DESIGN AND DEVELOPMENT OF A LONG RANGE GLIDER

by

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DESIGN AND DEVELOPMENT OF A LONG RANGE GLIDER

ABSRACT

Glider is a vehicle that operates with no power supply and unmanned operating system. There are many types of glider that consist of the certain purpose of activities. Long range glider is referring to a glider that can be glide with a range and time. The impact of having a glider in the industry is too able an aircraft glide in emergency condition. The glider are going through design phase which consists of preliminary design and final design before undergo fabrication process. The fabrication process of the glider is using the balsa wood as the main materials for the wing and tail part besides the composite materials is used for the fuselage and the attachment between the wing and the fuselage. The purpose of the attachment is to attach the different types of the wing on the fuselage. The logic of the attachment is the glider have been construct with three different wings to determine the performance of the glider in term of the range while the other part are fixed. The test model are held at the different locations such as field test and stage test which the results of the test come out with the stage test are the highest with the range of 57.4 metre in 15.76 second of the gliding duration. The overall results state that the dihedral wing is the best performance wing followed by tapered and straight wing. The reason is the dihedral wing returns the wing to level when there is disturbance. The result obtain from the technique applied on the glider are record, compared and analysed in the current study.

REKABENTUK DAN PENGHASILAN PESAWAT LUNCUR JARAK JAUH

ABSTRAK

Glider adalah kenderaan yang beroperasi tanpa bekalan kuasa dan sistem operasi tanpa pemandu. Terdapat banyak jenis glider yang terdiri daripada tujuan tertentu aktiviti. glider jarak jauh adalah merujuk kepada glider yang boleh meluncur dengan pelbagai dan masa. Kesan mempunyai glider dalam industri terlalu dapat yang meluncur pesawat dalam keadaan kecemasan. buaian akan melalui fasa reka bentuk yang terdiri daripada reka bentuk awal dan reka bentuk terakhir sebelum menjalani proses fabrikasi. Proses pembuatan buaian menggunakan kayu balsa sebagai bahan utama untuk sayap dan bahagian ekor di samping bahan-bahan komposit digunakan untuk fiuslaj dan lampiran di antara sayap dan badan pesawat. Tujuan lampiran adalah untuk melampirkan jenis sayap pada badan pesawat. Logik lampiran adalah buaian telah membina dengan tiga sayap yang berbeza untuk menentukan prestasi buaian dari segi julat manakala sebahagian yang lain adalah tetap. Model ujian diadakan di lokasi yang berbeza seperti ujian lapangan dan ujian peringkat mana keputusan ujian keluar dengan ujian peringkat adalah yang tertinggi dengan lingkungan 57.4 meter di 15.76 kedua Tempoh luncuran. Keputusan keseluruhan menyatakan bahawa sayap dihedral adalah sayap prestasi yang terbaik diikuti dengan sayap tirus dan lurus. Sebabnya ialah sayap dihedral mengembalikan sayap ke tahap apabila terdapat gangguan. Hasilnya mendapatkan daripada teknik yang digunakan pada glider adalah rekod, dibandingkan dan dianalisis dalam kajian semasa.

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In the name of Allah…

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Wassalam

DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

NOR FARIDAH HANIM AZIZ UJANG

Date:

STATEMENT 1

This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

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LIST OF SYMBOLS

Greek Symbols

α	angle of attack
ρ	density of fluid
ρ_∞	free stream density
μ	dynamic viscosity of fluid
μ_∞	free-stream fluid dynamic viscosity
γ	gliding angle
τ	shear stress
δ	boundary layer thickness
ε	blockage correction factor

Roman Symbols

a	speed of sound
AR	wing aspect ratio
b	wing span
c	length of model
C	wing chord length
D	aerodynamic drag force
h	stage height
L	aerodynamic lift force
M	Mach number
q	Dynamic pressure

R	range
Re	Reynolds number
T	temperature
t	time duration
v	flow velocity
V_∞	free stream velocity

Abbreviation

FYP	final year project

CHAPTER 1

INTRODUCTION

This chapter describes the motivation behind the design and development of a long range glider. The overview, motivation, objective and thesis organization on the research are presented and discussed.

