Hogeschool van Amsterdam
Amsterdam University of Applied Sciences

AVIATION STUDIES

DESIGN, BUILD AND FLY MINOR

PUBLICATION: 22-10-2014

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3A

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Summary

The project group has been assigned to do this project which is intended to give students insight in the design aspects of an aircraft. The first phase of the design, build & fly minor has resulted in a RC glider design with a wingspan of 2 meters and the used airfoil type is HQ2.5/10. It will be made of carbon fiber in the rods, glass fiber for the fuselage and furthermore wood and plastics will be used for some structure part. According to estimations, the mass will be around 1.0 kg. After a 5 minute engine powered climb, the RC glider will be at a height of about 606 m. Then, according to the performance calculations, the RC glider will glide 11 minutes and 54 seconds. The report includes 3D sketches and drawings of the final design of the RC glider that has been designed by the project group.

During the first 'design' phase of the project, an electronically powered single motor RC glider had to be designed to stay as long in the air as possible without using motor power. This will be tested during a competition at the end of the second 'build and fly' phase of the project. The purpose of this report is to give the reader all the necessary details that are required for an understanding of the approach of the project, the methods that have been used, the results of the project and the necessary background knowledge that must be known. The report that is about the first 'design' phase of the project consists of 4 chapters. The project group decided to create three separate phases of the design phase.

In the theoretical phase, the necessary background knowledge that must be known to understand the fundamental theoretics of the vital topics are explained. This includes: acting forces on aircraft, aircraft stability, aircraft control, flight performance, wing characteristics, construction methods, materials and the applicable regulations for RC flying.

During the conceptual phase, the selection criteria for the most important design aspects have been explained. These design aspects have been subdivided into five parts: wing, tail, flight controls, fuselage and landing gear. In each part, the potential embodiments of all the aspects have been compared to each other. On the basis of a morphological overview and their criteria's, three different designs have been selected. These designs are designated as the performance design, the constructability design and the combined (performance/constructability) design. The performance design, which is designed to achieve the highest performance, has been chosen as the final model design to gain the best results during the competition.

In the design phase, the optimal dimensions of the components such as wing, tail and control surfaces of the RC glider are calculated. Also the structural stability calculations for the design of the glider are computed. Furthermore, several interesting characteristics such as flight performance and endurance of the glider have been estimated to know whether the glider will theoretically fulfill the expectations or not.

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Introduction

The board of the Design Build and Fly (DBF) minor has requested to design and construct a single engine model glider with a wingspan of maximum two meters, which can stay in the air as long as possible after 5 minutes motor power and land safely. The constructed aircraft needs to comply with the EASA CS-22 regulations regarding wing strength. The design and construction of the aircraft will be supervised by the project leader Arthur Bandell and will be carried out by project group 3A, which consists of seven Aviation Studies students of the University of Applied Sciences located at Amsterdam and one Aviation student of the University of Applied Sciences located at Graz, Austria.

Before constructing the aircraft, it is necessary to describe and understand the basics of a glider RC aircraft. This includes basic information about an aircraft such as the flight controls, aspect ratio, stability, thrust and drag formulas, climb and glide ratio and the endurance formula. Furthermore it will mention the information regarding the regulations concerning RC aircrafts. **(1)**
When the basic information is explained, the components of a glider are described in detail. This will include information about the electronic components which are provided by the school and will also cover information about the additional parts of the glider which the students need to provide themselves, like the servos. Furthermore this chapter will explain the pros and cons of the different components such as the different types of wing and tail designs. Thereafter it is possible to put it into a morphologic overview which will result in three possible glider designs. With a weighing table the optimal glider design will be determined. **(2)**
When the desirable design has been chosen, the dimensions of the gliders components, such as wing, tail and aileron dimensions can be calculated. Thereafter the flight performance of the RC glider can be calculated. This includes calculations about the thrust delivered by the propeller, the aircraft aerodynamic values and the climb and glide performance. All these calculations are necessary to determine the endurance of the glider. **(3)**

During the course of the report several information sources have been used. The most important information sources were: the Daniel P. Raymer's, Simplified, *Aircraft Design for Homebuilders*. Other important sources have been added into the appendices list. Also the report will include other important appendices containing a detailed 3D sketch of the RC glider, an excel sheet with the calculations and couple of graphs of the cl/cd.

1 Theoretical Phase

To make a gliding model plane it is first needed to describe the basic of flight. Which contain the forces of an aircraft and the climb and glide performance, known as the physics of flight **(1.1)**. After that it is possible to describe the information about the glide performances **(1.2)**. To find the optimal material and building method information about the construction is needed **(1.3)**. An Aircraft needs to be stable in flight to perform the optimal glide, the so-called aircraft stability **(1.4)**. When the aircraft is stable it can be controlled **(1.5)**. A glider plane needs to have a small glide angle, to accomplish that it is possible to use different kinds of material to improve the weight of an aircraft **(1.6)**. The required strength of a wing is described in regulations for model aircraft **(1.7)**.

1.1 Physics of flight

During flight there are a few forces acting on an aircraft **(1.1.1)** which are determine the flight performances. These performances need to be calculated, this is possible with the climb performance **(1.1.2)** and the glide performance **(1.1.3)**. An aircraft is maneuvering over his axes of movement **(1.1.4)** with his flight controls.

1.1.1 Acting forces

A force can be seen as a push or pull in a certain direction. A force is a vector quantity, so a force has both a magnitude and a direction. The following figure shows the forces acting on an aircraft during flight **(Figure 1.1)**.

1. Centre of Gravity
2. Lift
3. Weight
4. Drag
5. Thrust

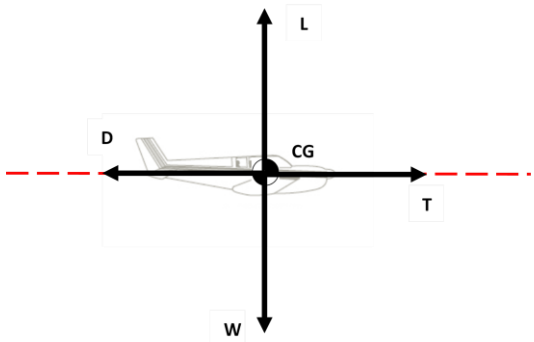


Figure 1.1; Acting forces

Ad 1. *Centre of Gravity*

All forces are acting on different points of the aircraft, but assuming that all forces are collected and acting through a single point called the center of gravity [CG]. In flight the aircraft rotates about the center of gravity. For a stable flight with an aircraft the CG must be in limits **(Figure 1.2)**, meaning that the CG must be located at $\frac{1}{3}$ of the Mean Aerodynamic Chord [MAC].

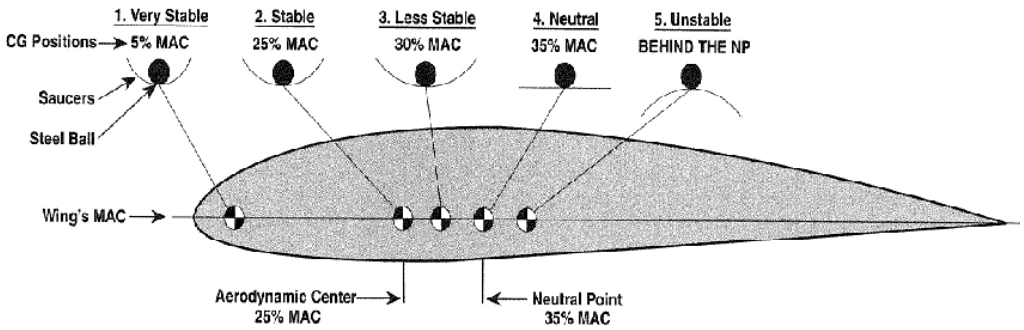


Figure 1.2; Limits of the CG

Ad 2. *Lift*

The wings create a force perpendicular to the relative airflow which is called the lift. Most of the lift is generated by the wings of the aircraft. The difference of the airspeed generates a differential pressure, where the pressure on the upper side of the wing is lower than the pressure on the lower side of the wing that generates lift **(Appendix IA).** Also the coefficient of the lift can be calculated **(Appendix IB).** The distribution of lift around the aircraft is important for the controllability.

Ad 3. *Weight*
On the aircraft works the gravitational force that arises due to the mass of the aircraft times the gravitational acceleration. Weight is a force that is always directed toward the center of the earth. The magnitude of the weight depends on the mass of the whole aircraft **(Appendix IC)**.

Ad 4. *Drag*
Drag is the aerodynamic force that is generated by the air. There are many factors that affect the magnitude of the drag force. The total drag consists of the induced drag and the parasitic drag. Parasitic drag is a combination of form drag, skin friction and interference drag. Form drag depends on the shape of an aircraft and skin friction depends on how smooth the surface of the aircraft is. Interference drag is created by the airflow between the airframe and components.
Induced drag is a consequence of the produced lift that is not aligned with the force of the gravity. The air on top the wings tend to flow downward hereby the pressure will decrease. The Equations of the drag can be found in the **Appendix ID** and **Appendix IE.**

Ad 5. *Thrust*
The force that propels the aircraft is called thrust. Thrust is a force that requires energy to produce propulsion and this comes from the motor of the aircraft. That force must also overcome the drag of the aircraft. To maintain altitude at a constant speed, the required thrust is constant. Climbing or descending an aircraft whilst maintaining at a constant speed, the thrust must be increased or decreased. Because the motor generates the thrust, the aircraft cannot climb with the motor turned off without losing speed. If the motor is turned off at a specific altitude, an aircraft will glide. Therefore it is important to have enough altitude and speed. The magnitude of the thrust depends on the forward force from the propeller and the density of the air. To calculate the thrust, the following formula is required **(Equation 1.1).**

Equation 1.1

Thrust

$$\boldsymbol{F = \frac{1}{2} \times \rho \times A \times (v_e - v_0)^2}$$

Symbol	Variable	Unit
$\boldsymbol{F}$	Thrust	Newton [N]
$\boldsymbol{\rho}$	Density	Kilogram per cubic meter [kg/m3]
$\boldsymbol{A}$	Surface	Square meter [m2]
$\boldsymbol{v_e}$	Velocity exhaust	Meter per second [m/s]
$\boldsymbol{v_0}$	Velocity aircraft	Meter per second [m/s]

1.1.2 Climb performance
An aircraft has certain climb performance, during flight with engine power an aircraft is flying along a climb angle **(1.1.2.a)** to climb. This climb has a ratio of climb **(1.1.2.b)** can work to find an optimal climb performance.

1.1.2.a Climb Angle
The thrust works on the line of the aircraft, but the flying direction is not in line with the trust. The angle of attack [α] and the angle of climb [γ] give the line of the chord of the airfoil of the aircraft, but for the next calculations assuming that the thrust is in line with the aircraft chord. The direction of flight [DOF] can be determined with the angle of climb from the horizontal line **(Figure 1.3)**. The lift of the aircraft in flight is also perpendicular to the direction of flight. The drag works in the opposite direction of the DOF in line of the incoming airflow.

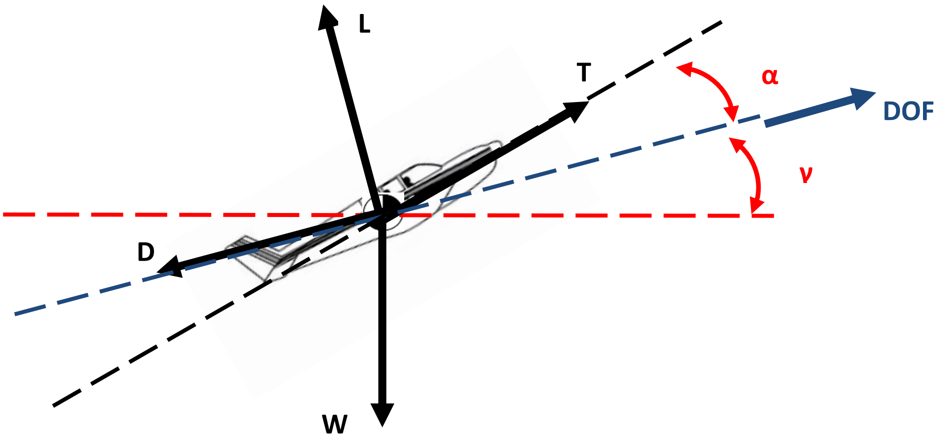


Figure 1.3; Climb Angle

1.1.2.b Climb Ratio

The aircraft's vertical speed is also referred as rate of climb, which is the change in altitude **(Figure 1.4)**. The expression is in feet per minute although sometimes it is possible to express the rate of climb in meter per second. There is also a rate of descent or sink rate. Decreasing in altitude corresponds with a negative rate of climb. If there is a lot of thrust, the induced drag will be lower. And when the weight is less the better the climb performance will be. More power means also a higher rate of climb. The rate of climb depends the angle of climb. The rate of climb can be calculated by True Air Speed [TAS] times sinus gamma **(Equation 1.2)**.

Equation 1.2		
Rate of Climb		
$$\boldsymbol{Rate\ of\ Climb = TAS\ \times \sin\gamma}$$		
Symbol	**Variable**	**Unit**
$\boldsymbol{Rate\ of\ Climb}$	Rate of climb	Meter per second [m/s]
$\boldsymbol{TAS}$	True Air Speed	Meter per second [m/s]
$\boldsymbol{\sin\gamma}$	Sinus Gamma	Degrees [°]

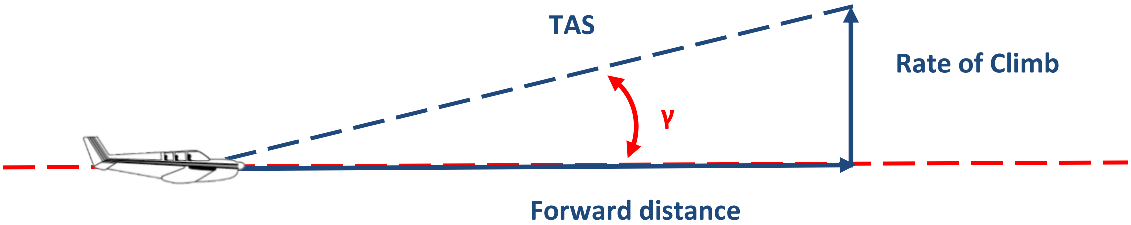


Figure 1.4; Climb Ratio

1.1.3 Glide performance

Now the climb performance are calculated, almost the same equations to calculate the glide performance. When the engine is off there is no thrust component and the aircraft will decrease of height. The decrease of height can be seen as glide angle **(1.1.3.a)**. It is then also possible to determine the glide ratio **(1.1.3.b)** which can result in the optimal glide performance.

1.1.3.a Glide Angle

The glide sketch has almost the same components as the climb sketch but during glide the engine is shut down, so there is no thrust component in the sketch **(Figure 1.5)**. The angle of attack can still be positive of the horizontal line, only without a thrust component the DOF changes. The glide angle is negative relative to the horizontal line. The glide angle can be calculated with the lift and drag component **(Equation 1.3)**.

Equation 1.3		
Glide Angle		
$$\tan\gamma = \frac{1}{\left\{\frac{L}{D}\right\}}$$		
Symbol	**Variable**	**Unit**
$\tan\gamma$	Glide angle	Degrees [°]
L	Lift	Newton [N]
D	Drag	Newton [N]

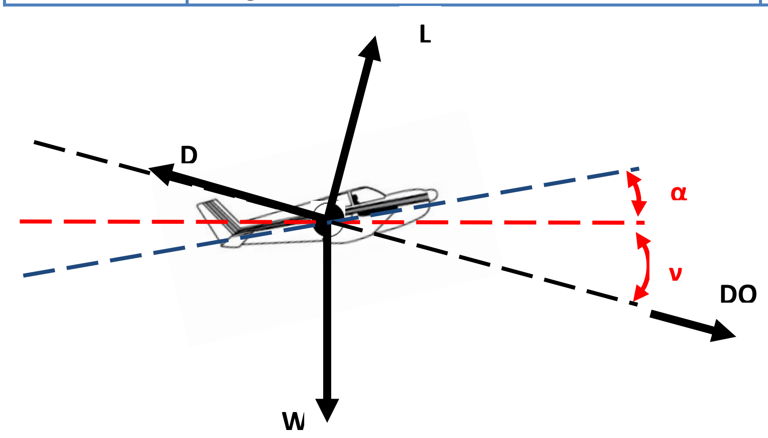


Figure 1.5; Glide Angle

1.1.3.b Glide Ratio

The rate of glide is about the same as the rate of climb, but the thrust is the missing component because during the glide the motor is turned off. The aircraft will not have an upward vector but a downward vector, so the aircraft is descending **(Figure 1.6)**.It is important to maintain the airspeed. In addition, it is also important to put the aircraft at a specific attitude that the gravity force component is in the direction of speed vector, which balances the drag factor. With the TAS and the glide angle the rate of glide can be calculated **(Equation 1.4)**.

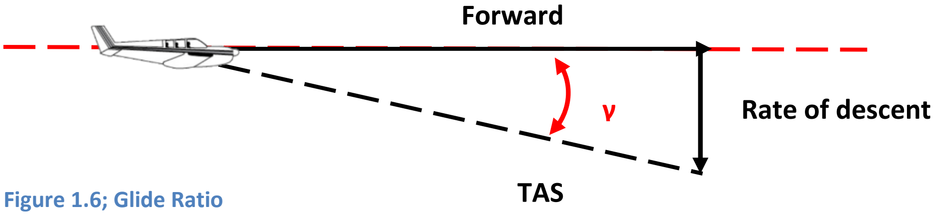


Figure 1.6; Glide Ratio

Equation 1.4		
Rate of Glide		
$$Rate\ of\ Glide = TAS\ \times \sin\gamma$$		
Symbol	**Variable**	**Unit**
$Rate\ of\ Glide$	Rate of Glide	Meter per second [m/s]
TAS	True Air Speed	Meter per second [m/s]
$\sin\gamma$	Sinus Gamma	Degrees [°]

1.1.4 Axes of movement

In order to understand the movements of an aircraft, it is important to know the axes. There are three different kinds of exes whereby the aircraft will rotate. The normal Axis or yaw axis **(1.1.4.a)**.The Lateral Axis **(1.1.4.b)** will pitch the nose of the aircraft and the Longitudinal Axis **(1.1.4.c)** will roll the aircraft.

1.1.4.a Normal Axis

The top axis is an imaginary line that goes vertically through the center of gravity of the aircraft **(Figure 1.7)**. A twist to the top axis is a change in the horizontal direction, affecting the direction nose of the aircraft points horizontally. In order to prevent unintentional movements of an aircraft, the aircraft is equipped with a vertical tail stabilizer. Sometimes the pilot wants to make a coordinated turn, therefore the aircraft will yaw intentionally using the rudder.

1.1.4.b Lateral Axis

With the lateral axis the aircraft will pitch. The lateral axis is an imaginary line that goes horizontally between the wingtips **(Figure 1.7)**. A twist in the lateral axis, the position of the nose will change the vertical direction. The pitch will change and will influence the lift. The aircraft is equipped with elevators to intentionally affect the pitch.

1.1.4.c Longitudinal Axis

With the longitudinal axis the aircraft tend to roll. The longitudinal axis is an imaginary line that goes from the nose to tail **(Figure 1.7)**. A twist in the longitudinal axis, the bank angle will change. Through the change in angle de lift will change also. Increasing the lift of one wing will decrease on the other. This lift differential is caused by bank rotation. In order to make an intentional rolling movement, the aircraft is equipped with ailerons. Combining role and yaw, the aircraft will make a coordinated turn.

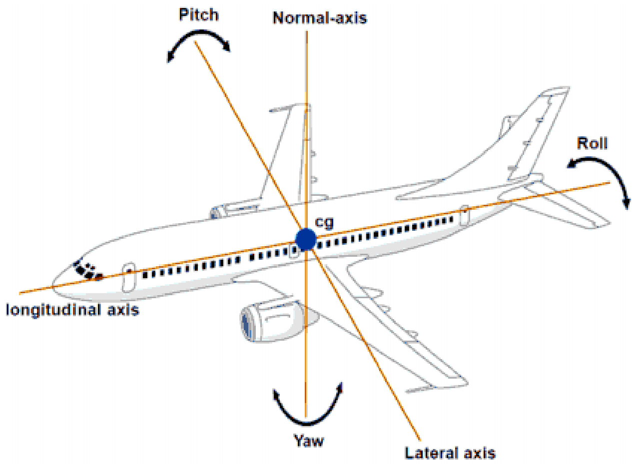


Figure 1.7; Axis of movement

1.2 Glider Basics

Gliders do have different characteristics than conventional airplanes. Because of the lack of propulsion the design of the airplane can be done in a different way. One of the most distinctive features of a glider is the large aspect ratio and the related Oswald factor **(1.2.1)**. Also the airfoil **(1.2.2)** of the glider determines the specific characteristics of a glider. And to allow long gliding flights the glide ratio has to be designed as high as possible **(1.2.3)**.

1.2.1 Aspect Ratio and Oswald Factor

Two very important properties of a fixed wing airplane are the aspect ratio **(1.2.1.a)** and Oswald factor **(1.2.1.b)**. Both of these fundamentally determine the flying characteristics of the airplane. Another feature that is important for the design of the airfoil of the wings is the Reynolds number **(1.2.1.c)**.

1.2.1.a Aspect ratio

The aspect ratio AR indicates the ratio between the wing span b and the wing mean aerodynamic chord MAC **(Equation 1.5)**. Example: a wing with a relatively large wingspan compared to the mean aerodynamic chord will have a larger aspect ratio than a wing with a relatively small wingspan compared to the mean aerodynamic chord. It can also be described as the ratio between wingspan squared and wing surface **(Equation 1.6)**. It must be mentioned that this formula is only applicable to wings with a rectangular plan form.

