilled to put together this UAV was estimated to be around 86 000 krs (including employer contribution, insurance etc)



**Figure 13 Self drawn diagram showing the different costs.**

Figure 13 describes how different costs of the aircraft can be broken down, by using this graph, it becomes clear which parts of the aircraft are expensive (and should be the focus when cutting costs). The costs are shown in table 3.

**Table 3 Itemized cost list**

Element	Price	Quantity	Cost
Styrofoam	200 kr/kg	0.2 kg	40 kr
Carbon fibre	500 kr/kg	0.4 kg	200 kr
GoPro Hero 9	4200 kr	1	4200 kr
Battery "GensAce Tattu"	2179 kr	1	2179 kr
Motor	708 kr	1	708 kr
Labour	86 000 kr/month	1 month	86 000 kr
Overhead	20 000 kr/month	1 month	20 000 kr

After having looked at the design, it was suggested that for this particular project the overwhelming cost would come from the labour costs from manufacturing this plane. Hässler analysis was shown to be correct (as supported by the above chart). One can see that the costs tied to manufacturing (86 000 kr) greatly outweigh that of the cost of material and components (7 327). Furthermore Hässler theorized that the second prototype might only take two weeks to manufacture, and the hundredth plane perhaps as low as three days. The reasoning behind this dramatic decrease in time, Hässler argues in the fact that the process becomes more efficient and tools more specialized (jig for example). Another discussion about the cost analysis was the possibility of producing this in a low cost country like China, in order to bring down the massive cost of labour. Hässler stressed that for making few and expensive products, domestic production is preferred because then communication (and the iterative process) is easier.

### **3.10 Conclusions**

The goal of this project was to design a UAV suitable for surveying land. All of the demands linked with this task were met except one with respect to velocity, this was later accepted to be within reasonable bounds. The specific goals in respect to flight mechanics and performance for this work group were met. The estimated cost of the plane was reasonable. Overall this could be a functioning plane and the next step would be to build it according to the chosen design and test it for further improvements.

### **3.11 Further work**

In order to design a fully functioning, commercially viable UAV, more calculations and simulations have to be conducted. In this project more basic mechanics have been analyzed, however there could be a need to investigate yaw and roll.

## Appendix A

Data for the propeller 10x6E that have been used in the design [5].

```
10x6E                                (10x6E.dat)                                12/19/14

===== PERFORMANCE DATA (versus advance ratio and MPH) =====

DEFINITIONS:
J=V/nD (advance ratio)
Ct=T/(rho * n**2 * D**4) (thrust coef.)
Cp=P/(rho * n**3 * D**5) (power coef.)
Pe=Ct*J/Cp (efficiency)
V (model speed in MPH)

PROP RPM =      11000

V          J          Pe          Ct          Cp          PWR          Torque          Thrust
(mph)      (Adv Ratio)                                     (Hp)          (In-Lbf)      (Lbf)
0.0        0.00        0.0000        0.1166        0.0626        0.670        3.839        4.494
2.9        0.03        0.0525        0.1161        0.0617        0.661        3.785        4.476
5.8        0.06        0.1060        0.1155        0.0608        0.651        3.729        4.452

PROP RPM =      13000

V          J          Pe          Ct          Cp          PWR          Torque          Thrust
(mph)      (Adv Ratio)                                     (Hp)          (In-Lbf)      (Lbf)
0.0        0.00        0.0000        0.1193        0.0801        1.415        6.859        6.420
3.4        0.03        0.0427        0.1188        0.0774        1.367        6.628        6.397
6.8        0.06        0.0881        0.1183        0.0746        1.319        6.394        6.367
10.3       0.08        0.1365        0.1175        0.0718        1.269        6.154        6.328
```



## References

- [1] J. Gundlach, *Designing Unmanned Aircraft Systems: A Comprehensive Approach*, 1st ed. Reston, VA, USA. American Institute of Aeronautics and Astronautics, Inc. 2012.
- [2] D. P. Raymer, *Aircraft Design: A Conceptual Approach*, 6th ed. Reston, VA, USA. American Institute of Aeronautics and Astronautics, Inc. 2018.
- [3] D. P. Raymer, *Aircraft Design: A Conceptual Approach*, 4th ed. Reston, VA, USA. American Institute of Aeronautics and Astronautics, Inc. 2006.
- [4] J. Anderson Jr., *Introduction to Flight*, 8th ed. New York: McGraw Hill Education, 2016.
- [5] UIUC Applied Aerodynamics Group “UIUC Propeller Data Site.” [online] <https://m-selig.ae.illinois.edu/props/propDB.html> (accessed Feb, Mars. 2021)
- [6] Ivan Willis Rasmussen, Chinese Drones, Data set of all publicly recorded Chinese unmanned aerial vehicles March 2021. [Online] <http://ivanrasmussen.com/research/chinese-drones/>
- [7] Wikipedia Aircraft principal axes June 2021. [online] [https://en.wikipedia.org/wiki/Aircraft\\_principal\\_axes](https://en.wikipedia.org/wiki/Aircraft_principal_axes)
- [8] XFLR5 is an analysis tool for airfoils. [online] <http://www.xflr5.tech/xflr5.htm> (accessed Feb, Mars. 2021)