1.1 Overview

In December 1st 1804, Sir Gorge Cayley was the first scientist that managed to address the issue of the effect of aerodynamics on the glider by invented, designed and operated the first glider. He tested his idea with a simple kite that modified as a glider, the first aeroplane to fly. The motivation of his study is to get from the issue that the wing was subjected either to a uniform pressure distribution [Ackroyd, 2011]. Cayley glider had inspired many scientists and engineers to improvise, modify and innovate the existing model with specific purpose such as air sports of gliding, hang gliding and paragliding.

Moreover, based from the source he chose the location to locate the centre of gravity as to lie close to the wings mid-area in the belief that the latter location would be the centre of pressure. If so, he may have been guided by a belief that the wing was subjected either to a uniform pressure distribution. Experience had then taught him that the tail plane should be set at its high positive incidence in order to achieve successful glides. To achieve successful glider, the horizontal tail from the low to high position resulted in configurations which were longitudinally stable throughout the angle of attack. For lateral case, the vertical tail contributes the directional stability to increase by moving the wing from the high to the low position. This is due to the sidewash at the vertical tail arising from the wing fuselage interface. The addition of a horizontal tail in the low position produced a further increase in directional stability. The results also indicated that at low angles of attack the effective dihedral due to wing-fuselage interference increased as the wing height was increased [Alex.G, 2011]. The wing's centre of pressure must have been forward of the centre of gravity at its mid-area location. Of course, due to the wing's likely substantial downwash, the tail's nose-down moment would not have been as large as its high positive setting angle of 11.5° might suggest.

Gliders are defined as unpowered aircraft that due to their basic construction that are used only for free gliding. In general, glider is used commonly for aeronautical purpose such as paragliding where the aerodynamic forces and moments on the body are due to two basic sources. The sources are based on the pressure distribution (act normal to the surface) and shear distribution (act tangential to the surface and caused by friction between the body and air). These sources will respond to the performance of the glider in term of the range and speed.

1.2 Motivation

As a local research university in Malaysia the development in aerospace industry has inspired the researcher to improve aerospace industry of the nation. The development of the glider also is to identify the range of the glider glide. The focus of this project is to design and develop a long range glider to identify the lift and drag coefficient as the basic aerodynamic characteristic in an aircraft. The main parameter of this project is the range in unit metre. The lift and drag coefficient influent the performance of the glider in term of range. This will be discussing detail on after this and prove by the equations. Thus, this particular project can provide expose to the student's learning on aerodynamics.

1.3 Objectives

The main objective of the current project is to satisfy several objectives as below:

i. To identify the range and the duration of the gliding glider
ii. To determine the aerodynamic characteristics of the glider
iii. To determine the performance of the wings in term of range

1.4 Thesis Organization

This thesis is divided into 6 chapters where each chapter provides details on the overall project. The first chapter consists of the overview topic, problem statement and objectives is stated to provide a big picture of the whole project. Chapter 2 discussed the literature review which included the past studies and researches related to this project. Moving on to Chapter 3, theories are required to provide the fundamental elements to this project are presented. In Chapter 4, the methodology is described to give an overview on the method and technique used in completing the project. Chapter 5 presents the results from the experimental work and from there, discussion and analysis is carried out on related subjects. Finally, in Chapter 6, will summarize and conclude the whole project.

CHAPTER 2

LITERATURE REVIEW

This chapter describes the previous work carried out in topics that are related to the current project. There are several projects that are related to the glider that can be used during the design process. This project involved with the development and design of the glider. The development of the glider consists of the part of the glider's main component such as the wing, fuselage and the tail. The results from the previous studies will be discussed and used to design a new glider configuration. The literature review for this project focus on the components such as listed below:

i. Fuselage
ii. Tail
iii. Wing

2.1 Fuselage

Based on the previous work conducted by [W. Hart, 1971] that focused on the fuselage glider that undergo initial drawing board layout were made by Torva. The drawing has been made with the object of deriving a basic shape of the fuselage to satisfy both aerodynamic and geometrical constraints. The aerodynamic satisfaction is based on the lift and drag coefficient on the geometrical constraints that are related to the size and shape of the component. The position of the fuselage should be under the wing to minimise the superposition of increased velocities due to the wing and fuselage flows. The effect on the position is preventing the turbulent air flow to exist at the position [Alex.G, 2011]. Basically, the important part of the glider is the fuselage part where the attachment of the wing and tail are made.