Equation 1.5

Aspect Ratio

$$AR = \frac{b}{MAC} = \frac{b^2}{S}$$

Symbol	Variable	Unit
AR	Aspect ratio	"dimensionless"
b	Wingspan	Meters [m]
MAC	Mean aero dynamical chord	Meters [m]
S	Wing surface	Square meters [m^2]

The aspect ratio influences several flight characteristics such as the wing lift curve slope, lift-to-drag ratio and induced drag. The wing lift curve slope C_L is directly proportionally influenced by the AR as can be derived from **Equation 1.6**, meaning a larger AR is preferred for a higher wing lift curve slope. The larger C_L as a result of a larger AR is caused by the fact that a wing gets more similar to a 2D airfoil lift curve slope C_l as the wingspan increases. As a result of that, the C_L increases more towards the theoretical maximum lift coefficient.

Equation 1.6

Lift curve slope

$$C_{L_\alpha} = \frac{C_{l_\alpha}}{1 + \frac{C_{l_\alpha}}{\pi * AR}}$$

Symbol	Variable	Unit
C_{L_α}	3D wing lift curve slope	"dimensionless"
C_{l_α}	2D airfoil lift curve slope	"dimensionless"
AR	Aspect ratio	"dimensionless"

Another characteristic of the airplane that is affected by the AR is the maximum lift-to-drag ratio **(Equation 1.7)**. The wing induced drag factor is known by K. It can be inferred that an increase of the AR results in a larger maximum lift-to-drag ratio. For glider design is a higher maximum lift-to-drag ratio preferred.

Equation 1.7

Lift drag ration

$$\frac{L}{D}_{max} = \frac{1}{2\sqrt{KC_{D_0}}} \quad where \quad K = \frac{1}{\pi * e * AR}$$

Symbol	Variable	Unit
$\frac{L}{D}_{max}$	Maximum lift-to-drag ratio	"dimensionless"
$\mathbf{K}$	Wing induced drag factor	"dimensionless"
C_{D_0}	Zero drag coefficient	"dimensionless"
e	Oswald factor	"dimensionless"
$\mathbf{AR}$	Aspect ratio	"dimensionless"

Also a smaller induced drag coefficient **(Equation 1.8)** can be obtained by increasing the AR. Furthermore, a higher angle of attack caused by a higher AR shows an increase of the wing stall angle.

Equation 1.8		
Lift drag ration		
$$C_{D_i} = \frac{C_L^2}{\pi * e * AR}$$		
Symbol	**Variable**	**Unit**
C_{D_i}	Induced drag coefficient	“dimensionless”
C_L	3D lift coefficient	“dimensionless”
e	Oswald factor	“dimensionless”
AR	Aspect ratio	“dimensionless”

Besides, the lateral maneuverability is increased with a smaller AR due to the mass moment of inertia around the lateral axis. However there are a lot of aspects preferring a larger AR, there is a certain limit. This is caused by the structural limits of the wing construction. Also a larger AR results in more weight, as there are other construction methods needed for a very wide wing. Both another construction and adding more weight could result in higher building and operational costs. A typical glider should have an AR of at least 20, varying to 40.

1.2.1.b Oswald efficiency number

The Oswald efficiency number is used to correct the change of drag with lift that occurs in real wings. This effect is caused by the 3D-aspects of a wing compared to an ideal 2D wing. The Oswald factor can be determined using **(Equation 1.9)** in the case of a wing with a leading edge sweep less than 30°. For wings with a wing leading edge sweep higher than 30°, **(Equation 1.10)** must be used. A higher Oswald factor leads to higher maximum lift-to-drag ratio $\frac{L}{D_{max}}$ and a lower Induced drag coefficientC_{D_i}.

Equation 1.9		
Oswald factor for straight wings		
$$e = 1.78 * \left(1 - 0.045 * AR^{0.68}\right) - 0.64$$		
Symbol	**Variable**	**Unit**
e	Oswald factor	“dimensionless”
AR	Aspect ratio	“dimensionless”

Equation 1.10		
Oswald factor for swept wings with sweep a sweep angle more than 30°		
$$e = 4.61 * \left(1 - 0.045 * AR^{0.68}\right) * (cos(\Lambda_{LE}\,)^{0.15} - 3.1$$		
Symbol	**Variable**	**Unit**
e	Oswald factor	“dimensionless”
AR	Aspect ratio	“dimensionless”
Λ_{LE}	Leading edge sweep	Degrees [°]

1.2.1.c Reynolds number

During the design process of the wings, *Cl/Cd* diagrams will be necessary to understand the differences between the different airfoil characteristics. Each airfoil does have its own *Cl/Cd* diagrams, where also different diagrams per Reynolds number specified. To determine which diagrams are relevant, the Reynolds number **(Equation 1.11)** has to be calculated. The Reynolds number indicates whether the air flow is laminar or turbulent.

Equation 1.11		
Reynolds number		
$$Re = \frac{\rho * v * l}{\mu}$$		
Symbol	**Variable**	**Unit**
Re	Reynolds number	“dimensionless”
ρ	Density of the air	Kilogram per cubic meter [water: 1.225 kg/m3]
v	Velocity	Meter per second [m/s]
l	Length of the cord	Meter [m]
μ	Dynamic viscosity	Pascal second [air: $17.897*10^{-6}$ Pa*s]

1.2.2 Airfoils

The type of airfoil depends on the kind of airplane. First the components of an airfoil and the characteristic diagrams will be explained **(1.2.2.a).**Airfoils can be divided in three types: symmetrical airfoils **(1.2.2.b)**, semi-symmetrical airfoils **(1.2.2.c)** and flat bottom airfoils **(1.2.2.d).** The properties of the three types of airfoils will be explained with the aid of the characteristic diagrams.

1.2.2.a Characteristics of an airfoil

An airfoil is a cross section of the wing. The shape depends on the type of airplane, but every airfoil consists of the same components **(Figure 1.8).** The total length of the airfoil is the chord **(1)**. The front is the leading edge **(2)** and the back is the trailing edge **(3)**. The leading edge can be seen like a circle, which is the leading edge radius **(4)**. The curve of the airfoil is designated as camber line **(5)**, which divides the upper camber **(6)** and the lower camber **(7)**. The angle of attack **(8)** has also influence on the lift. A diagram can be made for every airfoil with the lift coefficient plotted against the angle of attack **(Appendix II)**.

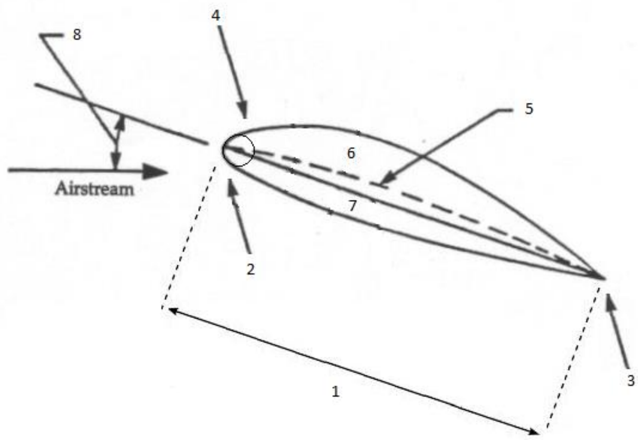


Figure 1.8; Characteristics of an airfoil

The curve in the diagram depends on the type of airfoil. At a certain angle, the lift coefficient will not increase more, which is the critical angle of attack. If the angle will increase more, the airflow will separate from the wing, which is known as stall.
A diagram can be made with the relation between the lift- and drag coefficient **(Appendix IIB)**. From this diagram the optimal lift/drag ratio can be determined. The drag coefficient increases with the thickness. By increasing the thickness to 15 percent of the chord length, the lift coefficient will increase as well. The lift coefficient will decrease by increasing the thickness more than 15 percent chord length. The trailing edges radius has effect on the sharpness of the stall curve. A bigger radius gives a gentler stall curve than a smaller radius. Increasing the camber line will result in a higher lift coefficient with an angle of attack of zero degrees.

1.2.2.b Symmetrical airfoils

A symmetrical airfoil is identical along the chord line. These types are used for aerobatic airplanes, because they provide also lift flying upside down. By a symmetrical airfoil, at an angle of attack of zero degrees, there is no lift **(Figure 1.9)**. The lift/drag ratio is not very favorable.

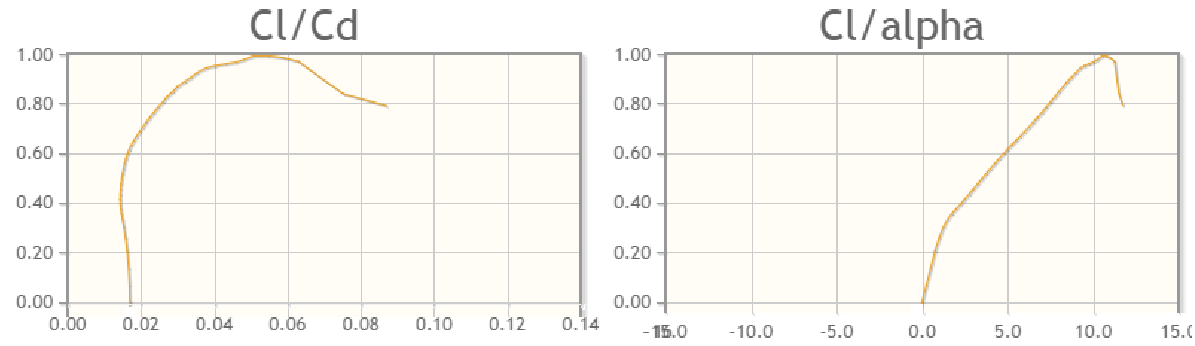


Figure 1.9; CL Graphs

1.2.2.c Semi-symmetrical airfoils

The upper camber is bigger than the lower camber. Gliders are using these airfoils because it provides a good lift/drag ratio. Another advantage is that it provides lift at an angle of attack of zero degrees**(Figure 1.10)**.

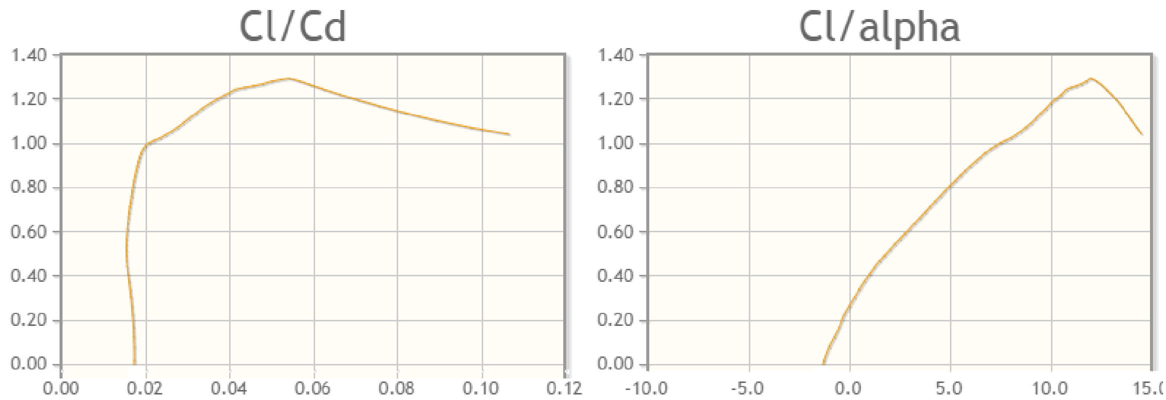


Figure 1.10; CL Graphs

1.2.2.d Flat bottom airfoils

The lower surface is parallel to the chord line. The advantage of flat bottom airfoils, is that there can be flown with a very low velocity. In the Cl/alpha graphic is showed that the lift coefficient is higher than the other two type of airfoils. The disadvantage is when there will be flown faster, it will produce more drag than the other airfoils **(Figure 1.11)**.

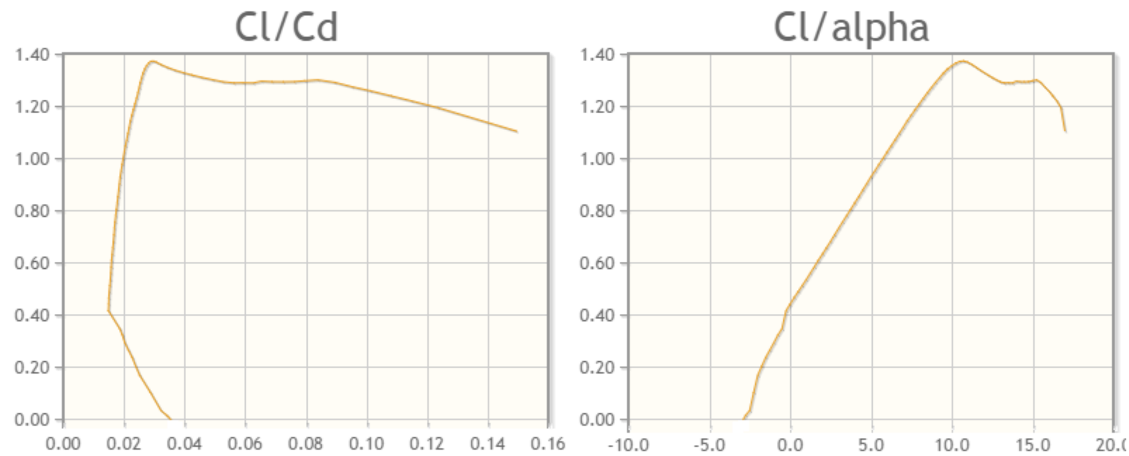


Figure 1.11; CL Graphs

1.2.3 Glide Ratio

The glide ratio expresses the forward distance against the altitude. The glide ratio applies only to an unpowered airplane. For example, a glider flies 40 meter forwards and descents 1 meter, the glide ratio will be 1:40. The glide ratio depends on the type of airfoil. To find the optimal lift/drag ratio a straight curve from the axis origin has to be made **(Figure 1.12)**. This indicates the most efficient lift coefficient with the corresponding most efficient drag coefficient. With the lift coefficient, the favorable angle of attack can be determined

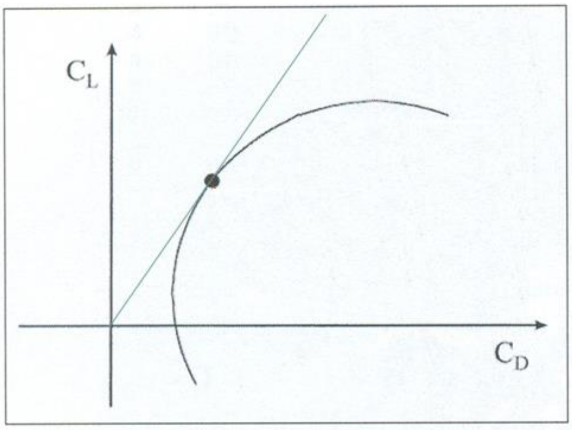


Figure 1.12; Cl/Cd

1.3 Construction

There are lots of different possibilities to design an airplane with the required flight characteristics and the associated glider model properties. The most important part of the airplane is the wing, where various properties can be chosen **(1.3.1)**. Then the tail properties **(1.3.2)** have to be determined. Also the fuselage requirements must be known to design the fuselage **(1.3.3)**. Normally in the front of the aircraft there is a propeller for the propulsion **(1.3.4)**. At last there must be designed a landing gear for save landing, take off and ground maneuvering **(1.3.5)**.

1.3.1 Wing

The construction of the wings is one of the most important design aspects during the design phase of an aircraft, because the wings have a major impact on the overall characteristics of the aircraft. The number wings **(1.3.1.a)** and the vertical wing location **(1.3.1.b)** must be determined. Also the taper ratio **(1.3.1.c)**, dihedral angle **(1.3.1.d)** and wing sweep **(1.3.1.e)** will be explained. Then the construction of the wing will be explained **(1.3.1.g)**.

1.3.1.a Number of wings

In the past there were some construction related issues that caused the need for two **(Figure 1.13b)** or three wings **(Figure 1.13c)**. Nowadays airplanes are almost always equipped with a one wing configuration **(Figure 1.13a)**. A reason for two or three wings could be to increase the maneuverability, which is caused by the two shorter wings. Since this project is about designing and building a glider and the construction of a two meter wide wing, one wing is sufficient.

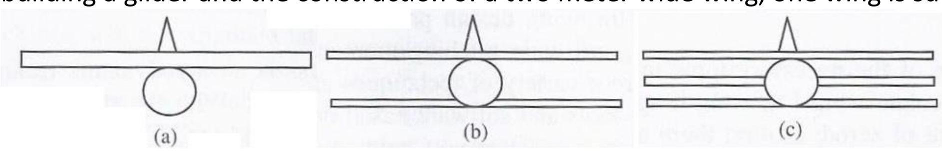


Figure 1.13; Different number of wings constructions

1.3.1.b Vertical wing location

There are mainly three different types of vertical wing location, each having a number advantages and disadvantages. These types can be divided by 'high wing' **(Figure 1.14a)**, 'mid-wing' **(Figure 1.14b)** and 'low wing' **(Figure 1.14c)**.In this paragraph, only the properties that apply to gliders will be discussed. The high wing structure has as advantages that it is suitable for using a strut that can carry higher tensile stresses. The use of a strut could decrease the weight of the wing construction. High wing constructions let the weight of the fuselage contribute to the lateral stability of the airplane. Mid wings do have smaller front surface, decreasing drag. It is also more streamlined and it creates less interference drag than the other vertical wing location types. In most airplanes, the fuselage space is used for passengers or cargo which means the wing spar must be cut and a strut for reinforcement of the wing structure must be provided. The low wing structure has a better take off performance due to the greater ground effect. Also a gear retraction system can be built into the wing using less space because of the smaller retraction system. Since no strut is necessary, the airplane will be lighter. Because the wings have a smaller downwash on the tail, the tail surfaces are more effective. This results in a lighter tail section. The airplane will have less lateral stability due to the fuselage weight that is now located above the wings.

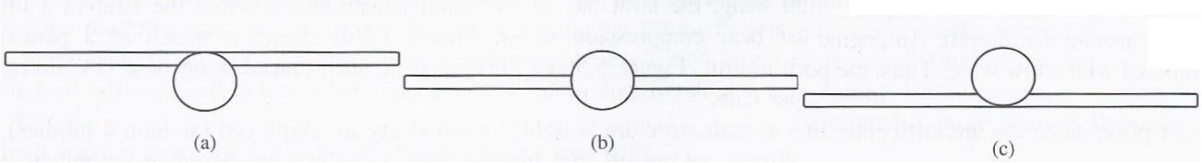


Figure 1.14; Different vertical wing location types

1.3.1.c Taper ratio

The taper ratio is the ratio between the tip chord and the root chord of the wings. The taper ratio can also be applied to the horizontal tail and the vertical tail. The definition of the taper ratio is defined in **(Equation 1.12)**. There are three main taper ratios that can be described as: rectangular (λ = 1) **(Figure 1.15a)**, trapezoidal (0 <λ< 1) **(Figure 1.15b)** and Triangle/delta shaped (λ = 0) **(Figure 1.15c)**. Wing tapering is used to improve lift distribution characteristics. It creates the possibility to design the wings with a more elliptical lift distribution, which can be positive for the characteristics. However, the use of wing tapering means that the wing ribs (when used) each will be shaped differently, which can result in higher production costs. The use of wing tapering will result in better lateral control, since the mass moment of inertia of the wings around the longitudinal axis will be less.

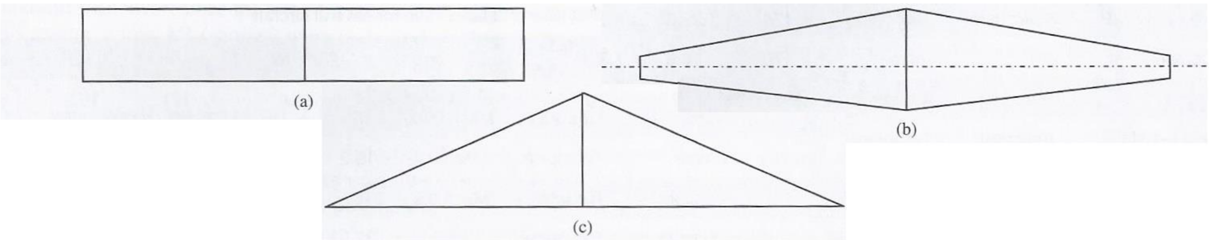


Figure 1.15: Different taper ratios

Equation 1.12		
Lift Coefficient		
$\lambda = \frac{C_t}{Cr}$		
Symbol	**Variable**	**Unit**
λ	Taper ratio	"dimensionless"
C_t	Tip chord	Meter [m]
Cr	Root chord	Meter [m]

1.3.1.d Dihedral angle

The dihedral angle Γ is the angle between the wing and the xy plane. If the wing tips are above the xy plane, the angle is called (positive) dihedral **(Figure 1.16a)**. If the wing tips are under the xy plane, the angle is called anhedral or negative dihedral **(Figure 1.16b)**. Both left and right sections of the wing have their own dihedral angle, but they must be the same for the symmetry of the airplane. The dihedral angle affects the lateral stability of the airplane. The lateral or dihedral stability can be described as the tendency of the aircraft to get back to the stable flight situation during a roll or influences by the wind.

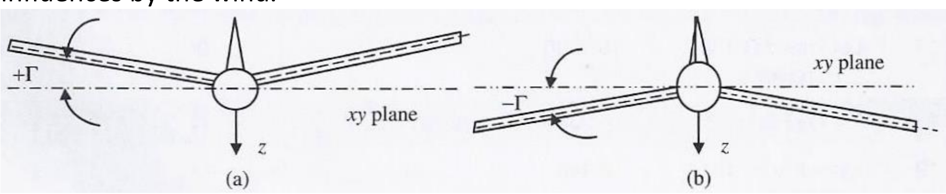


Figure 1.16: Dihedral angle and anhedral angle

1.3.1.e Wing sweep

The wing sweeps are the angles between the wing edges and the longitudinal y axis of the airplane as seen from above. There are two types of wing sweep: leading edge sweep (Λ_{LE}) and trailing edge sweep (Λ_{TE}). The leading edge sweep can be described as the angle between the wing leading edge and the y axis. The trailing edge sweep can be described as the angle between the wing trailing edge and the y axis. One of the reasons of applying a swept wing is to improve aerodynamic characteristics during transonic and faster speeds. However due to the project assignment, this will not be discussed here.