According to W. Hart on 1971, the technique that used to determine the fuselage body is by dividing the fuselage to three different part (front, centre and rear fuselage) while each part have the own shape as shown at Figure 2.1 below. The result of the dividing the fuselage parts make the airflow to separate nicely at the fuselage surface. This will decrease the tendency of the turbulent air flow to be created.

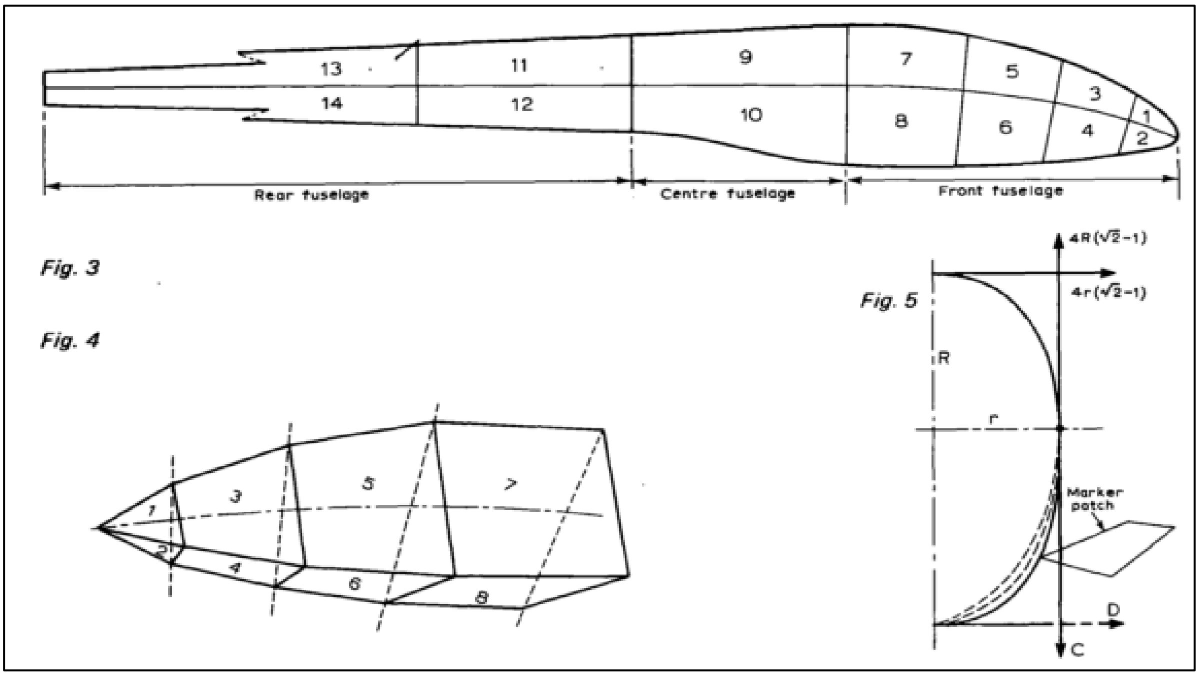


Figure 2.1: The devision of the fuselage body [W. Hart, 1971]

However, according to [F. Nicolosi, 2016] the technique that are used for this work of the fuselage body are divided into three different part with the same size of the nose and tail but different in cabin size (front, centre and rear). The main reason is to stabilize the whole fuselage by different size and weight of the wing at the centre fuselage and the tails at the rear fuselage. The computing method is allowed the fuselage drag coefficient as the sum of the contributions of each component (nose, cabin, and tailcone). This approach does not allow evaluating some sources of drag as leakage, wiper, surface roughness, and excrescences. The hypothesis of the super-positioning of the effects has been verified, since the geometry modifications of one part of the fuselage affect only the drag coefficient of that part [F. Nicolosi, 2016].

More in detail, the drag due to the after body is the sum of pressure drag due to the skin friction drag that depends on the wetted surface. The longer is the tail, the higher is the value of drag coefficient. This is due to the increased wetted area. In this last case, what is saved in skin friction (wetted area) is lost in pressure drag, since a fuselage has a more extended area of flow separation due to greater adverse pressure gradient.