1.3.1.f Winglets

Winglets are almost vertical extensions of the wings that reduce induced drag. Tip vortices are created because of the difference in air pressure above and under the wing. This results in more induced drag and reduced lift at the wingtips. The loss in lift can be compensated by creating longer wings or adding winglets that also reduce induced drag. The induced drag may be reduced, but the parasitic (form) drag is increased while using winglets. Nevertheless, the loss of induced drag has more advantages and parasitic drag is only significant at higher speeds.

1.3.1.g Wing construction

The most common wing structure for smaller aircraft is the wing-box design **(Figure 1.17)**.Hereby the wing construction consists of spars, ribs and the skin to form a box. There are two spars, the front spar **(1)** and the rear spar **(2)**.The spars will handle the tension and compression forces on the wing. The spars are attached to the fuselage so they can transfer the forces to the fuselage, where it will be spread over the entire construction. The ribs **(3)** are intended to give the wing the right airfoil and also stabilize the construction. They provide rigidity and strength in the wing. The ribs transfer the forces from the skin **(4)** to the spars. The skin is also a part of the construction to resist the forces on the wing.

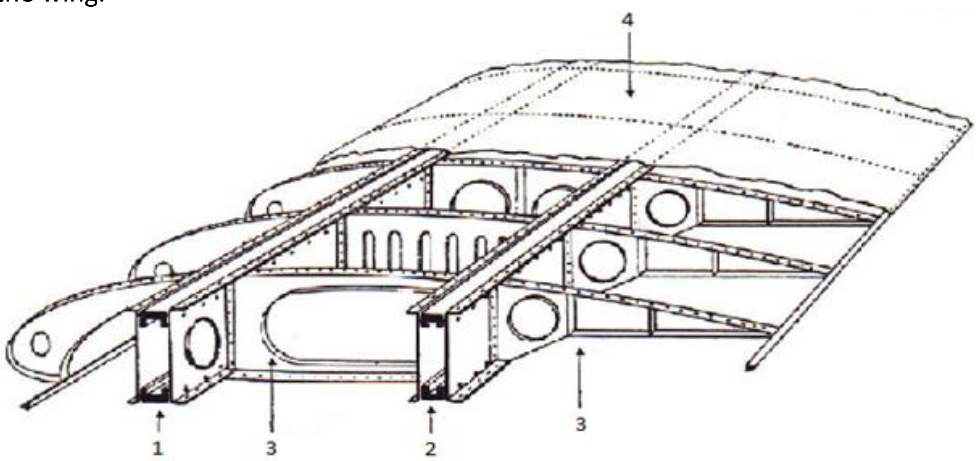


Figure 1.17; Wing box design

1.3.2 Tail

After the design of the wing, the next step in the design process is the design of the tail. The purpose of the tail is to ensure longitudinal and directional stability to the airplane. The tail provides stability and the feature of control and trim in the directions mentioned above. There are several types of aft tail configurations, but only a few will be discussed here. These types are:

1. Conventional tail
2. T-tail
3. Cruciform tail
4. V-tail

Ad 1. *Conventional tail*

The conventional tail is the simplest type of aft tail configuration and is very lightweight. It consists of a vertical surface and a left and right section of the horizontal surface. It is the most used configuration and performs in a regular way.

Ad 2. *T-tail*

The T-tail configuration consists of a vertical surface mounted on the tail and a horizontal surface mounted on the vertical section of the tail. It has the advantage that the surfaces are not affected by unwanted wing air flows such as wing wake and downwash and vortices. This makes the T-tail configuration very efficient. Furthermore, there will appear fewer vibrations since the surfaces of the tail can be smaller due to higher efficiency. However there are some disadvantages of this structure. The structure may be heavier due to the construction that is needed for this tail configuration. Also T-tail configuration creates the risk of deep stall.

Ad 3. *Cruciform tail*

The cruciform is a combination of the conventional tail and the T-tail. This configuration combines the advantages and disadvantages of both types, which can be the best option in some cases.

Ad 4. *V-tail*

The V-tail combines the horizontal and vertical surfaces of a conventional tail configuration. It is used to reduce the tail surface area. The conventional inputs for the horizontal and vertical control surfaces are combined to create one input for the V-tail. The diagonally configured surfaces consist of a horizontal (x) and vertical (y) component, which creates the ability to control both longitudinal and directional directions. Although a reduced tail surface area slightly reduces drag, an amount of extra unnecessary drag is created in some situations. For example, if the V-tail control surfaces are moved upwards to create a moment of forces to nose-up the airplane. In that case, two forces of both sides of the V-tail in y-direction are added together to create the pitching moment. But also two (opposite) forces in x-direction are created, which cancel each other. However this creates unnecessary drag that negatively influences the performance of the airplane.

1.3.3 Fuselage

After the wing and tail has been designed, the fuselage must be designed. During the design phase of the fuselage, the functions and requirements of the tail must be determined. This includes the accommodation for payload and people such as crew and passengers. Also space must be provided for systems, energy source, motor/engine(s) and mechanical structures. Besides, the fuselage should generate as less drag and weight as possible. Eventually there should be made some compromises between these requirements. Since the project assignment implies the designing of an RC glider without the need to carry payload or people, these primary functions of the fuselage are no longer a requirement for the fuselage. Providing space for the required electronics and mechanical structure and ensure good aerodynamics, stability (correct weight distribution) and a low weight are the most important demands for sufficient flight. In the case of this project, the costs are not a big issue. When the design requirements are determined, the optimum length-to-diameter ratio can be calculated. The optimum length-to-diameter ratio indicates the ratio between the length and the diameter of the fuselage. At the optimum value of this ratio, the lowest zero-lift drag that the fuselage can create is obtained.

There are a three basic structure types to construct a fuselage; the truss construction **(1.3.3.a)**, the monocoque construction **(1.3.3.b)** and the semi-monocoque construction **(1.3.3.c)**.The monocoque variants depend on the strength of the skin and the truss type depends on the strength of the beams. Every structure type has its own advantages and disadvantages.

1.3.3.a Truss construction

The frame is made with beams and tubes **(Appendix III)**. It consists of longerons and struts. Too reinforce and rigid the frame, there has to be between every struts diagonal struts. This technique is used by small light weighted aircrafts. The skin is not used for the strength, the strength of the frame is based on the internal beams.

1.3.3.b Monocoque construction

The skin is the primary structure of the fuselage **(Appendix IIIB)**. It is attached on multiple formers to create the right shape. The skin has to be very strong because it will handle all the stress of the fuselage. The main issue is to construct the fuselage light weighted. Reducing the skin thickness will reduce also the strength of the fuselage.

1.3.3.c Semi-monocoque construction

The formers are reinforced with stringers that are following the longitudinal axis **(Appendix IIIC)**. The stringers and the skin are carrying together the stress. This method is very useful for bigger aircrafts. The skin can be made thinner, but with the stringers the fuselage is able to resist the stress.

1.3.4 Propeller

The use of a propeller is a one possible way of propulsion of the airplane. The propeller converts the power of the rotating axis of the motor to accelerated air. The characteristics of the propeller are determined by the length and the pitch of the blades. The length of the blades creates a surface area where air is accelerated. The pitch of the blades specifies the distance that is passed during one full revolution. Together with the rotation speed of the axis, the volume/mass flow and speed of the accelerated air can be calculated. With these data, the thrust can be calculated. In the RC world not only fixed propellers are used but also folding propellers are available. These folding propellers have the advantage that the blades fold to the nose of the airplane when not rotating and thereby create less drag.

1.3.5 Landing Gear

The first phase in the design of a landing gear is to decide what configuration the landing gear should be. Since this project is about the design of a glider, only the plausible landing gear configurations for a glider will be listed and explained. These landing gear configurations are applicable for a glider:

1. No landing gear
2. Skid landing gear
3. Single main landing gear
4. Bicycle landing gear
5. Tail landing gear

Ad 1. *No landing gear*

Although in real aviation there are always landing gears used, in the RC world exists the option of simply designing an airplane without a landing gear. It is not very often used, but if the RC airplane is very light, flies really slow and the fuselage is strong enough, it is possible to land without a landing gear. No landing gear is the most lightweight option.

Ad 2. *Skid landing gear*

As a possible compromise between the weight efficiency of no landing gear and the airplane protective option of a landing gear there is the option of implementing skid. The skid gear consists of special surfaces that are used to slide over the ground. The skid surfaces could wear very vast if an insufficient material is used. However, if an RC aircraft intended for taking off and landing on grass is used, the material should only be able to carry the weight and wear is not a big problem.

Ad 3. *Single main landing gear*

The single main landing gear **(Figure 1.18a)** is the simplest implementation of a landing gear with two wheels located on the longitudinal axis of the airplane. It consists of one big wheel underneath the fuselage near the main wings that carries almost the complete airplane. A second relatively very small wheel is located under the nose or under the tail. In the case of a small wheel under the nose, the main wheel is often located just behind the center of gravity. The main wheel is often located just in front of the center of gravity. The construction of a single main landing gear is very simple since there is often no retraction system used. However there is the advantage that the airplane is very unstable on the ground and there could occur wear at the wing tips during maneuvering on the ground.

Ad 4. *Bicycle landing gear*

The bicycle landing gear **(Figure 1.18b)** consists of two approximately similar sized wheels that are aligned along the longitudinal axis. It can be seen as a variation of the single main landing gear where the fundamentally smaller wheel has been replaced by a wheel that has a more similar size as the main wheel. Just like the single gear the bicycle gear has the disadvantage of reduced ground stability. But it has the advantage of low weight. As an extension, each wingtip could be supplied with a small wheel to reduce the risk of a wing deflecting the airplane to one side during ground contact.

Ad 5. *Tail landing gear*

The tail landing gear **(Figure 1.18d)** consists of three wheels including two main wheels that are located on the front side of the airplane center of gravity and one small wheel located under the tail. In this configuration, the airplane is not leveled during ground maneuvering. This means that a take-off requires a longer distance to gain enough speed, because of the high angle of attack caused by the tilted position of the airplane. Besides there is the possibility of losing control during ground maneuvering caused by a ground loop. There is also a higher risk of 'nose-over' accidents, where the nose of the airplane gets into the ground as a result of a wrong mechanical moment along the lateral axis.

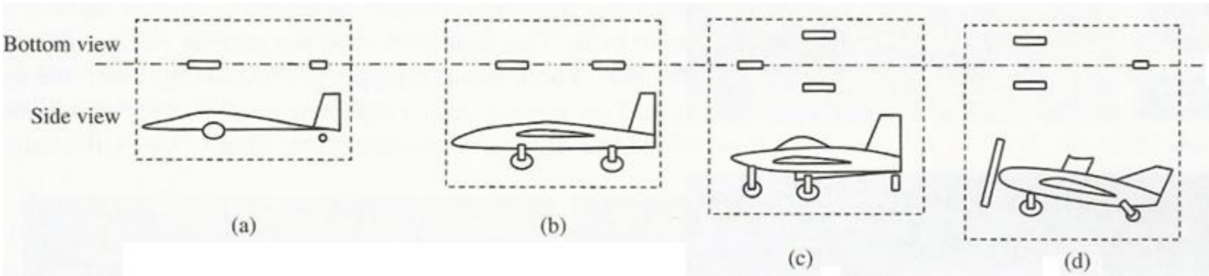


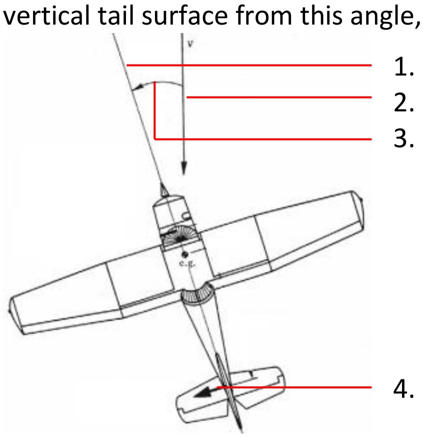
Figure 1.18; Different landing gear configurations

1.4 Aircraft stability

An aircraft in flight is constantly exposed to forces that disturb it from its flight path. It is desirable for a glider to be positively stable, meaning it will restore itself into horizontal flight. Stability may be directional **(1.4.1)**, lateral **(1.4.2)** or longitudinal **(1.4.3)** for each of the three axes.

1.4.1 Directional stability

Directional stability is the stability around the vertical axis, and is also known as yawing stability. The vertical tail surface enhances the stability when a destabilizing force around this axis causes the airplane to divert from facing the relative airflow head-on **(Figure 1.19)**. If there is a difference between the heading **(1)** and the airflow **(2)**, there is a sideslip angle **(3)**. When the airflow hits the vertical tail surface from this angle, it will generate lift as a stabilizing force **(4)**.



1. Heading
2. Relative airflow
3. Sideslip angle
4. Stabilizing force

Figure 1.19; Directional stability

1.4.2 Lateral stability

Lateral stability is stability around the longitudinal axis, and is also known as roll stability. Lateral stability can be achieved through dihedral wing configuration **(1.4.2.a)** or high wing placement on the fuselage **(1.4.2.b)**.

1.4.2.a Dihedral

A wing configuration is positively dihedral when the tip of the wing is elevated relatively to the base of the wing. When an airplane banks it will accelerate sideways, which causes the lower wing to experience a greater angle of attack towards the relative airflow than the raised wing, and results in greater lift for the lowered wing as can be seen in **Appendix IV**. The difference in angle of attack can be calculated using **(Equation 1.13)**.
Dihedral wing settings also provide spiral stability for sailplanes during thermal turns.

Equation 1.13		
Static Margin		
$$\Delta\boldsymbol{\alpha} = \boldsymbol{\beta} \cdot \sin\Gamma$$		
Symbol	**Variable**	**Unit**
$\Delta\boldsymbol{\alpha}$	Difference in a.o.a. of lowered wing	Degrees
$\boldsymbol{\beta}$	Difference between heading and relative airflow	degrees
Γ	Dihedral angle	degrees

1.4.2.b Wing placement

High or low wing placement affects the airplane lateral stability. When the wings are placed high on the airplanes fuselage, the center of mass is located below the lift created by the wings and will stabilize a rolling airplane, which is known as the pendulum effect.

1.4.2.c Keel effect

For an airplane with its wings mounted to the top of the fuselage, there is a so-called keel effect **(Figure 1.20a)** that occurs when banking. The airflow around the body of the aircraft that is caused by the sideslip creates a stabilizing force when the airflow is obstructed by the top mounted wings.

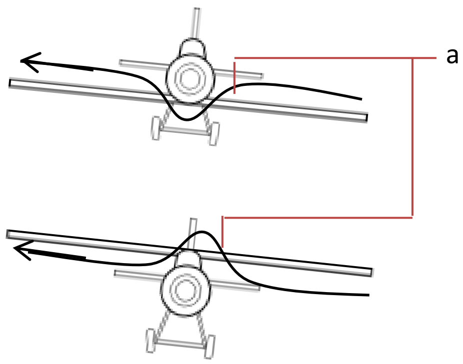


Figure 1.20; Keel effect

1.4.3 Longitudinal stability

Longitudinal stability is concerned with an airplanes pitching motion. An airplane is statically stable in a longitudinal sense when moments are generated that return the airplane to the equilibrium when disturbed. The stability is affected by the tail volume **(1.4.3.a)** and the location of the center of gravity **(1.4.3.b)**.

1.4.3.a Horizontal tail volume

The distance between the main wings and the horizontal tail surface, as well as the surface area of the tail greatly affect the longitudinal stability. The stability can be enhanced through the right horizontal tail volume coefficient **(Equation 1.14)**. An aircraft is generally longitudinally stable when the coefficient is equal to or greater than 0.3.

Equation 1.14		
Tail volume coefficient		
$$\boldsymbol{V_h} = \frac{\boldsymbol{S_h} \cdot \boldsymbol{X_h}}{\boldsymbol{S_w} \cdot \boldsymbol{C}}$$		
Symbol	**Variable**	**Unit**
$\boldsymbol{V_h}$	Horizontal tail volume coefficient	*Dimensionless*
$\boldsymbol{S_h}$	Horizontal tail surface area, or horizontal reference	Square meters [m^2]

	area for a V-tail	
X_h	Distance between c.o.g. and tail aerodynamic center	Meters [m]
S_w	Wing gross area	Square meters [m^2]
C	Mean Aerodynamic Chord	Meters [m]

1.4.3.b Center of gravity

A rule of thumb to achieve positive longitudinal stability is to have the center of gravity at a third of the aerodynamic chord of the main wings. The stability can be enhanced more specifically through the static margin, which is used to characterize the static stability and controllability of airplanes. A longitudinally stable aircraft has a positive static margin, whereas the B-2 stealth bomber for example has a static margin of -0.1 to be highly maneuverable. The precise static margin can be calculated as follows **(Equation1.15)**.

Equation1.15

Static Margin

$$SM = \frac{X_{np} - X_{cg}}{C}$$

Symbol	Variable	Unit
SM	Static Margin	Percentage
X_{np}	Distance to aircraft neutral point	Meters [m]
X_{cg}	Distance to aircraft center of gravity	Meters [m]
C	Mean aerodynamic chord	Meters [m]

The neutral point is the aerodynamic center of the complete airplane, and is located behind the center of gravity for a stable aircraft. The distance to the aircraft neutral point can be calculated from the aerodynamic center of the wings **(Equation 1.16)**. For incompressible flow around thin airfoils, the aerodynamic center is located at a quarter chord of the wing.

Equation 1.16

Neutral point

$$h_{np} = h_{ac} + C_{Lw,\alpha} \cdot V_h \cdot \left(1 - \frac{d\varepsilon}{d\alpha}\right)$$

Symbol	Variable	Unit
h_{np}	Distance to aircraft neutral point	Percentage
h_{ac}	Distance to wing aerodynamic center	Percentage
$C_{Lw,\alpha}$	Lift coefficient slope for the main wing	*Dimensionless*
V_h	Tail volume coefficient	*Dimensionless*
$\frac{d\varepsilon}{d\alpha}$	Downwash gradient (see Appendix VII)	*Dimensionless*

1.5 Control

The flight controls are the moveable surface on an aircraft that allows the pilot to control the aircraft its direction and attitude during the flight. The flight controls systems **(Figure 1.21)** are being divided into the primary and the secondary flight controls **(Appendix V)**, however for a glider the primary flight controls are more relevant. The primary flight controls consist out of the aileron, **(1.5.1)** the elevator **(1.5.2)** and the rudder **(1.5.3)**, each of these flight controls has their own types and configurations, for example the ruddervator.

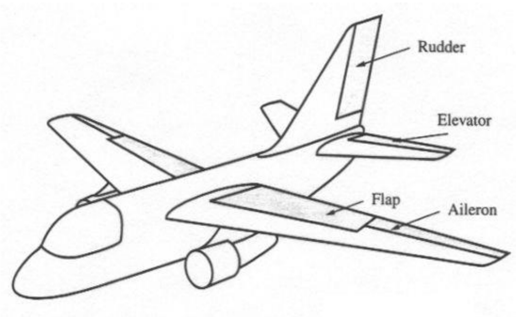


Figure 1.21; Primary flight controls of an aircraft

When the primary flight controls are being operated, the aircraft will rotate around the axes of motion. So the aileron controls the motion around the longitudinal axis, the elevator controls the motion around the lateral axis and the rudder controls the motion around the vertical axis. In the majority of the light and general aviation aircraft, it is common that the basic flight control systems are being operated mechanically, although they were being used on the oldest aircraft types. The mechanical components such as the cables and pulleys will transmit the movement of the flight deck controls to the control surfaces.

1.5.1 Aileron

The ailerons control the movement about the longitudinal axis of an aircraft, called a roll movement. The ailerons are located on the outboard trailing edge of each wing and will move in the opposite direction of each other. During the upward deflection of the right aileron the camber of wing reduces which will result in a decreased lift. Exactly the opposite will happen during a downward deflection of the left aileron, which will cause the camber of the wing increases, resulting in an increased lift where after the aircraft will roll to the right.
However by using the ailerons as mentioned above the left wing will not only increase in lift but will also cause an increase in drag. This will cause the wing to slow down which results in a rotating movement of the aircraft, this is called an adverse yaw. The solution to overcome the yaw is done by rudder input during entering and exiting of a turn. Furthermore there are a couple of engineering solutions, which includes differential ailerons and coupled ailerons and rudder.

1.5.2 Elevator

The elevator is a primary flight control surface, which affects the aircrafts pitch. In most cases an aircraft has two elevators located on the trailing edge of each half of the horizontal stabilizer. During operation the elevators are moved symmetrically in an upward or downward deflection. So when the elevator surface deflects downwards, the camber of the horizontal stabilizer increases resulting in an increased lift. This will cause a rotation around the lateral axis of the aircraft causing the aircraft to descent. The opposite happens when the elevator surface is deflected upwards.

1.5.3 Rudder

The third flight control surface of an aircraft is the rudder, which controls the rotation about the vertical axis of the aircraft. This movement is called the yaw. The rudder is located on the trailing edge of the vertical stabilizer and is mostly used to overcome the adverse yaw. When the rudder is deflected to the left, this will cause a rotation about the vertical axis, which will move the aircraft nose slightly to the left. The effects of the rudder increase with the aircraft its speed. So when flying at low speed, it is necessary to have a larger rudder input to achieve the same result as flying with high speed.

1.6 Materials

The knowledge and understanding of strength, properties and characteristics of materials is vital to construct and design an aircraft. Materials make an impact on shape, weight, stability and lifespan of a plane. For exactly this reason is the consideration of the physical properties during the designing phase essential. These physical and mechanical properties **(1.6.1)** and the difference between isotropic and anisotropic behavior **(1.6.2)** are elucidated in following paragraphs. To achieve high performance requirement the advantages of different material are combined into one part. This combination of several materials is called hybrid material **(1.6.3).** A comparison of the physical and mechanical properties of often used materials is shown in paragraph **(1.6.4).**

1.6.1 Physical and Mechanical Properties

Of primary concern in aircraft designing are the knowledge of general properties as hardness **(1.6.1.a),** density **(1.6.1.b),** strength **(1.6.1.c),** elasticity **(1.6.1.d),** ductility, toughness and so forth. By selection of suitable materials a lot of different requirements, needed for the aircraft design, can get accomplished. Therefore the knowledge of physical and mechanical characteristics of used materials is necessary. To be able to compare different materials with each other, the most important terms, which are important for aircraft designing, are explained in the following paragraphs.