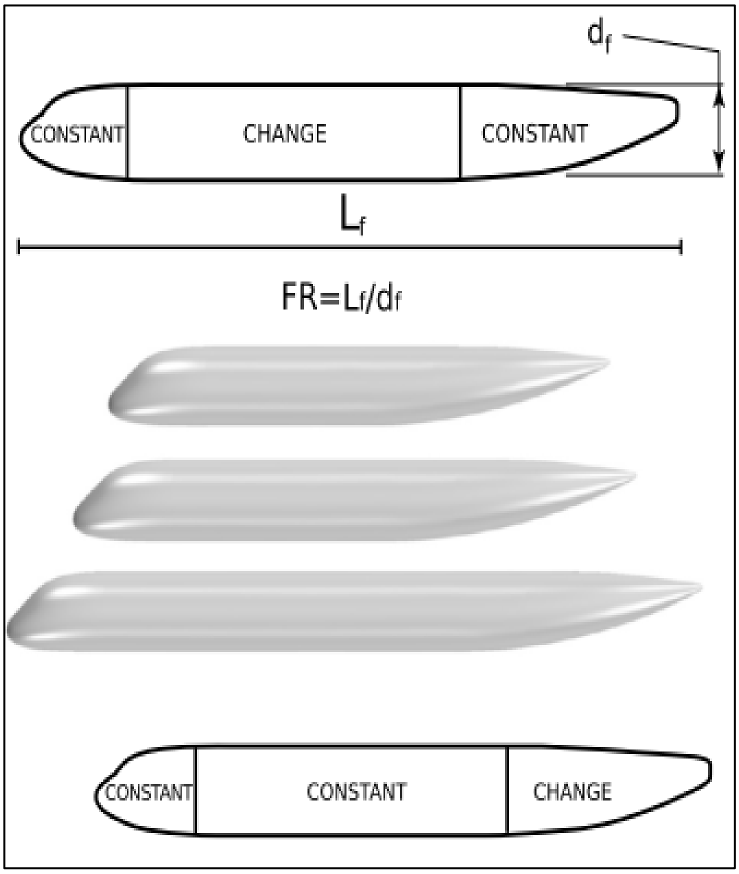


Figure 2.2: The fuselage geometry [F. Nicolosi, 2016]

The nose part or called as front fuselage is test out to identify the suitable nose to be used is by using the technique of wind tunnel test. Based on Horner S.F. (1965), there is several shape of geometry of the nose which each of it has the coefficient drag that influence these election of the nose. The coefficient drag at the nose the basic of the aerodynamic stated that component with small value of drag coefficient is the most suitable component to be used. Thus, the results by Horner of the wind tunnel on the variable nose part gives the different drag coefficient for the two different value for the shape of the cone and rectangular where the result of the drag coefficient of the rectangular is higher (75%) compared to the cone shape as shown at the Figure 2.3 below.