1.6.1.a Hardness

The hardness can be described as the ability to resist being permanently deformed, when a load is applied. The resistance to abrasion and cutting action is also affected by hardness. Therefore hardness is a function of ductility, elastic stiffness, strain, strength, toughness and viscosity and temperature.

1.6.1.b Density

The volumetric mass, called density is the relationship between the mass of a material and its volume. Density is an important consideration of aircraft designing in order to ensure the proper weight and balance of an aircraft. Below the equation for definition of density is given.

1.6.1.c Strength

The strength of a material is defined as the capability to withstand an applied external load without deforming or breaking. It is one of the most important properties of materials to perform lightweight construction of aircraft.

1.6.1.d Elasticity

The ability of a material to deform when an external force is applied and return to its initial shape is called elasticity. In engineering, elasticity is described by two types of material parameters. The first parameter is called Young's modulus, which expresses which amount of force per area must affect the material to reach a given deformation. The unit modulus is the affecting force (Newton) per cross sectional area. With this value of elastic modulus it is possible to compare the elasticity of different materials. Therefore the higher the value of the modulus, the harder it is to deform the material. The other parameter, which is called elastic limit, determines the upper border of the elastic area. When the deformation overruns the elastic limit, the material gets plastic deformed and doesn't return back in the initial shape. The range below the elastic limit is described by hook's law, which states that the deformation behaves linear proportional to internal forces (stress) occurring in the material.

1.6.2 Isotropic and Anisotropic Properties

Materials are divided into two main groups, the isotropic- and anisotropic materials. An isotropic material distributes all the mechanical characteristics in every direction in an equal way. Some well-known examples for this kind of material are steel, aluminum and thermoplastic polymers. The other group is called anisotropic materials. The mechanical properties of this group are not in every direction equal. Some examples are wood, glass-, aramid- and carbon fiber. This type can carry high loads in just one direction but has bad properties in all the other directions. If the direction of an external force is known, anisotropic materials have the advantage to be able to get trued up in exactly the same orientation. By applying this method it is possible to save a lot of weight in aircraft structures.

1.6.3 Hybrid Materials

Trough combination of more materials in the same part, the physical and mechanical properties can get highly improved. This technique is also utilized to protect certain material of environmental influences. Hybrid materials are quite common used for aviation purposes like Fuselage, Wing structure and interior. Carbon- and glass composite is also a well-known representative for combination of several properties. The strength of the materials is shown in **Appendix VI**.

1.7 Regulations

There are different regulations that apply to Model Aircraft. Instead of the regulations from EASA, ICAO and the FAA, the regulation for model aircraft differ in each country. In the Netherlands these regulations are set up by the "Inspectie Leef omgeving en Transport" (ILT) and the Agency of Telecom. The regulations for model sailplane aircraft can be split up in three different parts. The transmitter and receiver frequencies **(1.7.1),** the regulations about flying with a model aircraft **(1.7.2)** and there are regulations that concern the structural integrity of the model aircraft.

1.7.1 Frequencies

There is standard transmitter/receiver frequencies designated for the use of model aircraft: The older 35mHz band, and the newer 2.4GHz band. Most of the new transmitters that are using 2.4GHz have a capability that is called Frequency-Hopping Spread Spectrum (FHSS). FHSS makes sure that there is no interference with other transmitters, and is therefore safer to fly.

1.7.2 Flight regulations

Beside the transmitter and receiver frequencies there are also some regulations about flying with a model aircraft. These regulations can roughly be divided into:

1. General regulation
2. Flight area
3. Height

Ad 1. *General regulation*

The first part of the general regulation is that the pilot should not endanger other persons. Another law in the regulations states that the pilot must be able see the model aircraft from his position on the ground. So officially it is not allowed to fly with first person view (FPV).

Ad 2. *Flight area*

The general part of the regulations states that the pilot should not endanger persons. This means that it is not allowed to fly above cultivation, large groups of people, highways, railroads and the CRT areas around airports.

Ad 3. *Height*

In normal situations above the ground and water it is allowed to fly op to 300 meters high when the flight area is located in the airspace class G (uncontrolled airspace).

The regulations about the frequencies and flight regulations can be found in **Appendix VIII**.

1.7.3 Structural integrity

CS 22 has different requirements of the structural integrity of sailplanes. The requirements are based on the two different loads **(CS-22.301)**: Limit load and Ultimate Load. Where limit load is the maximum expected load when the sailplane is in service. The Ultimate Load is the Limit load multiplied with the prescribed factors of safety. A standard safety factor of 1.5 will be maintained unless other safety factors are provided. **CS-22.305**contain the requirements for strength of the construction under limit and ultimate load:

a) The structure must be able to support the limit loads without permanent deformation. At any load up to limit loads, the deformation may not interfere with safe operation. This applies in particular to the control system.
b) The structure must be able to support ultimate loads without failure for at least three seconds. However, when proof of strength is shown by dynamic tests simulating actual load conditions, the three second limit does not apply.

According to the Flight Envelope **(Appendix VIII)** the structure needs to support different load factors in different situations. These different load factors are given in the table. Only column U (Utility) is use full for this project, column A is intended for aerobatic flight.

2 Conceptual Phase

The information from chapter one can now be applied in chapter 2. This will result in a morphological overview, which will show the best possibilities for a glider. For every component of the glider, multiple options will be discussed. The electrical components are provided by the HvA and therefore will not be added at the morphologic overview **(2.1)**. It is important to construct the right wing by using the correct airfoil. Thereby the weight must be minimized and has to be strong enough to withstand certain forces **(2.2)**. In addition to the wing, it is also important to examine the different kinds of tails **(2.3)**. Also the applicable flight controls will be discussed **(2.4)**. Furthermore the different types of fuselages which could fit the glider will be explained, thereby the pros and cons of every fuselage type will be mentioned **(2.5).** This chapter will also cover the possible landing gear options and its pros and cons **(2.6).** After all these parts are discussed, all the components of the glider will be outdrawn in a morphologic overview **(2.7)**. With the morphologic overview three possible gliders are selected, which will be compared to each other and this will result in a conclusion of the final glider **(2.8).**

2.1 Electrical components

The University of Applied Sciences of Amsterdam will provide the electrical components. First the technical information will be explained of each component, followed by the weight and dimensions. The components that are provided are:

1. Radio Control Set
2. Battery
3. Electronic Speed Controller
4. Electric Motor

Ad 1. *Radio Control Set*

The radio control set consists of a transmitter and a receiver. The Futaba 7C FASSR 2.4 GHZ is the transmitter and the Futaba 2.4 GHz FASST R617FS is the receiver. It is transmitting on a 2.4 GHz band and has 7 channels. The software can be used for airplanes and helicopters. The receiver needs a power supply between 4.8 and 6.0 volt. The size of the receiver R617FS is 41.6 x 27.5 x 9.2 millimeter and weighs 9.8 gram.

Ad 2. *Battery*

The Bionic 3S1P30C provides 11.1 voltage of power and has a capacity of 1550 mAh. The battery is made of lithium-polymer. It consists of three cells, each one has a voltage of 3.7. The battery has a C-rate of 30. This means that the maximum discharge can be calculated by multiplying it by the capacity. This results in a maximum discharge of 46.5 Ampere. To multiplying this current with the voltage of the battery, the maximum power is 516.15 Watts. The size of the Bionic 3S1P30C battery is 91.25 x 30.76 x 23.53 millimeter and weighs 135 gram.

Ad 3. *Electronic Speed Controller*

The HvA provided a RobbeRoxxy BL Control 9100-6 electronic speed controller (ESC). The ESC converts the DC current of the battery to AC current. It also reduces the voltage down to a correct level for the electrical motor. Besides it also converts the 11.1 voltage to 5 voltages for the other electronic components such as the servo's and receiver. The size of RobbeRoxxy BL Controller is 75 x 27 x 13 millimeter and weighs 67 gram.

Ad 4. *Electric Motor*

The electric motor will be the Fusion 3529/10. The maximum current is 21 Ampere and the optimum current is 10 to 15 Ampere. The revolution is 1300 kv or rounds per minute per volt. The project group has the opportunity to choose the propeller of the electric motor by them self. The requirement is that the propeller needs to be 8x4 inch. The size of Fusion 3529/10 is 35 x 29 millimeter and weighs 78 gram. In addition to the engine is a propeller just as important. There are two propellers, which can be applicable. A standard fixed propeller, and a folding propeller. In the standard propeller, it is possible to apply it in 2 different ways, namely as a tractor or pusher. To hang like a tractor propeller, the propeller has to be placed on the front of the aircraft, thereby the propeller pulls the aircraft forward. It is important that the blades placed in a way that it is running against the clock. At a push propeller, the propeller should also run against the clock. As a result, the aircraft will be pushed aircraft forward. The folding propeller has an important advantage that it will reduce drag when the motor is turned off. The blades are hinged at the roots. When the motor is running, the blades are in a normal position. Thereby the propeller has a tractor effect. Turning off the motor, the wind over the blades will push the blades backward. The blades lie flat on the nose of the glider, which reduce drag. Turning the motor on, the blades will take the normal position and generate thrust. The push propeller has to many disadvantages, hardly to construct and weight construction needs to be considerate. Also it will affect the center of gravity. A tractor propeller with a folding configuration is the most suitable to apply by the glider because it produces less drag.

2.2 Wing

The wing is a fin shaped surface of the aircraft, which provides the aircraft with the aerodynamic forces necessary for flight. This paragraph will cover the selection criteria's of the wing **(2.2.1)**, which are necessary for the model. Also different options of wing types and configurations will be discussed **(2.2.2)**.

2.2.1 Selection Criteria

The wing of the glider is required to produce enough aerodynamic forces to keep the glider as long as possible in the air after the engine has been shut down. To optimize an as long as possible glide, it is necessary to search for the optimal wing with the least induced drag and the best stability. Furthermore the glider needs to have the most optimal wing plan form.

2.2.2 Comparison

The wing comes in various different types and configurations, however this depends on the type of aircraft. Therefore all the relevant possible component types and configurations for a glider will be compared to each other. First of all it is necessary to compare the possible aspect ratios **(2.2.2.a)**, where after the different kinds of wing placement **(2.2.2.b)** and the options for wing sweep **(2.2.2.c)** will be compared. Furthermore the chord variations **(2.2.2.d)** are being discussed. To conclude the subparagraph, an elaboration about the anhedral/dihedral configurations **(2.2.2.e)** and the airfoils options are being given **(2.2.2.f)**.

2.2.2.a Aspect Ratio

With the information from chapter one it is possible to make a selection of which aspect ratios are the most suitable for a glider aircraft. So it is clear to rule out the low and moderate aspect ratio configurations, due to the fact that a high aspect ratio will provide more lift. Therefore a glider aircraft with a high aspect ratio should be chosen for the design. This option has it benefits that it is more aerodynamically efficient and that it has less induced drag. To give an indication about what specifications the glider will have, a couple of assumed aspect ratios were chosen. With the AR formula the chord and the surfaces could be calculated. However when the aspect ratio is getting too high, the connection between the wing and the fuselage needs to become stronger and also the wing needs to be firmer.

Aspect Ratio	Wingspan (m)	Chord (cm)	Surface (m^2)
20	2	10	0.2
25	2	8	0.16
30	2	6.67	0.13

2.2.2.b Wing placement

For the wing placement the low wing configuration for a glider aircraft could be ruled out because it provides a less stable aircraft which also maneuvers a lot. Therefore the mid wing and the high wing configurations are the relevant designing options for the AC glider. The biggest advantage of the mid wing is that it is constructed through the fuselage which will make this construction quite strong.

Furthermore the drag will be slightly lower. However when the emphasis lies with designing a more stable aircraft, a high wing configuration is more suitable.

Placement	Advantages	Disadvantages
Mid Wing	- Less form drag	- Difficult to assemble - Lower stability - More interference drag
High Wing	- Higher stability - Easier to assemble - Less interference drag	- more form drag

2.2.2.c Wing Sweep

Furthermore there are multiple wing sweep possibilities, which are used for a variety of reasons, the relevant options for an AC glider are the straight configuration and the forward swept. The straight configuration is the most common used wing sweep for low-speed designs and it has the most structurally efficient wing. Also the forward swept wings are possible, which avoids stall problems and it reduces tip losses so smaller wings are possible. However it requires greater stiffness to avoid flutter. The reason to rule out the swept back wing is because it is only used during high velocity.

Sweep	Advantages	Disadvantages
Straight	- Structural efficient - Easy to build - Light weight	- Requires bigger wings
Forward Swept	- Avoid stall problems - Reduces tip losses - Allowing smaller wings	- Requires greater stiffness - Difficult to recover from stall

2.2.2.d Chord Variations

Another wing configuration, which needs to be taken into account for structural and aerodynamic reasons are the chord variations. The different types of variations are:

1. Constant chord
2. Tapered
3. Semi tapered
4. Elliptical

Chord	Advantages	Disadvantages
Constant	- Easiest to assemble	- Outer wing inefficient in generating lift
Tapered	- More efficient structurally - More efficient aerodynamically - Easier to assemble than elliptical	
Semi tapered	- Same advantages as constant chord - More efficient outer section in generating lift	
Elliptical	- Most efficient plan form	- Most difficult to assemble

2.2.2.e Anhedral and Dihedral

Then there are a couple of options to resolve various design issues, such as the stability and the control in flight. This can be done by angling the wing up or down. These options are called the dihedral configuration, which adds more lateral stability and the polyhedral upward cranked configuration, this is a combination of an anhedral wing and dihedral wing.

Anhedral/Dihedral	Advantages	Disadvantages
Dihedral	- Adds more lateral stability	- Dutch roll could occur
Polyhedral	- More stable	- Complex to make

2.2.2.f Airfoils

The purpose of the challenge is to fly as long as possible with the engine shut off. To fly as long as possible the right airfoil has to be chosen. The drag coefficient has to be as less as possible and the lift coefficient has to be as high as possible. There will be flown with an airplane with a maximum wingspan of two meters, so the velocity will be relative low. To glide for a long time, the glide ratio has to be very high, this dependent also on the airfoil, this will be the deciding factor to choose three airfoils. To choose three possible airfoils, multiple airfoils have to be examined. In the search of airfoils that are used on small gliders with low velocity, fifteen possible airfoils have been found [note 1]. To compare these airfoils, the proper Reynolds number has to be used. As explained in **(1.2.1.c)**, the Reynolds number dependents on the velocity and cord length. It is necessary to make an assumption. Probably there will be flown with a velocity between 40 and 70 km/h. The cord length will be also an assumption. This is will be estimates between 10 and 20 centimeters.[1]
It is now possible to complete the formula to determine with which Reynolds number will be flown.

$$Re = \frac{1.225 * (40/3.6) * 0.1}{17.897 * 10^{-6}} = 61.000 \qquad Re = \frac{1.225 * (70/3.6) * 0.1}{17.897 * 10^{-6}} = 133.000$$

$$Re = \frac{1.225 * (40/3.6) * 0.2}{17.897 * 10^{-6}} = 152.000 \qquad Re = \frac{1.225 * (70/3.6) * 0.2}{17.897 * 10^{-6}} = 266.000$$

To understand the approach, the NACA 23012 airfoil will be explained. The glide ratio can be found from the Cl/Cd diagram by dividing the lift coefficient through the drag coefficient, as explained in **(1.2.3)**. The glide ratio will be calculated for the Reynolds number 50.000, 100.000 and 200.000 as showed in the table. The green line gives the Cl/Cd curve for the Reynolds number of 200.000. The glide ratio will be found by making a straight line form the axis origin against the curve. By the NACA 23012 airfoil the lift coefficient is 1.00 and the drag coefficient is 0.02.
The glide ratio will be:

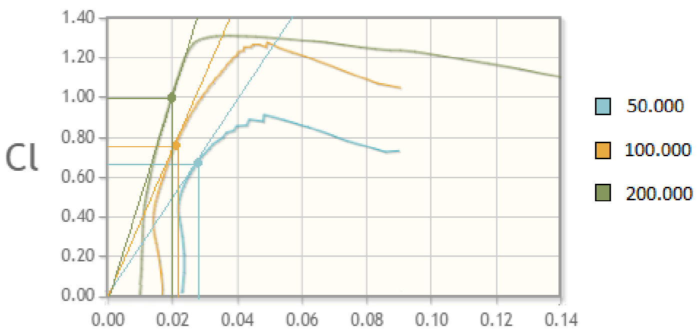


Figure 2.1; Cl/Cd diagram of NACA 23012 air foil

$$Glide\ ratio = 1.00\ /\ 0.02 = 50.0$$

Airfoil	Reynolds #50.000	Reynolds #100.000	Reynolds #200.000
NACA 23012	0.68 / 0.028 = 24.2	0.75 / 0.022 = 34.1	1.00 / 0.020 = 50.0
AH 6-407	1.17 / 0.028 = 41.8	1.07 / 0.016 = 66.9	1.10 / 0.012 = 91.7
HQ 2.5/12	1.05 / 0.031 = 33.9	0.95 / 0.022 = 43.2	0.95 / 0.015 = 63.3
HQ 2.5/10	0.96 / 0.026 = 36.9	0.95 / 0.015 = 63.3	0.87 / 0.011 = 79.1
Selig 3021	1.09 / 0.034 = 32.1	1.00 / 0.019 = 52.6	0.90 / 0.013 = 69.2
Clark Y	1.25 / 0.042 = 29.8	1.10 / 0.025 = 44.0	0.90 / 0.018 = 50.0
CR-001	1.15 / 0.028 = 41.1	1.05 / 0.016 = 65.6	0.98 / 0.011 = 89.1
DU 86-084/18	0.68 / 0.021 = 32.4	0.68 / 0.014 = 48.6	0.62 / 0.009 = 68.9
E375	0.75 / 0.023 = 32.6	0.70 / 0.015 = 46.7	0.80 / 0.012 = 66.7
MH32	0.95 / 0.027 = 35.2	0.87 / 0.015 = 58.0	0.80 / 0.012 = 66.7
RG15	0.83 / 0.024 = 34.6	0.80 / 0.015 = 53.3	0.70 / 0.010 = 70.0
S4083	0.81 / 0.026 = 31.2	1.20 / 0.023 = 52.2	1.10 / 0.015 = 73.3
S7012	0.98 / 0.029 = 33.8	0.95 / 0.018 = 52.8	0.90 / 0.015 = 60.0
S7075	1.01 / 0.026 = 38.8	0.95 / 0.017 = 54.1	0.80 / 0.010 = 80.0
SD7037	1.00 / 0.029 = 34.5	0.90 / 0.020 = 45.0	0.80 / 0.012 = 66.7

[1] i.a. ''Summary of Low-Speed Airfoil Data, Volume 2, by M.S. Selig, C.A. Lyon, P. Giguere, C.P. Ninham and J.J. Guglielmo'' is been used

This will be done for every airfoil, so it will be possible to make a comparison between all the airfoils. From these results, the three best airfoils can be determined. These airfoils will be further explained:

1. AH 6-407
2. HQ 2.5/10
3. CR-001

Ad 1. *AH 6-407*

With a Reynolds number of 50.000 the glide ratio is 1:41.8. The lift coefficient is 1.17 and the drag coefficient is 0.028. With the known lift coefficient, the optimum angle of attack can be determined from the Cl/alpha graph. The optimum angle of attack will be 5.0 degrees.
The glide ratio with a Reynolds number of 100.000 is 1:70. The lift coefficient is 1.07 and the drag coefficient is 0.016. The optimum angle of attack will be 3.75 degrees.
Flying with the highest Reynolds number the glide ratio is 1:73.1. The optimum angle of attack will be 3.0 degrees.

Ad 2. *HQ 2.5/10*

With a Reynolds number of 50.000 a glide ratio of 1:36.9 will be achieved. The angle of attack will be 6.5 degrees.
The glide ratio with a Reynolds number of 100.000 is 1:63.3. The corresponding angle of attack with a lift coefficient of 0.95 is 5.5 degrees.
The glide ratio with a Reynolds number of 200.00 will be achieved with an angle of attack of 4.75 degrees.

Ad 3. *CR-001*

A glide ratio of 1:41.1 can be achieved with an angle of attack of 6.75 degrees. An angle of attack of 5.5 degrees gives the corresponding glide ratio with a Reynolds number of 100.000. With a Reynolds number of 200.000, the glide ratio of 1:89.1 will be achieved with an angle of attack of 4.25 degrees.

2.2.2.g Winglets

There is also an option to add winglets to the wing of the glider. The two options are winglets and no winglets. When adding winglets to the glider the induced drag will reduce, however the parasitic drag will increase but this is marginal and doesn't have any influence on the performance of the aircraft.

Winglets	**Advantages**	**Disadvantages**
Winglets	- Reduces induced drag	- Parasitic drag increases slightly
No winglets	- Has lower parasitic drag	- Produces more induced drag

2.3 Tail

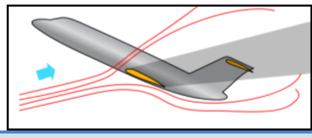
A tail plane, which is also known as a stabilizer, is a small surface located on the tail of the aircraft which provides lateral and vertical stability of an aircraft. However not all fixed wing aircraft have a horizontal stabilizer, such as the canard and tailless aircraft. In the following paragraphs the important selection criteria **(2.3.1)** and the advantages and disadvantages **(2.3.2)** are shown.

2.3.1 Selection criteria

The tail of a glider is required to provide the aircraft with stability and controllability. Furthermore the tail will help to adjust the changes in center of pressure and center of gravity caused by change in altitude and speed. A typical glider needs a tail which creates minimal drag and ensures a stable flight behavior at low speeds. Also the manufacturability and weight which is needed for mechanical stability have to be considered. Due to these facts the V-Tail and T-Tail are selected for the comparison.

2.3.2 Comparison

For comparison reasons are the advantages and disadvantages shown in the following table.

Tail	Advantages	Disadvantages
V-Tail	- Less parasitic drag - Lighter-weighted - Mechanical more stable	- Difficult manufacturing - More drag while deflecting
T-Tail	- Easier to build - Less drag while deflecting (separate control surface)	- More parasitic drag - Heavier-weighted (Vertical component must carry all loads of horizontal part) - Mechanical less stable - **Deep stall** 
Conventional Tail	- Easiest to assemble - Less sensible for deep stall -	- The elevator is located in the accelerated slipstream coming from the engine - More parasitic drag than the T-tail

2.4 Flight controls

In this paragraph are the important selection criteria for the flight controls discussed **(2.4.1)**, which are necessary for gliders. Thereafter several options of realizing the control over the movements of the longitudinal, lateral and vertical axes are compared and the pros and cons are listed in a comparison **(2.4.2)**.

2.4.1 Selection criteria

The most important requirement of flight controls is to ensure the controllability of an aircraft. A glider has different flight aspect than a regular aircraft and for selecting the right components for this glider it is important to consider the advantages and disadvantages of the controlling devices.

2.4.2 Comparison

Gliders utilize ailerons **(2.4.2.a)** to stabilize the fuselage around the longitudinal axes. The stability around the lateral axis is controlled by the elevator **(2.4.2.b)**. To operate a glider around the vertical axis, the rudder **(2.4.2.c)** is activated. The servos that control the flight controls needs to be placed on the glider there are different options for that **(2.4.2.d)**.

2.4.2.a Ailerons

For the glider it is important to be light-weight constructed. By consideration of this requirement, Ailerons, Flaperons and a separate aileron-flaps variant are selected for the comparison. The advantages and disadvantages of the different aileron variants are given in the table.

Ailerons	Advantages	Disadvantages
Normal configuration ailerons	- Not much influence on the lift - Produce not much drag while deflecting	- Slower roll performance
Flaperons	- Better roll control - Reduce stall speed - More light-weighted - Reduce number of servo's and actuators	- While activated flaps roll performance is poorer - Reduce stall speed - Difficult to find the optimal adjustment for the flaps without long test flights
Separated Flaps and Ailerons	- Better adjustment at current flight state - Best aerodynamic performance	- Heavier and more drag (more servo's are needed)

2.4.2.b Elevator

The possible options of the realization of the elevators concern the normal elevator and the taileron which is also known as horizontal stabilizer. These options can be used on a glider and the advantages and disadvantages are show in:

Elevator	Advantages	Disadvantages
Normal Elevator	- Influence small part of the aerodynamics - Produce less drag - Light-weight construction - Easier to assemble	- Slower pitch performance
Tailerons (Stabilizer)	- Better and faster roll control - Combination of ailerons and Elevator	- Construction difficult (just one connection point to carry applied loads) - Difficult to adjust with just one test flight - Best performance at high velocities

2.4.2.c Rudder

The rudder is the control surface on the tail of the glider that can make the glider yaw around its normal axis. For controlling movements around the vertical axes different rudder forms are used:

Rudder	Advantages	Disadvantages
Rectangular Rudder	- Easier to construct - Rudder is as long as the height of the tail - Intense control	- Create a lot of drag when deflected - Have to handle higher forces
Swept Rudder	- Aerodynamic behavior is better	- More complicated to construct - Smaller tolerances are necessary - More difficult to assemble

2.4.2.d Placing

The incoming steering movements from the controller will be received by the receiver on the glider which gives the signal to the servo's. The transmission of signals can happen thru a connection with electric cables. The servo receives this signal and makes a pull or push movement. This movement will be transferred via push and pull filaments to the control devices. The control devices make a deflection up or down, left or right or in or out which is depending on the input of the pilot. The placing of the transmission wires, the servo's and the electrical cables can be placed on different options. When placing these components and accessibility for repairing purposes should be given and aerodynamic aspect have to be considered:

Placing	Advantages	Disadvantages
Servo Inside	- Less drag	- Complicated to construct - Needs free space in wing
Servo Outside	- Easier to assemble - Easier to repair - Wing structure is not interrupted	- More drag - Easier to damage
Connection Inside	- Less drag	- Complicated to construct - Difficult to produce deflection moment
Connection Outside	- Easier to assemble - Less powerful servo needed - Easier to repair	- More drag - Easier to damage

2.5 Fuselage

The fuselage holds the aircraft together, this will mean that there are different requirements to design the best fuselage **(2.5.1)**. The unusable fuselages will be eliminated and there will be a comparison with the pros and cons of the remaining fuselages **(2.5.2)**.

2.5.1 Selection criteria

The glider needs to perform an optimal glide, a light, strong construction and an aerodynamic shape are needed to accomplish this requirement. As told in chapter one there are three different ways to construct an aircraft fuselage, the Truss, the monocoque and the semi monocoque structure. Because the truss structure is only built out of tubes and rods it does not have a good streamline or aerodynamic shape. This option therefore does not meet the requirements and is eliminated. The monocoque structure and the semi-monocoque structure are useable because there are more possibilities to create an aerodynamic and strong fuselage.

2.5.2 Comparison

Two things determine the performance of the fuselage. As first the construction type will determine the strength and weight for the fuselage **(2.5.2.a)**. And the second thing that determines the performance of the fuselage is it's the shape, which should keep the amount of drag to a minimum **(2.5.2.b)**.

2.5.2.a Construction type

The best option for a semi monocoque construction is strong formers and stringers attached to the critical parts of the fuselage, stretched with a light, thin cover film. This combination results in a very light fuselage. A disadvantage of this is that it acquires damage more easily without landing gear. A landing gear increases the weight of the aircraft including the aerodynamic drag during the flight, unless it is retractable which increases the weight. The monocoque structure has a thicker skin because the skin absorbs the forces in the fuselages. This has as result that the fuselage is less vulnerable for damage during the landing. This has as advantage that there is no landing gear required. Another advantage is the stiffer body, so the aircraft it is less sensitive to flutter. A disadvantage is that the fuselage in its standard form is heavier than the semi-monocoque structure. All the different advantages and disadvantages for the two construction types are given in:

Fuselage	Advantages	Disadvantages
Monocoque	Light Strong Good streamline No landing gear needed	Difficult repair Heavier due to partially unnecessary reinforcements
Semi-Monocoque	Good streamline Lighter than monocoque due to thinner skin	Skin is easier to damage Slight construction difficulty

2.5.2.b Fuselage shape

Different shapes are used in the aeronautical industry. As widely known, the droplet form has the lowest drag coefficient. So this is the ideal form for a glider fuselage. Because there is a propeller installed in the front of the aircraft is difficult to get the round shape at the front of the aircraft. However, it is possible to install a spinner on top of the propeller to approach the droplet shape as much as possible.

2.6 Landing gear

Landing gear is the undercarriage of an aircraft, which supports aircraft when it is not flying. This paragraph will explain what the selection criteria **(2.6.1)** of landing gear relevant for the glider are, and the pros and cons of the relevant designs **(2.6.2)**.

2.6.1 Criteria

The glider is required to land safely several times in order to take off again. This because a test flight is required and there are three chances at reaching the longest glide time. The landing gear has to protect all components of the aircraft from acquiring any damage at every landing. The most sensitive components in this case are the wingtips, tail and the propeller. Since the flying will happen at a grass field, wheels are not useful and are thus irrelevant.

2.6.2 Pros and cons

Each configuration of landing gear has different advantages, either in protectiveness, weight or aerodynamic properties.

Configuration	Advantages	Disadvantages
No landing gear	Very lightweight	No additional protection
Single main gear	Lightweight Basic protection	Little additional drag
Bicycle gear	Moderate protection	Moderate weight and drag
Tricycle gear	Full protection	Heavy weight and drag Complicated construction
Tail dragger	Full protection Easy construction	Heavy weight and drag

2.7 Morphologic overview

After considering all the important parts there is Morphologic overview created. A weighting factor table is created to explain the related criteria's **(2.7.1)**, which are stability, performance and construction. By using the pros and cons with the weighting factor, the final design can be determined. Thereby the design options must be explained **(2.7.2)**. Eventually the most executable and the best designing options will be outlined and compared within a conclusion **(2.7.3)**.

2.7.1 Criteria's

In order to choose the best glider, a weighting table will be made. By using different criteria's with weighing factors, the final design can be chosen. The criteria's are:

1. Stability
2. Performance
3. Construction

Ad 1. *Stability*

With a glider that is more stable, controlling the glider will be easier. The pilot doesn't have to continuously stabilize the glider and can focus on the right angle of attack to create the best glide ratio. The most stable glider will get the highest amount of points.

Stability	Points
Very stable	3
Semi stable	2
Not stable	1

Ad 2. *Performance*

The performance of the glider is a very important criteria. The glider must have a high lift coefficient and a low drag coefficient. The glide ratio has to be as high as possible. Also the weight of the glider will affect the performance of the glider. Furthermost the aspect ratio also needs to be very high, which influences the amount of lift. The drag depends, among others, on the type of tail.

Performance	Points
High: AR, glide ratio, lift coefficient Low: drag coefficient, weight	3
High:Weight, lift coefficient Low: AR, drag, glide ratio	2
High: Weight, drag coefficient Low: AR, glide ration, lift coefficient	1

Ad 3. *Construction*

The construction consists of the wing, fuselage and tail construction. For the three designs, the fuselage construction and wing sweep are the same. This will not have any influence on the points. The points depend on the cord variation, wing placement and the type of tail. An easier construction will have more points.

Construction	Points
Easy construction	3
Mean construction	2
Difficult construction	1

Not all criteria's are equally important. For each criteria a weighting factor will be determined. The performance is the most important criteria and will receive the highest factor. In addition, the weight of the glider has also a very high influence. This will receive the same factor. If the construction is very hard to make, it will have consequences for the building team. The stability will receive the lowest amount of points, because the stability can be easily adjusted by the controller.

	Weighting factor
Performance	2
Weight	2
Construction	1

2.7.2 Design options

The design possibilities were set out in a morphological overview **(Appendix X)**. Were after, it was possible to combine the different components with each other to get three potential glider designs. By using a pro's and cons with weighing factors one final design will be chosen. The three possible glider designs are the

1. Performance design
2. Constructability design
3. Combined design

Ad 1. *Performance*

The first design option is mainly focused on a high performance glider design. In this design possibility, there was chosen for a tractor folding propeller due to the fact the propeller can retract to reduce drag, when the engine has been shut off, and the propeller is located at the front of the aircraft. Furthermore the high performance design will have a mid-wing placement with an assumable high aspect ratio between 26 and 30. It will also have a straight wing sweep, a semi tapered chord and a slightly dihedral configuration. However due the high aspect ratio it seems better to build the HQ 2.5/10 airfoil because it will provide more strength in the wing. Also winglets are being added to the wings to reduce the induced drag. Next the tail design for this glider will be the V-tail design, because it produces less drag when there is no deflection of the control surfaces. For the flight controls there is decided for flaperons because this option does not require more equipment, it is just a setting in the transmitter. There is also chosen for ruddervators because in a V-tail configuration the rudder and the elevators are combined. To make the design more aerodynamic efficient there was decided to put the servo's inside the wing with the connections under the wing and under the tail because it is too difficult to place them inside the aircraft, also stronger servo's were necessary to create the torque. The fuselage of the design will be a monocoque construction in a droplet shape because this will deliver a strong fuselage with a very low drag. For the landing gear there was decided to have no landing gear because this will cause more drag during the flight. During the contest the aircraft won't have a runway start and it is going to land on a grass surface.

	Points	Factor	Total
Stability	2	1	2
Performance	3	2	6
Construction	2	2	4
Total points			12

Ad 2. *Constructability*

The main focus of the second design lies with constructability. Just as the previous design the propeller is going to be tractor folding. The wings of this design will be placed on top of the aircraft, which will cause for more drag but it is easier to assemble. Furthermore it will have an aspect ratio between 22 and 26 with a straight wing sweep, a constant chord and a dihedral configuration. And the chosen airfoil will be the CR-001 and no winglets are being added because it will be easier to assemble. For the tail a T-tail configuration will be assembled, which will provide lower drag during maneuvering. For the flight controls this design will completely differ from the previous one. This design will have normal ailerons, normal elevators and a rectangular rudder. These choices don't have many aerodynamic advantages, but are very reliable and are easy to assemble. The servo's will be placed exactly the same as the previous design; so the servo's are inside the wing and the connections are placed under the wings and under the tail. Also the fuselage connection and the landing gear will be the same, so a monocoque fuselage with no landing gear.

	Points	Factor	Total
Stability	3	1	3
Performance	1	2	2
Construction	3	2	6
Total points			11

Ad 3. *Combined design*

The third option is going to be a combination of a stable, constructability and performance design. Just as the other two designs this design will have the tractor folding propeller. The wings will be placed in the mid –wing configuration, it will have an assumable aspect ratio between 26 and 30. The plan form of the wing will be a straight wing sweep with a tapered chord and a dihedral configuration. There was chosen for the tapered chord because it is easier to assemble than the elliptical wing and the semi tapered wing. It also generates more lift than the constant chord. The airfoil of this design will be the AH 6-407 and also winglets are being added. The other components will be the same as the high performance option, so it will have a V-tail with flaperons and ruddervators. Also in the case of the servo's the fuselage and the landing gear, it will all be the same as mentioned above.

	Points	Factor	Total
Stability	2	1	2
Performance	2	2	4
Construction	2	2	4
Total points			10

2.7.3 Conclusion

Now it is possible to compare equally the three possible options.

	Performance design	Construction design	combined design
Performance	6	4	4
Construction	2	6	4
Stability	2	3	2
Total	12	11	10

2.8 Conclusion

In the morphologic overview, all the selected possibilities for every design aspect covered in chapter 2 have been compared to each other using criteria and weighing factors that are relevant for the specific part. This resulted in three design options: a "performance design", a 'constructability design' and a "combined design" **(Appendix X)**. The "performance design" will achieve the best performance for a glider. This design will be harder to construct than the "constructability design" and a "combined design", but this will be possible, and should be more beneficial during the contest.
The glider has to be as light-weighted as possible without breaking while the forces of flight occur on the structure. The wing ribs will be made of balsawood and the support beam of the wing will be made of carbon fiber. The surface of the wing is made of a special foil, covering foil. The fuselage will be made of glass fiber. It is easier to bring glass fiber in the right shape than carbon fiber. Also carbon fiber disturbs the signal of the transmitter. The ribs of the tail will also be made of balsawood, the surface will be of covering foil. The performance and dimensions of the chosen design needs to be calculated and a 3D sketch needs to be made, which will be explained in the following chapters.

3 Design Phase

For construction activities of a glider several things have to be considered, determined and calculated. To ensure a good flight behavior and controllability of an aircraft the optimal dimensions of components like wing, tail and control surfaces have to be ascertained **(3.1)**. Thereafter it is possible to estimate the flight performance and endurance of a glider **(3.2)**.

3.1 Optimal dimensions wing & tail

The right dimensions of each components of an aircraft are vital to ensure a safe flight. Therefore the following paragraph is discussing about the optimal wing **(3.1.1)** and tail **(3.1.2)** dimension. To check if the complete theoretical design is right, the longitudinal stability will be checked. This calculation includes the position of the center of gravity **(3.1.4)**.

3.1.1 Wing design

Wings are the most important component which influences the flight characteristics of a plane. The dimensions and shape of the wing affects stability and controllability of an aircraft. For this reason the following subjects has to be considered before it is possible to start the construction phase: Basic dimensions and speeds **(3.1.1.a)**, aileron dimensions **(3.1.1.b)**, winglets **(3.1.1.c)**, dihedral angle **(3.1.1.d)** and chord variation **(3.1.1.e)**.

3.1.1.a Basic dimensions and speeds

To calculate all the properties of the wings that will be designed for the glider, the first step is to determine the stall speed (V_{STALL}). The deciding factor of the V_{STALL} is the speed that the RC glider will have just after it has been launched by hand. It has been assumed that the glider throw speed by hand will be around 30 km/h. With this value in mind, the wing loading (W_L) can be calculated. The $C_{L_{MAX}}$ of the chosen airfoil HQ 2.5/10 is 1.2. The throw speed (which must be equal or greater than v_{STALL}) during launch as used for calculation is chosen as 27.2 km/h, which is 7.55 m/s. Filling in the equation with the predetermined values gives a W_L of 42.58 N/m², which is equal to 43.4 g/dm². This is an acceptable value for RC gliders, according to common aircraft design literature.

Equation 3.1		
Wing loading		
$\boldsymbol{W_L = \frac{W}{S} = \frac{1}{2} \cdot \rho \cdot v_{STALL}{}^2 \cdot C_{L_{MAX}}}$		
Symbol	**Variable**	**Unit**
$\boldsymbol{W_L}$	Wing loading	Kilogram per square meter [kg/m^2]
$\boldsymbol{W}$	Weight	Newton [N]
$\boldsymbol{S}$	Surface	Square meter [m^2]
$\boldsymbol{\rho}$	Density (Standard 1.225 kg/m^3)	Kg per cubic meter [kg/m^3]
$\boldsymbol{v_{STALL}}$	Airspeed	Meter per second [m/s]
$\boldsymbol{C_{L_{MAX}}}$	Maximum lift coefficient	'dimensionless'

After the wing loading has been calculated, the next step is to calculate the minimal wing surface that is required to fly with the most efficient glide ratio. According the equation for wing loading, the wing loading is equal to the weight divided by the wing surface. Using the calculated W_L of 43.4 g/dm² and an assumed weight of 1.0 kilograms, the wing surface proves to be 0.2304 m^2.

The stall speed is interesting during take-off and landing but during the glide phase which is more important, the most efficient airspeed is more significant to reach the highest glide ratio. The most efficient glide ratio can be reached by flying with the most efficient lift coefficientC_L**.** For the gliding phase are the parameters with the highest C_L/C_D ratio used. This fact results in a C_L coefficient of 0.9. The lift formula can be used to calculate the most efficient airspeed, using the C_L and the calculated surface. This results in airspeed of 31.7 km/h, at which the glide ratio will be optimal.

Now that the wing surface S is known, the average chord can be determined. The wing span is fixed at 2.00 m by the regulations of the University of Applied Sciences of Amsterdam. Preliminary designs show that the width of the fuselage will be 7.6 cm, which means there is a resulting wing length of 1.92 m left. By dividing the required wing surface by the wing length, the average chord will be 0.12 m. The aspect ratio than can be determined using the **(Equation 1.5)** for aspect ratio. If the total wing span and wing surface are filled in, it gives an aspect ratio of 16.

As mentioned above, the weight of the RC glider is assumed to be 1.0 kilograms. This assumed weight was created considering the weight of internal components that the glider will include and a rough estimation of the weight of the construction of the glider. It cannot be calculated exactly, as the final design is not known at this stage. It has been determined that in the worst case the total weight could increase to 1.5 kg. By the time that the final weight is known, it might be too late to alter dimensions of the RC glider. Therefore, some extra calculations give an idea about the effect of a difference in weight of 1.0 kg and 1.5 kg. Using the methods mentioned above in this paragraph, the new speeds that must be flown can be calculated. With a weight of 1.5 kg, the v_{STALL} will be 32.46 km/h and the ideal speed for gliding will be 37.48 km/h. The v_{STALL} can be considered as achievable as it is really close to the assumed 30 km/h throw speed.

3.1.1.b Aileron dimensions

Now the aspect ratio and the wingspan are determined, the dimensions of the ailerons can be calculated. In the design process of an aileron, there are some parameters that need to be determined. The aileron planform area and the aileron chord need to be declared. Also the location of inner Edge will be assumed at a specific length. The project group took three values to calculate precisely, namely minimum, average and maximum length **(Table 3.1)**. Multiplying the wingspan with a percentage will form the aileron length. The minimum length of the aileron will be 20 % of the wingspan, average length will be 25 % and maximum will be 30 %. Also the aileron planform area is calculated in three values. The minimum planform area will be 5 % of the wing area, the average planform will be 7.5 % of the wing area and the maximum will be 10 %.

With the aileron length and the planform area the aileron chord can be calculated. To calculate the aileron chord, the aileron planform area must be divided by aileron length. The location of inner Edge will be at 75 % of the wingspan **(Appendix XI).** The maximal deflection will be +/- 30 degrees.

Ailerons	Minimum	Average	Maximum
Aileron area	0.01152 m² [5%]	0.01728 m² [7.5%]	0.02304 m² [10%]
Aileron length	0.384 m [20%]	0.48 m [25%]	0.576 m [30%]
Aileron chord	0.03 m	0.036 m	0.04 m
Location distance of inner Edge	1.5 m [75%]	1.5 m [75%]	1.5 m [75%]
Maximum deflection	+/-30 °	+/-30 °	+/-30 °

Table 3.1: Calculated aileron dimensions

3.1.1.c Winglets

There are no equations to calculate the best dimensions for the winglets that will be used on the design of the RC glider. Therefore the dimensions of the winglets are not mentioned here. However it can be noted that the winglets will have surfaces on both sides of the wing. The actual dimensions of the winglets can be found in the final design 3D sketches and drawings.

3.1.1.d Dihedral Angle

Increasing the dihedral angle creates more induced drag while improving the stability of the aircraft. A dihedral angle of 3 degrees provides lower susceptibility to side wind gusts, but does not affect the spiral stability. However, spiral stability is no design requirement since the aircraft is not required to make any sharp turns.

3.1.1.e Chord variation (tapering)

Implementing a chord variation by tapering the wings has some advantages, as mentioned in chapter 1. Therefore, the design will have a wing tapering of 0.7. This is a value that is often used for RC gliders. While designing the wings with a taper ratio of 0.7, the total wing surface should be maintained. The average wing cord has been determined to be 0.1280 m and can be used to calculate the required wing root chord and wing tip chord. The average wing chord can be defined as the wing chord in the middle of both wing sides. As the wing root chord can be seen as 100 % of the chord, a taper ratio of 0.7 will mean that the tip chord will be 70 % of the wing root chord. This means that the average wing chord can be seen as 85 % of the wing root chord, as it is in the middle of both wings. Then the wing root chord and wing tip chord can be calculated. For the wing root chord: $\frac{0.1280}{0.85} = 0.1506$ m. For the wing root chord: $\frac{0.1280}{0.85} \cdot 0.70 = 0.1054$ m. By calculating the total wing surface using these two values, it can be confirmed that these chords are correct.