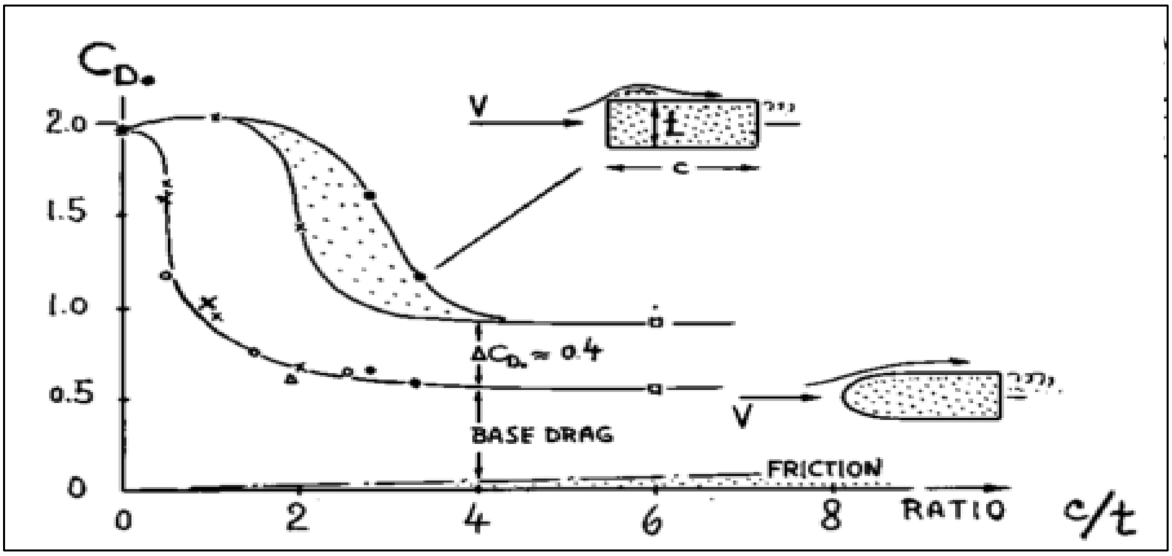


Figure 2.3: The result of the wind tunnel test of the nose [Horner S.F., 1965]

However, the test also carried out for the radius of the nose components where there are three different radiuses on the wind tunnel with the diameter of 0.02 m, 0.05 m and 0.08 m. The drag coefficient drops accordingly, between 50 and more than 90% depending on the shape of the body. Therefore, the result of the test is acceptable with his theory with the increasing of the radius size will increase the value of the drag coefficient as shown at Figure 2.4. However, for these both experiment tests the specimens is undergo with 2.9×10^3 non dimensional Reynolds number.

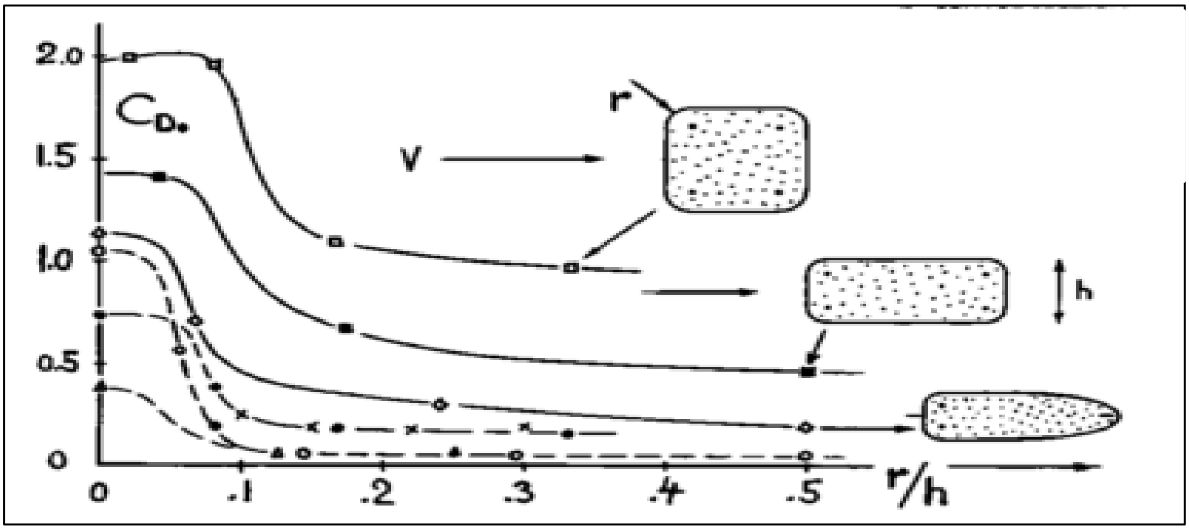


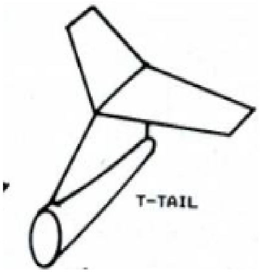
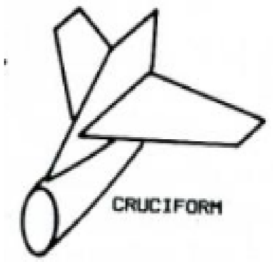
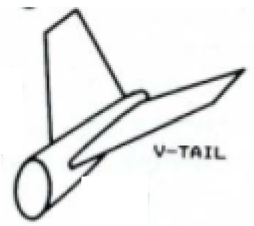
Figure 2.4: The result of the wind tunnel on the radius aspect [Horner S.F. 1965]