3.1.2 Tail design

The dimensions of the tail are also important to calculate. Therefore the design of the tail will be analysed further so it is possible to determine and calculate the dimensions of the tail **(3.1.2.a)**. Furthermore it is also required to determine and calculate the dimensions of the flight control surface, the ruddervator **(3.1.2.b).**

3.1.2.a Tail design

The calculations of the tail are also required to design a good working glider. The next step is to calculate the tail surface. The total tail surface is the horizontal tail size plus the vertical tail size.

Equation 3.2

Aspect Ratio

$$S\,Tail = S_{horizontal\ tail} + S_{vertical\ tail}$$

$$S\,Tail = C_{HT} \times \frac{W_S \times W_{C_{AVERAGE}}}{Distance\ MAC\ to\ Elevator} + C_{VT} \times \frac{W_b \times W_S}{Distance\ MAC\ to\ Elevator}$$

Symbol	Variable	Unit
C_{HT}	Coefficient horizontal tail	“dimensionless”
C_{VT}	Coefficient vertical tail	“dimensionless”
W_S	Wing area	Square meters [m^2]
$W_{C_{AVERAGE}}$	Average wing chord	Meters [m]
$dist.\ MAC\ to\ elevator$	Distance MAC to elevator	Meters [m]
W_b	Wingspan	Meters [m]

There are some typical tail coefficients given for a typical glider. Therefore the C_{HT} is 0.5 and C_{VT} is 0.04. The tail surface will be 0.0394 m^2. The tailspan is the root of the tail surface multiplied by AR of the tail. The AR of the tail will be 6. The tailspan will be 0.486 m for both sides. Divided by 2 will be 0.243 m for each side. The Tail chord will be calculated by the tailspan divided by AR of the tail, which will be 0.081 m.

To understanding how a glider act like it does, the tail volume coefficient is a handy tool. With the tail volume coefficient formula in chapter one can be determined whether the tail satisfies the requirements, which states that the tail volume coefficient has to be 0.3 at least. A coefficient of 0.933 means that the calculations indicates that the tail is big enough.

3.1.2.b Ruddervator dimensions[2]

With the tail area it is possible to calculate the elevator area, elevator chord and the elevator span. Also here there have been a number of calculations done to create more options and precise answers, namely minimum, average and maximum values **(Table 3.2).** The minimum elevator area is 15 % of the tail area. The average elevator area is 27.5 % of the tail area and the maximum elevator area is 40 % of the tail area. The minimum elevator chord is 20 % of the tail chord, average elevator chord is 30 % of the tail chord and the maximum elevator chord is 40 % of the tail chord.
With the elevator area and the elevator chord the elevator span can be calculated. To calculate the elevator span, the elevator area must be divided by elevator chord.
The maximum up-deflection at all the three cases is -25 degrees. The maximum down-deflection is +20 degrees. The angle between the two sides of the tail is 110 degrees.

Ruddervator	Minimum	Average	Maximum
Elevator area	0.00591 m^2 [15%]	0.01083 m^2 [27.5%]	0.01576 m^2 [40%]
Elevator chord	0.0162 m [20%]	0.0243 m [30%]	0.0324 m [40%]
Elevator span	0.36 m	0.45 m	0.49 m
Maximum up-deflection	-25 °	-25 °	-25 °
Maximum down-deflection	+20 °	+20 °	+20 °

Table 3.2; Ruddervator dimensions

3.1.3 Structure

This paragraph will explain the required structure dimensions to support the flight forces and the regulation requirements. The wing structure calculations **(3.1.3.a)** will be finished first, followed by the fuselage **(3.1.3.b)** and finally the connection to the tail **(3.1.3.c)**.

3.1.3.a Wing structure calculation

To determine the minimal material specifications for the wings that are required by the glider, strength calculations have to be done. Calculating a real wing would be too hard to do without the use of computer-aided design software. Autodesk Inventor will be used to calculate the required material specifications of the wings. The model consists of carbon fiber tubes which carry all the loads of the wings.
The center of lift according to **Appendix XII** is located at 45.7 cm from the root. The aircraft is expected to weight 1.0 kg in the worst case scenario, meaning both wings carry 19.6 N at the center of lift with the Utility load factor of 4.0 from **(1.7.3)**. According to an Autodesk Inventor simulation using an 8 x 6 carbon fiber rod will result in a safety factor of 1.7. This is sufficient since the minimal safety factor should be at least 1.5. There are smaller carbon fiber rods available, but using a rod that is one size smaller will result in a safety factor lower than 1.5.

3.1.3.b Fuselage structure calculation

The fuselage is going to be created with glass fiber, fitted around a mold in the construction. Theoretically, a 1 mm thick glass fiber tube with a diameter of 3.5 cm could carry 50 kg of stretching force. These dimensions are used because it is difficult to create a smooth glass fiber surface thinner than 1 mm, and the force it is capable of withstanding will be lower in reality.

3.1.3.c Tail connection structure

The horizontal tail surface is 0.036 m^2 which creates a lifting force of 8.6 N with a maximum rudder deflection and at maximum velocity. Including the weight of the tail the total force on the connection is about 10 N. A 15x13 carbon fiber rod 70 cm long will easily support this.

3.1.4 Longitudinal Stability

As explained in chapter one the longitudinal stability depends on the static margin, the distance between the centre of gravity and the neutral point. The aircraft is stable when the neutral point is

[2] Mohammed Sadraey, Aircraft Design: A Systems Engineering Approach, September 2012, Wiley Publications

behind the centre of gravity. The minimum value for the static margin is 3 to 5 percent for conventional aircraft. To make sure that our glider is stable enough we took a minimum of 7.5% static margin.

The determined values are given in **(Table 3.3)**. It is possible to affect the static margin in different ways, the length of the tail and the location of the centre of gravity are the most effective ones. Now all the dimensions are already known from the previous paragraphs it is possible to calculate the location of the centre of gravity.

INPUT	Value	Unit
Static margin	7,500	*Percentage of chord*
S Wing	0,230	*Square meters*
S tail (horizontal reference)	0,032	*Square meters*
Mean aerodynamic chord	0,120	*Meters*
Clα slope	0,110	*ΔCl/α*
Δl c.o.g. and tail a.c.	0,800	*Meters*
Tail volume coefficient	0,933	*Dimensionless*
Downwash gradient	0,120	*Dimensionless*

Table 3.3; Static margin values

The downwash gradient is determined with a dε/dα graph which can be found in **Appendix VII**. All the other values are calculated in the previous paragraphs. Secondly the location of the neutral point is required and as last the location of the centre of gravity can be calculated **(Table 3.4)**. The exact calculations can be found in **Appendix XIV**.

Output	Value	Unit
Neutral point	34	*Percentage of chord*
Centre of gravity	27	*Percentage of chord*

Table 3.4; Centre of gravity calculations

3.2 Flight performance

This paragraph discusses the calculated performance of the glider design. According to the competition regulation of the Design, Built and Fly minor the use of a certain motor in combination with an 8 x 4 inch propeller is allowed for 5 min. Therefore first of all some information about the engine propeller and the static thrust will be discussed **(3.2.3)**. Thereafter it was possible to calculate the aircraft and aerodynamic values **(3.2.3)**. Furthermore the climb performance and the maximal height which can be achieved have to be calculated **(3.2.3)**. To be able to evaluate the design of the glider it is vital to compute the gliding performance and endurance of the aircraft **(3.2.4)**.
Additional the exact way of calculation is shown in the **Appendix XV**.

3.2.1 Engine Propeller

To calculate the performance of the glider it was necessary to do a couple of calculations. First of all it was vital to sum up some basic information about the propeller, such as the maximum rpm load. With this information it was possible to fill in the thrust formula to calculate the propeller thrust, which is 7.4N. With the thrust it was possible to determine how fast the aircraft was climbing which will be discussed in a following paragraph.

Engine Propeller	
No load RPM	1300 rpm/V
Diameter	8 Inch
Pitch	4 Inch
Max RPM load	11500 rpm
Propeller thrust	7.4 N
	755.86 g

Table 3.5; Result of engine propeller calculation

3.2.2 Aircraft & Aerodynamic values

For the performance calculation of the glider some aircraft values and aerodynamic values were necessary. First of all it was possible to find the C_L max in the C_L/C_D graph, which is 1.2. Furthermore the Oswald factor could be calculated which is depending on the Aspect Ratio. So after the Oswald factor was calculated, which was 0.6122 it was possible to fill in the C_{d0} and the C_{di} formulas. This will give a total drag coefficient 0.107.

Aircraft & Aerodynamic Values	
Weight	1 kg
Wing span	2 m
Wing surface	$0.2304 m^2$
AR	16
C_{D0}	0.0606
c_{Lmax}	1.2
$c_{L\ gliding}$	0.9
$\alpha_{gliding}$	5°
Oswald factor	0.6122

Table 3.6; Result of aircraft and aerodynamic calculation

3.2.3 Climb performance

At first the stall speed by using angle of attack for the maximum C_L-coefficient is necessary to be determined for throwing the aircraft into the air and to start the calculation of the climb performance. Thereafter the drag and the required thrust to compensate the drag at stall speed have to be computed. This step is needed to determine the thrust surplus which can be delivered by the propulsion. This surplus of thrust leads to a higher velocity which is used for additional lift and to higher amount of drag. Due to simplify reasons the flight path and the angle of attack are equal. Thus is it possible to calculate the climb rate by split the velocity up into horizontal and vertical components. In the following table the calculated values of the glider's climbing performance can be found.

Climb performance	
V_{stall} at 10° Angle of Attack	7.55 m/s
Required Thrust for V_{stall}	2.6 N
Thrust surplus	4.9 N
V_{climb}	18.64 m/s
Rate of climb	3.37 m/s
Maximal calculated altitude after 5 min	1011 m
Realistic altitude after 5 min	606 m

Table 3.7; Result of climb performance calculation

3.2.4 Gliding performance

The ideal angle of attack has to be determined with which it has the highest C_L/C_D-Ratio. After this step the ideal gliding speed can be detected with the usual lift equation by utilizing the ideal lift coefficient. The produced drag-force at ideal gliding speed has to be compensated by the x-component of the weight-force. With this condition it is able to compute the required gliding angle for a constant gliding phase. Thereafter it is possible to determine the rate of decent and the endurance of the glider. The values of the gliding performance can be found in the following table **(Table 3.2)**.

Descend performance	
$V_{gliding}$ at 5° Angle of Attack	8.79 m/s
Required Angle for optimal glide performance	-5.5 °
Rate of descend	0.85 m/S
Endurance	**11.9 min**

Table 3.8; Result of gliding performance calculation

Conclusion

The aim of the minor design, build and fly is to design a glider which should glide as long as possible after 5 min of motor powered climb. The designed glider will use the HQ2.5/10 airfoil because of its high C_l/C_d ratio and the acceptable thickness for building purposes. The maximum lift coefficient is 1.2 and since the glider will take off being thrown by hand its stall speed has to be higher than 7.55 m/s, which is function of the wing surface if 0.2034 m^2. A taper ratio of 0.7 is applied to decrease the induced drag. The wings will have a dihedral setting of 3 degrees to decrease vulnerability to side wind gusts, thus increasing lateral stability.

The tail, which is in a V-configuration, has a horizontal reference surface area of 0.0394 m^2, and will be located 0.8 meters behind the leading edge of the main wings. With these dimensions the static margin will be 7,5%, meaning the aircraft is longitudinally stable.

The main structure rods will be made out of carbon fiber, the fuselage is made from glass fiber, the ribs of the wings from wood and the wings themselves will be covered with plastic. This combined with the electrical components and control surface connections will bring the total weight to 1.0 kilograms.

The total trust the propeller is able to deliver for climbing at the maximal angle of attack of 10° is 7.4 N, and the total drag coefficient is 0.107. The airspeed the aircraft reaches when the drag is equal to the delivered thrust is 18.6 m/s, so the vertical speed is 3.37 m/s with a climb angle of 10°. Theoretically, the aircraft will reach 1011 m in 5 minutes of powered flight, but realistically it is not possible to reach that altitude, because it is not possible to maintain the perfect flight state like angle of attack without using instruments. It is also not possible to control the aircraft with eye contact when it is more than 900 m away. Due to these facts the reachable height will be 607 m by using a reality factor of 0.6.

The optimal drag coefficient for gliding is 0.087, resulting in a horizontal velocity of 8.79 m/s. The total drag at this speed is 0.95 N, meaning the aircraft has to descend with 0.85 m/s. With this descend rate, the aircraft will be gliding for 11 minutes and 54 seconds.

The drawings of the final design of the developed glider are shown in **Appendix XVI**.

Bibliography

Books
Hoeven, M. v.d. (2012). Bouwen aan je Projectverslag. Amsterdam: Hogeschool van Amsterdam.

Mechanics of Flight, second edition 2010 –Warren F. Phillips.
Airplane Flight Dynamics and Automatic Flight Controls part 1 1995 –Jan Roskam

Summary of Low-Speed Airfoil Data, Volume 2, by M.S. Selig, C.A. Lyon, P. Giguere, C.P. Ninham and J.J. Guglielmo

Aircaft Performance Analysis, by M. Sadraey

Certification Specifications for Sailplanes and Power Sailplanes, CS-22, Amendment 1 (2008)

Aircraft Design: A Conceptual Approach, Daniel P. Raymer

Aircraft Design: A Systems Engineering Approach (2012), Mohammad Sadraey, Wiley Publications Mohammad Sadraey

Aircraft Design, A System Engineering Approach.pdf

Websites
Propeller thrust formula
http://www.grc.nasa.gov/WWW/k-12/airplane/propth.html
http://history.nasa.gov/SP-367/chapt9.htm#f141

Airfoil
http://www.airfoiltools.com

Aircraft axis movements
http://www.grc.nasa.gov/WWW/k-12/airplane/rotations.html
http://cfi-wiki.net/w/Aircraft_Stability_and_the_3_Axes

Climb angle
http://www.dept.aoe.vt.edu/~lutze/AOE3104/climb.pdf

Flight controls
http://www.skybrary.aero/index.php/Flight_Controls
http://www.skybrary.aero/index.php/Elevator
http://www.skybrary.aero/index.php/Ailerons
http://www.skybrary.aero/index.php/Rudder
http://www.skybrary.aero/index.php/High_Lift_Devices
http://www.skybrary.aero/index.php/Spoilers_And_Speedbrakes

Wing
http://en.wikipedia.org/wiki/Wing_configuration
http://2bfly.com/knowledgebase/airplanes/wing-configuration/
http://aviators.hubpages.com/hub/Aircraft-wings-Wing-platforms-and-configurations

Appendices

Appendix I. Acting Forces Equations

A. Lift formula 1

Equation		
Lift		
$$L = q \cdot S \cdot C_L$$		
Symbol	**Variable**	**Unit**
C_L	Lift coefficient	"dimensionless"
L	Lift	Newton [N]
q	Dynamic pressure (½ρv^2)	Pascal [PA]
S	Wing area	Square meter [m^2]

B. Lift formula 2

Equation		
Lift Coefficient		
$$C_L = \frac{L}{q \cdot S}$$		
Symbol	**Variable**	**Unit**
C_L	Lift coefficient	"dimensionless"
L	Lift	Newton [N]
q	Dynamic pressure (½ρv^2)	Pascal [PA]
S	Surface	Square meter [m^2]

C. Weight Formula

Equation		
Weight		
$$F_g = m \cdot g$$		
Symbol	**Variable**	**Unit**
F_g	Weight	Newton [N]
m	Mass	Kilo gram [Kg]
g	Gravitational acceleration	Meters per squared second [$\frac{m}{s^2}$]

D. Drag Formula 1

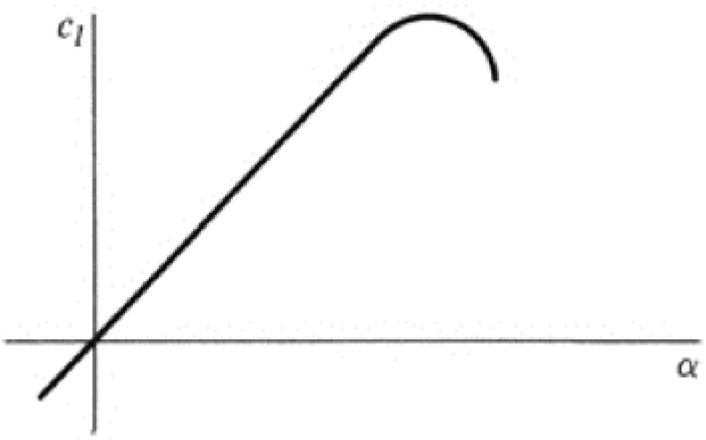
Equation		
Induced drag		
$$C_{Di} = \frac{C_L^2}{\pi} \cdot AR \cdot e$$ $$Di = C_{Di} \cdot ½\rho v^2 \cdot S$$		
Symbol	**Variable**	**Unit**
C_{Di}	Induced drag coefficient	"dimensionless"
C_L	Lift coefficient	"dimensionless"
AR	Aspect Ratio	"dimensionless"
e	Oswald factor	"dimensionless"
S	Surface	Square meter [m^2]
Di	Induced drag	Newton [N]
v	True airspeed	Meters per second [$^m/_s$]
ρ	Air density	Kilogram per cubic meter [$^{kg}/_{m^3}$]

E. Drag formula 2

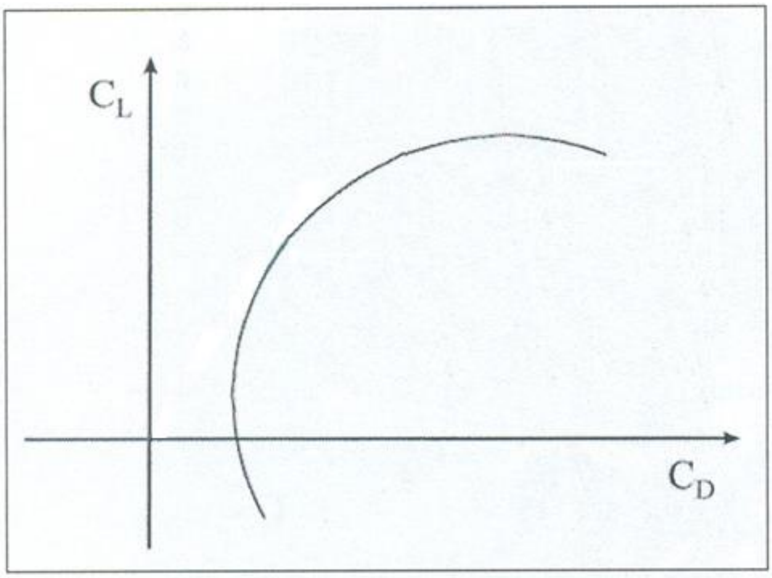
Equation		
Total drag		
$$\mathbf{Dtot = D0 + Di}$$		
Symbol	**Variable**	**Unit**
$\boldsymbol{Dtot}$	Total drag	Newton [N]
$\boldsymbol{D0}$	Parasitic drag	Newton [N]
$\boldsymbol{Di}$	Induced drag	Newton [N]

Appendix II. C_L diagrams

A. CL/Alpha diagram

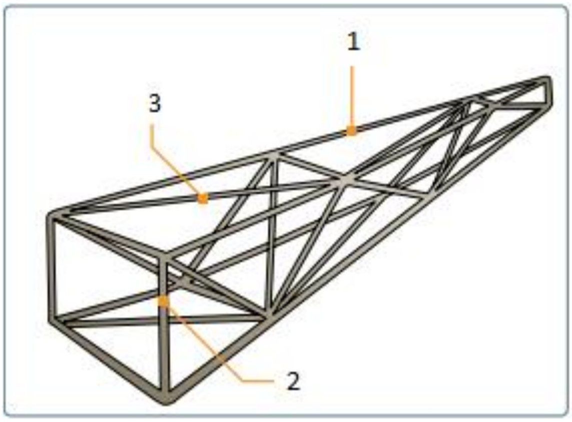


B. C_L/C_D Diagram



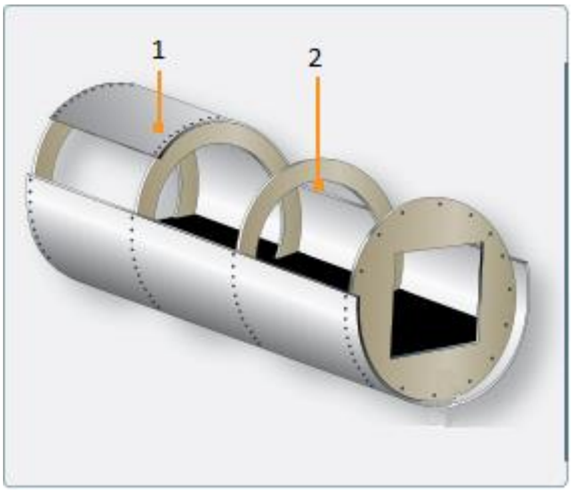
Appendix III. Construction types

A. Truss construction



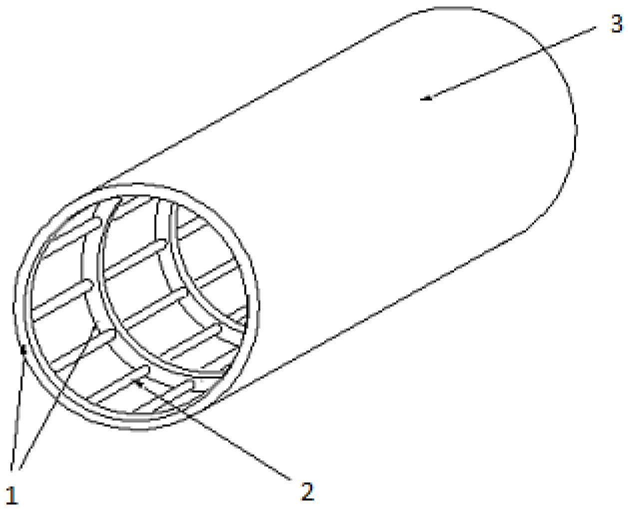
1= longerons, 2= struts, 3= diagonal struts

B. Monocoque construction



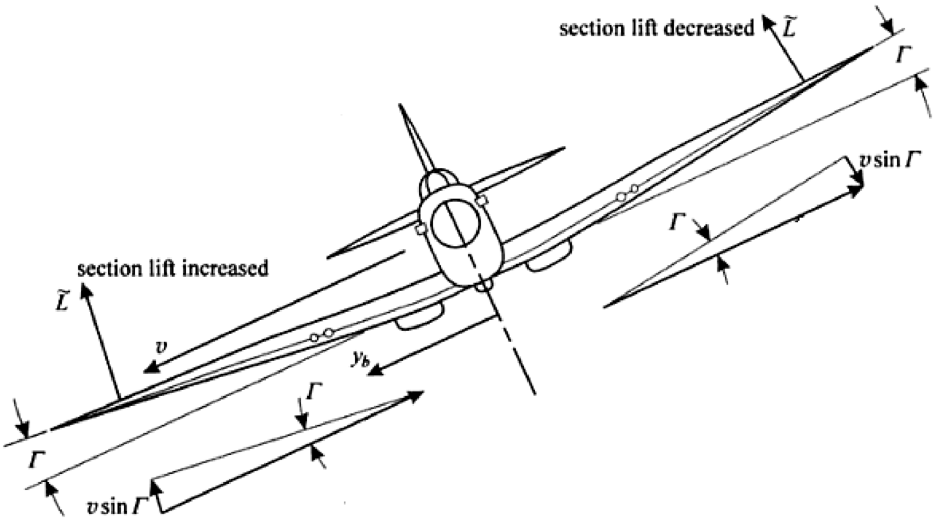
1= skin, 2= formers

C. Semi-monocoque construction



1= formers, 2= stringers, 3= skin

Appendix IV. **lateral stability through dihedral**



Appendix V. **Secondary Flight Controls**

The secondary flight controls surfaces consist out of four control surfaces, the trailing edge devices, the leading edge devices, the spoilers and trimmers. The trailing edge devices **(A)** are being used to improve the lift characteristics of the wing. The high lift devices **(B)** allow the wing to operate at a higher angle of attack. The spoilers **(C)** are being used to reduce the lift of an aircraft. And the trim tabs **(D)** are small surfaces on the trailing edge which are being used to control the trim of the controls.

A. The trailing edge devices

The flaps of an aircraft are located on the trailing edges of the wing and are being used to improve the lift characteristics of a wing. With flaps the speed of the aircraft can be reduced whereby the aircraft can be flown safely also the angle of descent can be increased for landing. Flaps can shorten take-off and landing distances by lowering the stall speed and by increasing the drag.
There are a couple of types of flaps:

B. Leading edge device

The slats are flight control surfaces located at the leading edge of the wing, when the slats are being used it allows the wing to operate at a higher angle of attack. As a result of the angle of attack and the speed a higher lift coefficient is being produced, hereby the aircraft can fly at slower speeds or take-off and land in shorter distances. The slats are often being used when the aircraft is performing manoeuvres close to a stall or when it is performing a landing, during flight the slats are being retracted to reduce the drag.

Besides the automatic slats there are a few other types of slats, which are the:

1. Fixed slats
2. Powered slats

Ad 1. *Fixed slats*

The fixed slats are permanently extended. This type is sometimes being used on aircraft specialized in low-speed flight.

Ad 2. *Powered slats*

This type of slats is the type which can be controlled by the pilot and are the most common used on airliners.

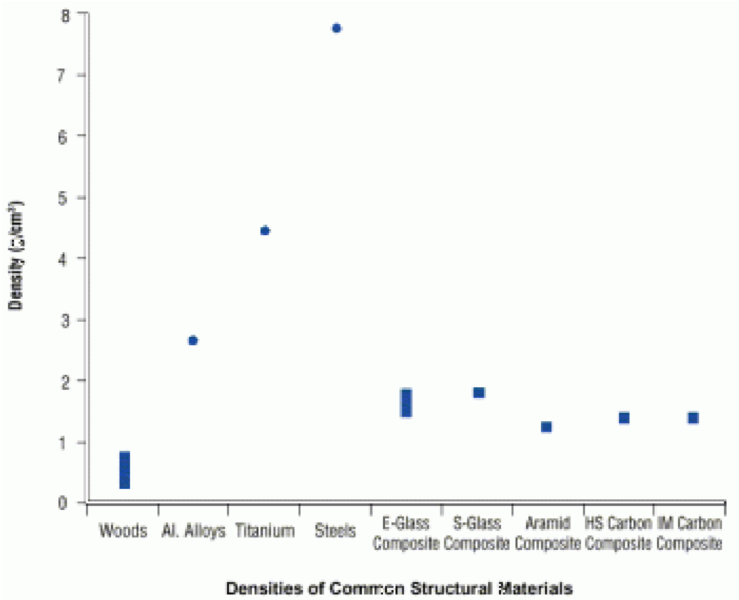
C. Spoilers

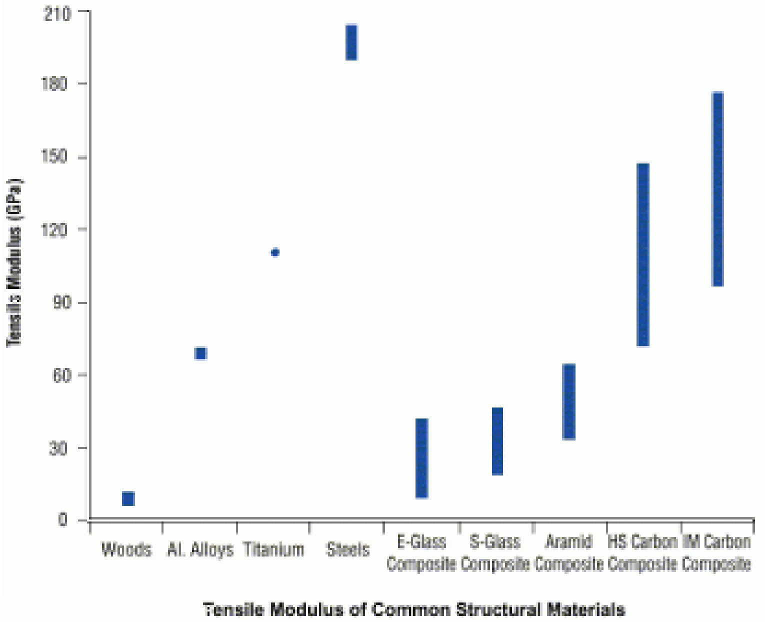
The spoilers are plates on top of the surfaces of the wing which can extend upwards to spoil the flowing airflow over the wing. This will result in a controlled stall over the part of the wing behind the spoilers. This will reduce the lift of the wing section greatly. Another kind of spoiler is the airbrakes. These are designed to increase the drag of the aircraft without affecting the lift, where the spoilers reduce the lift and increase the drag.

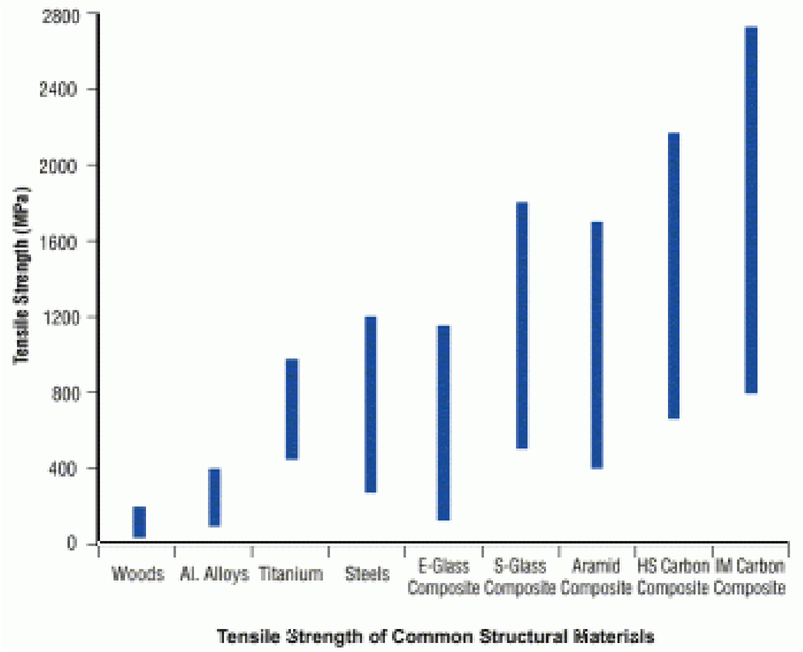
D. Trim tabs

The trim tabs are surfaces which are connected to the trailing edge and are being used to control the trim of the controls. This is necessary to counteract the aerodynamic forces and stabilize the aircraft in the desired attitude, without the need of the pilot to constantly apply a control force. This could be done by adjusting the angle of the trim tab.

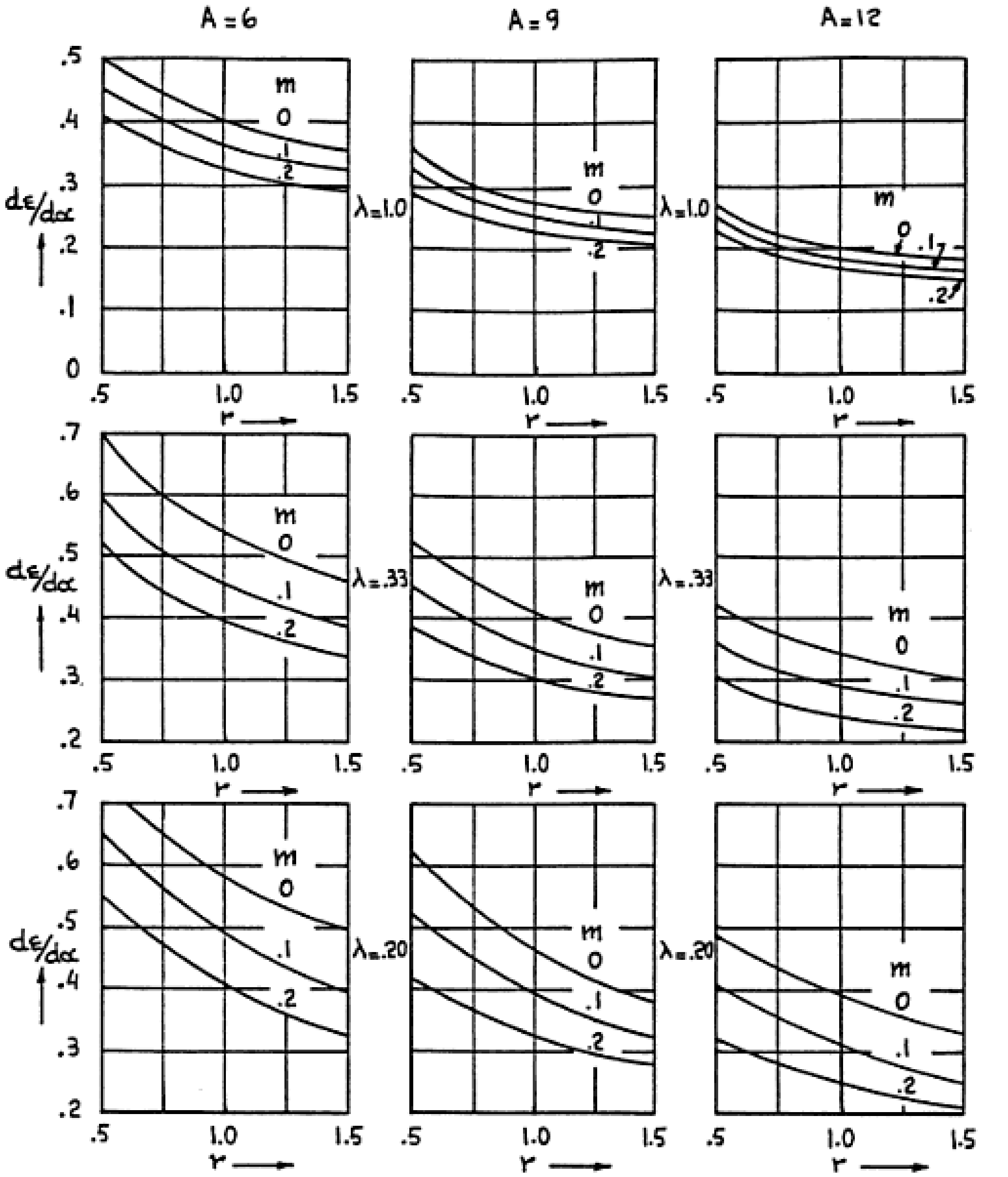
Appendix VI. **Strength of materials**







Appendix VII. **Downwash Gradient**



Notes: 1. Valid only for straight, tapered wings at low Mach Numbers
2. For other aspect ratios, interpolate or extrapolate
3. See Part VI of Reference 2.3 for a more general method

$$m = \frac{\text{Vertical distance of horizontal tail } 0.25\bar{c}_h \text{ above/below the wing zero lift line}}{b/2}$$

$$r = \frac{\text{Longitudinal distance of } 0.25c_r \text{ toward the horizontal tail } 0.25\bar{c}_h \text{ location}}{b/2}$$

Figure 2.14 Effect of Wing Aspect Ratio and Horizontal Tail Location on the Downwash Gradient

A = Aspect ratio
λ = taper ratio

Appendix VIII. **Model aircraft regulations**

a. de vlucht wordt uitgevoerd in overeenstemming met de algemene vliegvoorschriften voor zover daarvan niet wordt afgeweken in deze regeling;
b. de vlucht wordt slechts uitgevoerd onder omstandigheden en op locaties waarbij er vanaf de grond tijdens de gehele vlucht goed zicht is op het modelluchtvaartuig en het luchtruim daaromheen;
c. de bestuurder houdt tijdens de gehele vlucht goed zicht op het modelluchtvaartuig;
d. een hoogtemeter hoeft niet te worden gebruikt;
e. het is verboden voorwerpen of stoffen te verwijderen tijdens de vlucht, met uitzondering van zand, water of voorwerpen waarvan de massa niet meer is dan 200 gram per voorwerp overeenkomstig door de Minister van Verkeer en Waterstaat op grond van artikel 13 van het Luchtverkeersreglement te stellen regels;
f. een ander modelluchtvaartuig of een net of doek mag worden gesleept;
g. kunstvluchten mogen worden uitgevoerd;
h. de vlucht wordt niet uitgevoerd buiten de daglichtperiode, zoals gepubliceerd in de in artikel 60, onder a van het Luchtverkeersreglement bedoelde luchtvaartgids;
i. de vlucht wordt niet uitgevoerd boven gebieden met aaneengesloten bebouwing of kunstwerken, industrie- en havengebieden daaronder begrepen dan wel boven mensenmenigten of boven spoorlijnen of voor motorrijtuigen toegankelijke verharde openbare wegen, met uitzondering van wegen in 30 km-zones binnen de bebouwde kom en wegen in 60 km-gebieden buiten de bebouwde kom;
j. voor een vlucht wordt geen vliegplan ingediend;
k. gecontroleerde vluchten zijn niet toegestaan;
l. vluchten zijn toegestaan tot een hoogte van maximaal 300 meter boven de grond of het water in luchtruim met klasse G, mits
1° voor vluchten binnen een afstand van 3 km van een ongecontroleerde luchthaven of een terrein dat geschikt is om tijdelijk en uitzonderlijk te worden gebruikt, waarvoor krachtens artikel 8a.51 van de Wet luchtvaart ontheffing is verleend, geen bezwaar bestaat bij de exploitant van de luchthaven respectievelijk de houder van de ontheffing;
2° voor vluchten binnen een gebied waarin laag mag worden gevlogen door civiele of militaire luchtvaartuigen iemand met de bestuurder van het modelluchtvaartuig meekijkt om deze te kunnen waarschuwen voor luchtvaartuigen;
m. vluchten zijn toegestaan tot een hoogte van maximaal 450 meter boven de grond of het water, mits dit gebeurt binnen een aerodrome traffic zone van een militaire luchthaven waarop modelvliegen is toegestaan en dit gebied exclusief voor modelvliegen wordt gebruikt of met de andere gebruiker(s) sluitende afspraken zijn gemaakt inzake separatie;
n. vluchten zijn toegestaan in luchtruim met klasse C, mits op schriftelijk verzoek van belanghebbende een convenant is gesloten met de organisatie die de plaatselijke luchtverkeersleiding verzorgt en de bestuurder zich houdt aan de afspraken in dat convenant;
o. de regels voor de bediening van boordapparatuur voor het beantwoorden van vragen door radargrondstations gelden niet;
p. de regels voor de navigatie- en telecommunicatie-installaties waarmee een luchtvaartuig voor het uitvoeren van een VFR-vlucht is uitgerust, gelden niet.

ILENT – Luchtvaart Modelvliegers

- geen personen of zaken in gevaar mogen worden gebracht;
- niet mag worden gevlogen boven mensenmenigten, bebouwing, openbare wegen (autosnelwegen, autowegen en ontsluitingswegen) en spoorlijnen, en
- niet mag worden gevlogen in een plaatselijk luchtverkeersleidingsgebied (CTR), zonder dat men een convenant heeft gesloten met de organisatie die de plaatselijke luchtverkeersleiding verzorgt en men zich houdt aan de afspraken in dat convenant.

Telecom agency – Model aircraft

Uw afstandsbediening is bedoeld om korte afstanden te overbruggen en zal een gering zendvermogen hebben. In Nederland gebruikt u daarvoor frequenties in de 35 MHz-band en de 2,4 GHz-band. Dat zijn frequentiebanden voor vergunningsvrije radiotoepassingen, waarvoor geen meldings- en registratieplicht geldt.

Appendix IX. Flight envelope

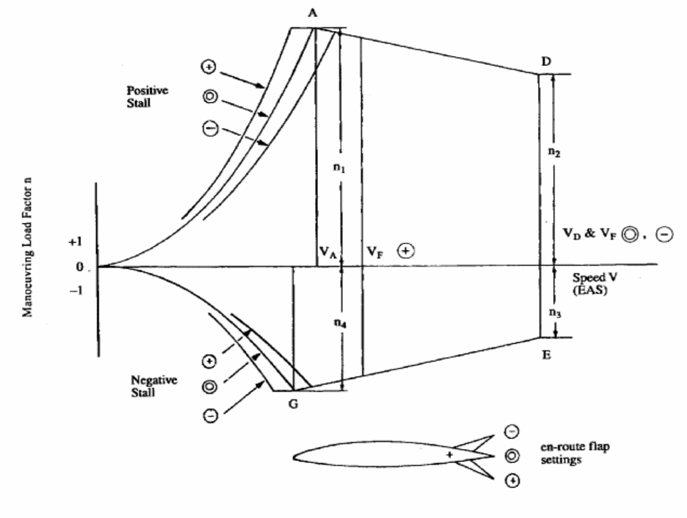
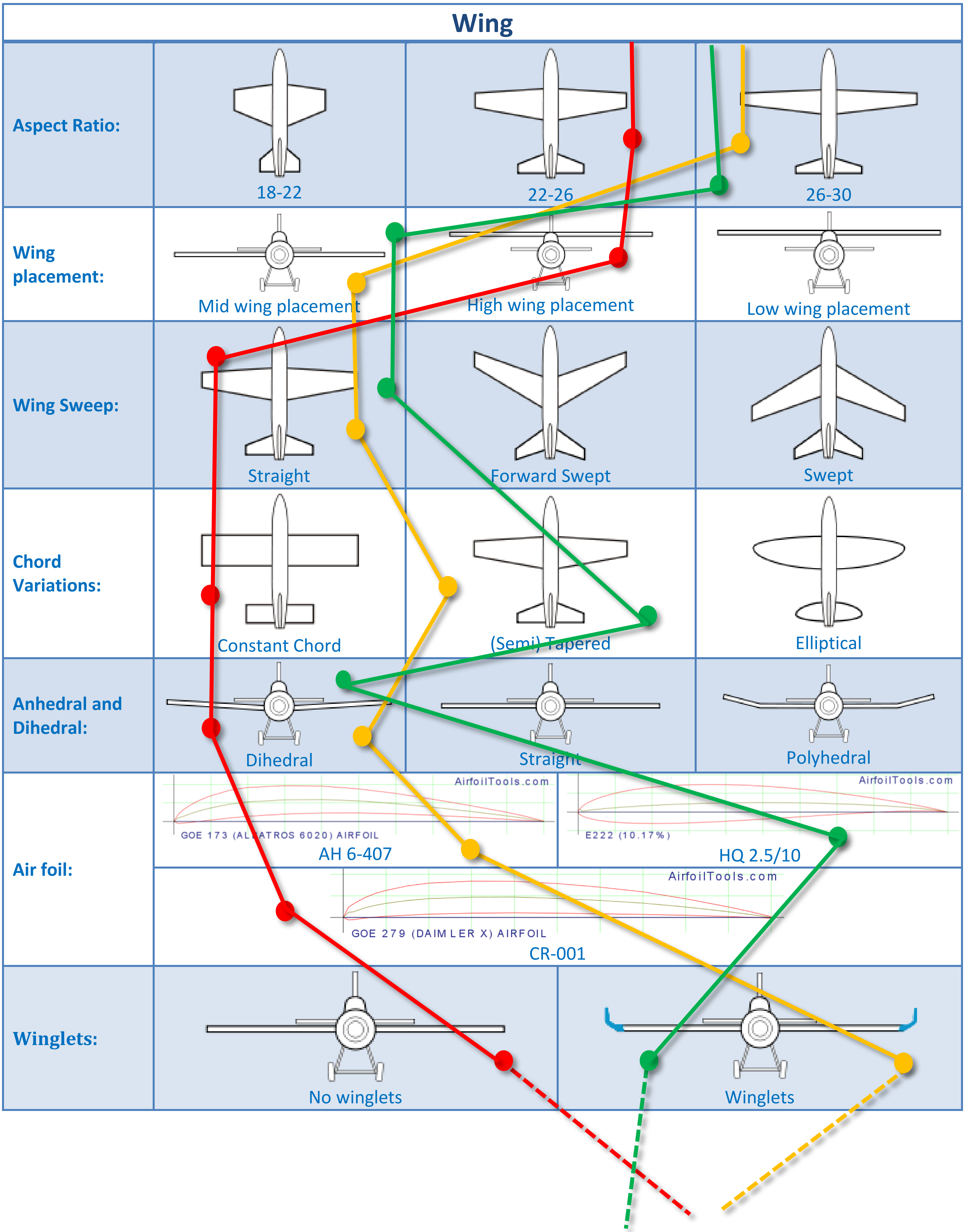


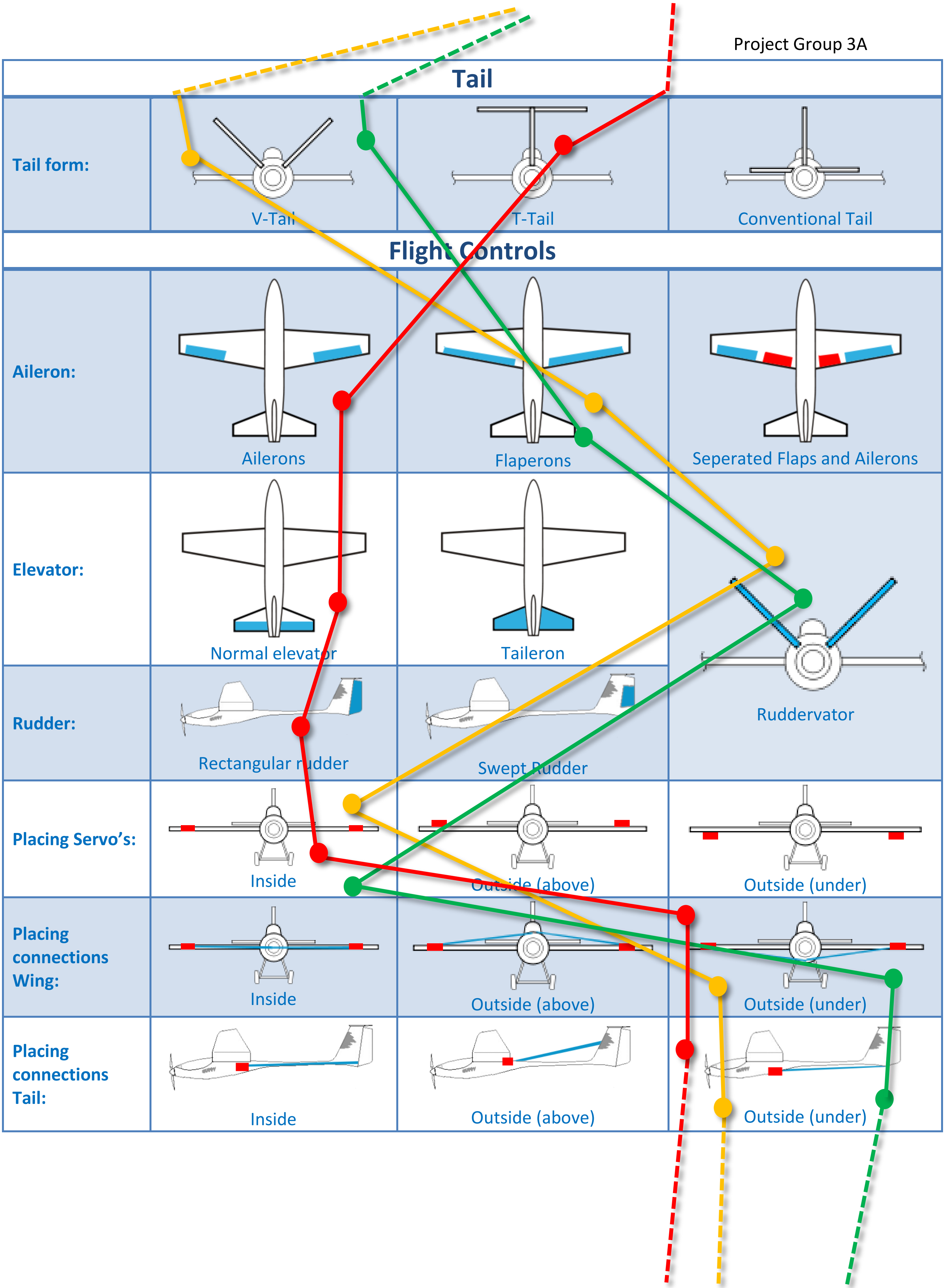
FIGURE 1 MANOEUVRING ENVELOPE

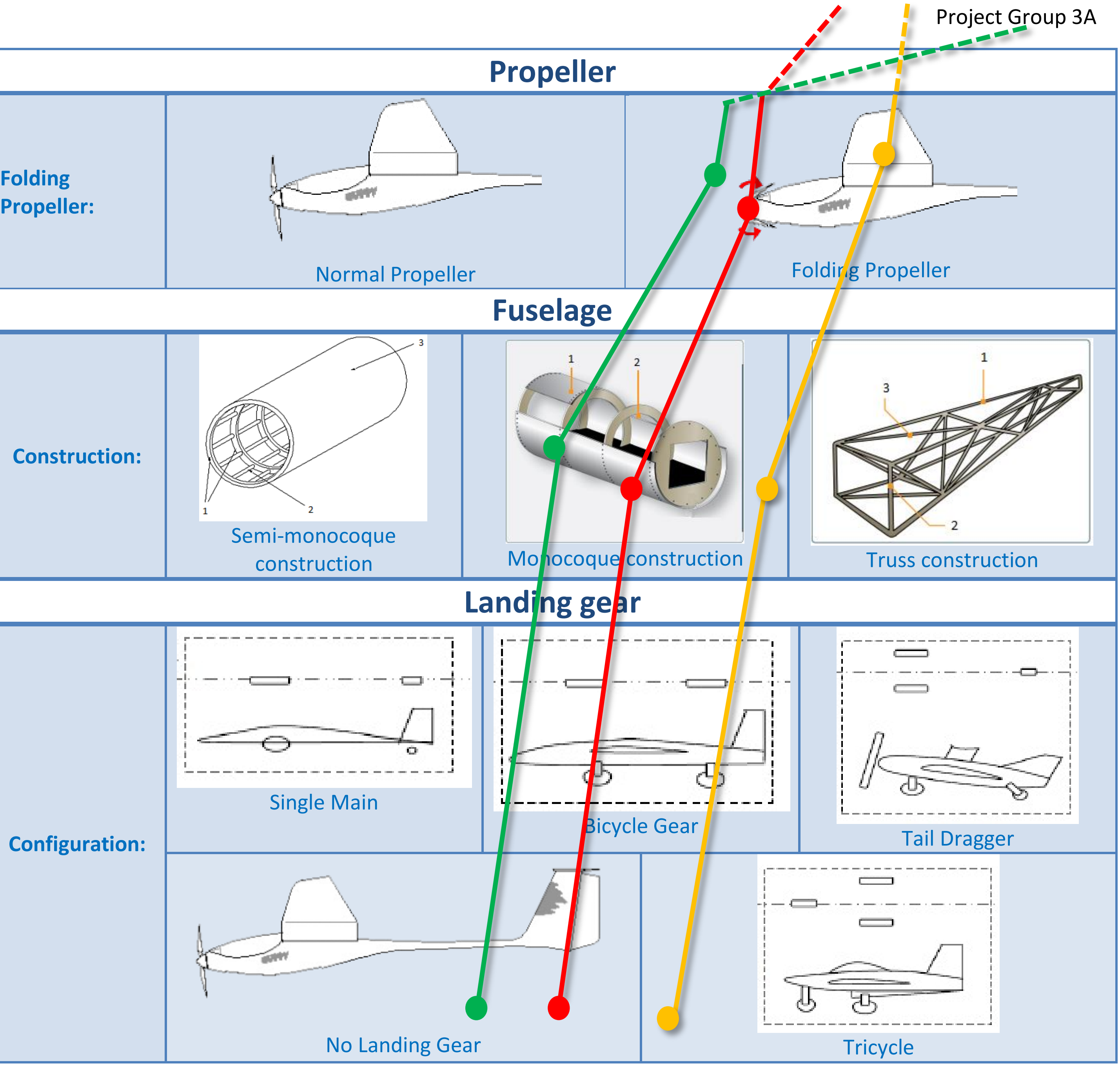
Where VA is: Design Speed
Where VF is: Speed with Flaps
Where VD is: Maximum Speed

Category	U	A
n_1	+5.3	+7
n_2	+4.0	+7.0
n_3	-1.5	-5.0
n_4	-2.65	-5.0

Appendix X. **Morphological Overview**




Tail
Tail form:
V-Tail
T-Tail
Conventional Tail
Flight Controls
Aileron:
Ailerons
Flaperons
Seperated Flaps and Ailerons
Elevator:
Normal elevator
Taileron
Ruddervator
Rudder:
Rectangular rudder
Swept Rudder
Placing Servo's:
Inside
Outside (above)
Outside (under)
Placing connections Wing:
Inside
Outside (above)
Outside (under)
Placing connections Tail:
Inside
Outside (above)
Outside (under)



Red line – Optimal constructability

Green line – Performance design

Orange line – Alternate option

Appendix XI. Control surface calculations

Calculation Sizing Control Surfaces

Input

General Wing form		
Aspect Ratio Main Wing	16,24	
Wing span	2,00 m	This value was set to 1,9 instead of 2,0 because the assumed width of the fuselage.

V-Tail		
Distance MAC to MAC-Elevator	0,8 m	0,8
Aspect Ration Tail	6	between 6 and 10

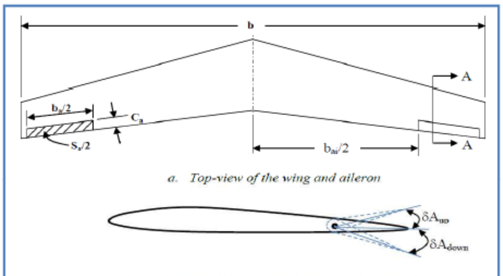
Output values

Wing Area	0,2463 m²	
Average wing chord	0,1232 m	12,32 cm

Tail Area	0,0436 m²	
Tail span	0,511 m	0,256 m per Side
Tail chord	0,085 m	
Tail volume coefficient	0,94169719	minimum 0.3

Ailerons

	Minimal	Average	Maximal
Aileron Area	0,01232 m²	0,01847 m²	0,02463 m²
Aileron Length	0,4 m	0,5 m	0,6 m
Aileron Chord	0,0308 m	0,0369 m	0,0411 m
Location of inner Edge	1,5 m	1,5 m	1,5 m
Maximal Deflection	+/-30 °	+/-30 °	+/-30 °



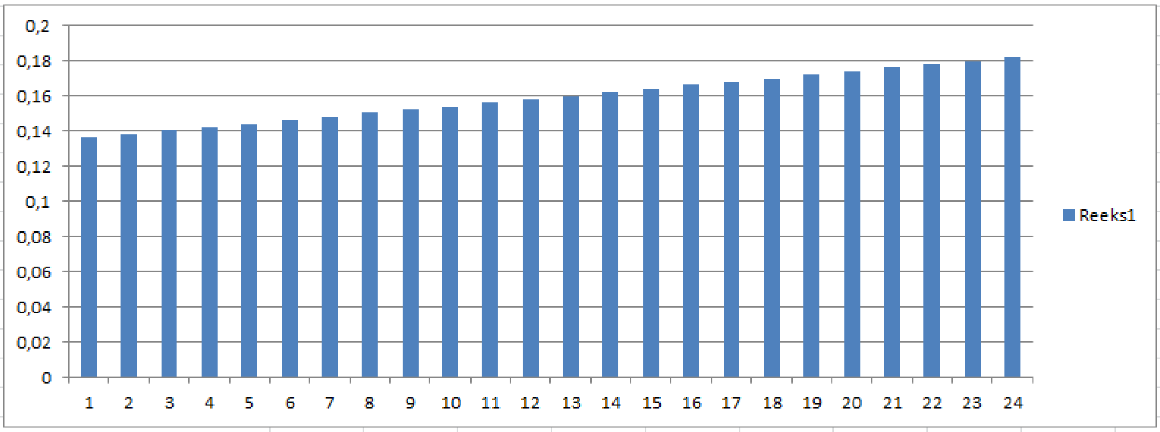
a. Top-view of the wing and aileron

b. Side-view of the wing and aileron (Section AA)
Figure 12.1. Geometry of aileron

Ruddervator

Distance angle 110°			
	Minimal	Average	Maximal
Elevator Area	0,00654 m²	0,01199 m²	0,01744 m²
Elevator Chord	0,0170 m	0,0256 m	0,0341 m
Elevator Span	0,38 m	0,47 m	0,51 m
Maximal Up-Deflection	-25 °	-25 °	-25 °
Maximal Down-Deflection	+20 °	+20 °	+20 °

Appendix XII. **Lift distribution**



The load is a distributed load (linear line)

Square	3,271724	On half-length of wing
Triangle	0,549268	On 1/3 of the root
total	3,820992	
Moment	1,746193	
Distance total force of the root	0,457	

Appendix XIII. cd0 & Thrust calculations

Cd0 Formula		
$$\boldsymbol{Cd0} = \frac{\frac{cd}{cl}\cdot W}{0.5\cdot\ \rho\ \cdot v^2\cdot S+\frac{\left(\frac{W}{0.5\cdot\rho\cdot v^2\cdot S}\right)^2}{\pi\cdot\frac{2^2}{S}\cdot e}}$$		
Symbol	**Variable**	
cd/cl $\boldsymbol{W}$ $\boldsymbol{v}$**stall** $\boldsymbol{\rho}$ $\boldsymbol{S}$ $\boldsymbol{e}$	0.053 9.81 7.36 1.225 0.25 0.61	Cd0=0.0606

First of all it was necessary to determine the cd/cl ratio. To determine this value it was necessary to search for the cl/cd ratio in the cl/cd graph. In this graph the cl was 1.2 and the cd was 0.064, this will result in a cl/cd of about 18.8. So to calculate the cd/cl ratio the following formula was used:

$$\frac{cd}{cl}=\frac{1}{cl/cd}=$$

$$\frac{cd}{cl}=\frac{1}{18.8}=0.053$$

Furthermore it was necessary to fill in the Oswald factor formula. Therefore the only value necessary was the Aspect ratio of 16. This will result in an Oswald factor of 0.612.

$$e=1.78\cdot(1-0.045\cdot AR^{0.68})-0.64\ =$$

$$e=1.78\cdot(1-0.045\cdot 16^{0.68})-0.64\ =0.612$$

All the other values for the cd0 formula were already given or were calculated in other paragraphs. So with all this information it was possible to fill in the cd0 formula. This will result in a cd0 of 0.0606.

$$Cd0\ =\frac{0.053\cdot 9.81}{0.5\cdot\ 1.225\ \cdot 7.24^2\cdot 0.25+\frac{\left(\frac{9.81}{0.5\cdot\ 1.225\cdot 7.24^2\cdot 0.25}\right)^2}{\pi\cdot\frac{2^2}{0.25}\cdot 0.612}}=0.0606$$

Thrust formula		
$$\boldsymbol{Thrust = \frac{1}{2} * \rho * A * (v_e^2 - v_0^2)}$$		
Symbol	**Variable**	**Unit**
$\boldsymbol{\rho}$	Air density	1.225 kg/m^3
$\boldsymbol{A}$	Surface propeller	Square meter [m^2]
$\boldsymbol{v_e}$	Exit velocity	Meter per second [m/s]
$\boldsymbol{v_0}$	Velocity of the aircraft	Meter per second [m/s]

With the specifications of the propeller and motor, the exit velocity can be calculated. The propeller has a diameter of 8 inch (0.2032m). The axis, which is mounted to the fuselage, has a diameter of 1 inch (0.0254m).

$$A = \left(\frac{1}{4} * \pi * 0.2032^2\right) - \left(\frac{1}{4} * \pi * 0.0254^2\right) = 0.0319\ m^2$$

The motor has 1300RPM/V and is connected to a battery that gives 11.1V. In theory, the rotation per minute will be 14430. When a propeller will be mound on the engine, the rotation per minute will be less than calculated. With the information from the manufacturer of the motor, the real life rotation per minute with different sizes of propeller can be determined.

M-FS3529/10					
2 Li-Po	10 x 5	7,200	15.1A	127W	8
2 Li-Po	9 x 6	7,300	14.7A	123W	8
3 Li-Po	7 x 5	11,700	14.5A	183W	11
3 Li-Po	8 x 4	11,500	16.7A	210W	13

$$RPM = 11.500$$

$$RPS = \frac{11.500}{60} = 191.667$$

The pitch of the propeller is 4 inch (0.1016m). This means that by one rotation of the propeller the exhaust air will travel a horizontal distance of 4 inch. The rotation per second is known.

$$v_e = 191.667 * (4 * 0.0254) = 19.473 \frac{m}{s}$$

With v_0 is zero m/s the static thrust can be calculated, this is when the glider will not move.

$$Static\ thrust = \frac{1}{2} * 1.225 * 0.0319 * (19.473^2 - 0^2) = 7.415\ N$$

When there will be flown with the stall speed (7.25 m/s) the minimum thrust can be calculated.

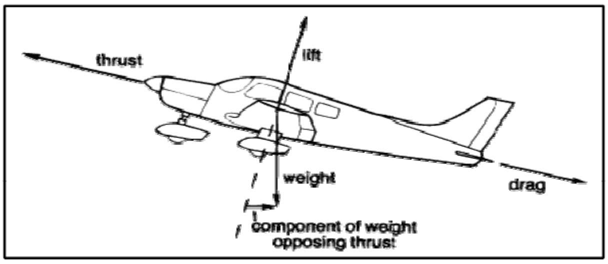
$$Thrust = \frac{1}{2} * 1.225 * 0.0319 * (19.473^2 - 7.25^2) = 5.547\ N$$

Appendix XIV. **Centre of gravity calculations**

INPUT	Value	Unit
Static margin	7.5	*Percentage of chord*
S Wing	0.26	*Square meters*
S tail (horizontal reference)	0.058	*Square meters*
Mean aerodynamic chord	0.13	*Meters*
Clα slope	0.11	*ΔCl/α*
Δl c.o.g. and tail a.c.	0.8	*Meters*
Tail volume coefficient	0.933	*Dimensionless*
Downwash gradient	0.12	*Dimensionless*
Neutral point		
$h_{np} = h_{ac} + C_{Lw,\alpha} \cdot V_h \cdot \left(1 - \frac{d\varepsilon}{d\alpha}\right)$ $h_{np} = 0,25 + 11 \cdot 0,933 \cdot (1 - 0,12) = 0.34 \text{ or } 34\%$		
Distance to neutral point		
$X_{np} = h_{np} \cdot C$ $X_{np} = 0.34 \cdot 0.12 = 0.041\ m$		
Distance to centre of gravity		
$X_{cg} = -SM \cdot C + X_{np}$ $X_{cg} = -0.075 \cdot 0.12 + 0.041 = 0.032\ m = 27\%\ of\ MAC$		

Appendix XV. **Flight performance calculation**

Climb



Drag coefficiant
$c_{di} = \frac{cL^2}{\pi\ e\ AR}$
cdi = 0,04679
$c_D = c_{d0} + c_{di}$
cD = 0,10739
cL/cD = 11,17405

Velocity - horizontal flight with AoA		
$TAS = \sqrt{\frac{2 * W * \cos\alpha}{\rho * c_l * S}}$		
TAS =	7,55	m/s
	27,19	km/h

Drag - horizontal flight with AoA		
$D = \frac{1}{2} TAS^2 * \rho * cD * S$		
D =	0,86	N

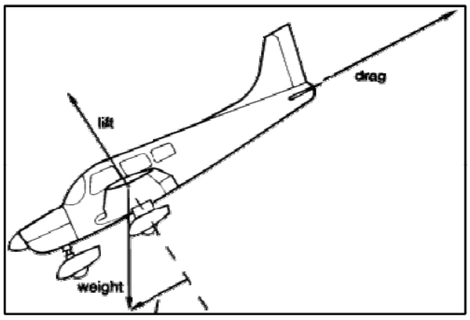
Required Thrust		
$T_{required} = W * \sin\alpha + D$		
$T_{required}$ =	2,57	N
$T_{overflow} = T_{max} - T_{required}$		
$T_{overflow}$ =	4,85	N

TAS max	
$D_{max} = D + T_{overflow}$	
Dmax =	5,71 N
$TAS_{max} = \sqrt{\frac{2 * D_{max}}{\rho * c_D * S}}$	
TAS_{max} =	19,41 m/s
	69,89 km/h

Rate of Climb	
$RC = TAS_{max} * sin(10°)$	
RC =	3,37 m/s

maximum Altitude	
$alt_{max} = RC * Time$	
alt max =	1011,32 m
Realitiy factor =	0,6
realistic altitude =	606,79 m

Descend



Drag coefficiant

$$c_{di} = \frac{c_{Lgliding}^{2}}{\pi * e * A}$$

cdi = 0,02632

$$c_D = c_{d0} + c_{di}$$

cD = 0,08692

cL/cD = 13,80575

Velocity - horizontal flight

$$TAS_{gliding} = \sqrt{\frac{2 * W}{\rho * c_{gliding} * S}}$$

TASgliding = 8,79 m/s

31,64 km/h

Drag - horizontal flight

$$D = \frac{1}{2} TAS_{gliding}^{2} * \rho * c_{Dgliding} * S$$

$D_{gliding}$ = 0,95 N

Required Angle for best gliding performance

$$\varphi = \sin^{-1}\left(\frac{D_{gliding}}{W}\right)$$

φ = 5,54 °

Rate of Descend

$$RD = \frac{D * TAS}{W}$$

RD = 0,849 m/s

Endurance

E = Calculated Altitude/RD

E = 714,89 s

11,91 min

Appendix XVI. **Glider drawings**

This page is intentionally left blank.
The drawings can be found on the provided A2 pages.