2.2 Tail

The primary function of the tail or called as empennage is to provide the stability on the glider. The function of the horizontal tail is to provide the longitudinal stability while the function of the vertical tail is to provide the directional stability. The tail function is to provide the necessary stability and control of the airplane. There are many configurations for the tail such as conventional, T-tail and cruciform. It does not suitable to use a cambered airfoil for tail section: rather, the vertical and horizontal tail on glider and airplane use a symmetric airfoil section [Anderson, 1999]. The reason is for the horizontal tail is focus on the balancing the aircraft because the vast majority of the lift comes from the wings and help balancing the aircraft without sacrificing too much drag [S Robinson, 2013].

Overall, the simple designed airfoil is that provides sufficient lift while minimizing drag as much as possible. A good vertical tail is more necessary for stability and control. Airfoil provides zero lift and zero moment. The aspect ratio, AR for the tail must be less than the AR of the wing. The reason is wings of lower aspect ratio will stall at higher angle of attack than wings with higher aspect ratio. Hence, if the horizontal tail has lower AR than the wing, when the wing stalls, the tail has some control authority [Anderson, 1999].

Table 2.1: Comparison of tail configuration on conventional, T-tail and cruciform tail [Anderson, 1999]

Configuration	Advantages	Disadvantages
Conventional 	• Light weight structural • Provide reasonable stability and control	• Very close to the ground, might cause damage
T-tail 	• Experience a smaller induced drag • Higher lift slope • AR can make small • Rudder is not blanked at stall • Structure strong	• Structure is heavier • Vertical tail must be strengthened to support the aerodynamic load and weight of the horizontal tail
Cruciform 	• Light weight structure	• Structure not strong • Easily to break • Complex fabrication process
V-tail 	• Only two instead of at least three lifting surfaces are necessary • Thus less structural weight.	• More complex flight control system • Less control surface effectivity, • Creates a relatively large roll moment.

2.3 Wing

Wing has many type of the design such as straight, swept, delta and tapered wing. However, the most suitable wing must be choosing to finish up this glider project. Based on the reading that carried out from the researcher the information that gain from the journal can be tabulated on the table to determine the advantages and disadvantages of the wings type and position on the aircraft. There are two considerations of the wing that are the geometric shape of the wing and its location relative to the fuselage [Anderson, 1999].

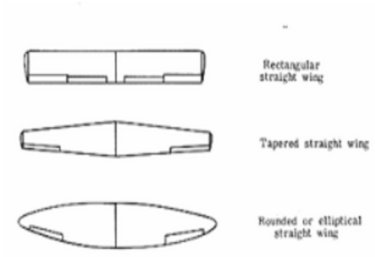
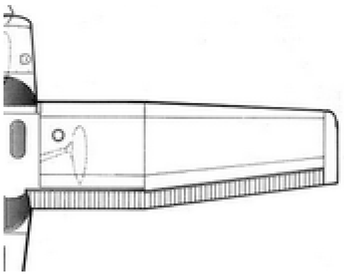
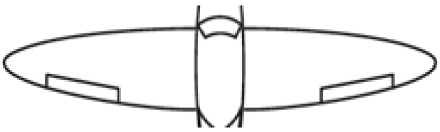
Briefly, the wing design is chosen based on the velocity air flow besides the purpose of the aircraft function. There are several parameter that influent the wing chosen and for this project the wing design are chosen based on the parameter of the range in unit of metre. For the low air flow speed, conventional straight wing and tapered wing can be used because of minimum induced drag [Anderson, 1999]; for the project the air flow speed is in a range between 2 to 3.2 ms^{-1}.

The advantages and disadvantages of the wing level at the high wing level, mid wing level and low wing level are shown at Table 2.2. While for the wing types such as straight, tapered and elliptical wing are shown at Table 2.3 at below.

Table 2.2: Comparison of wing level, high-wing, mid-wing and low-wing [Anderson, 1999]

Wing level	Advantages	Disadvantages
High wing 	• More stable in term of lateral, rolling motion • Create an increased lift on the lowered wing; dihedral • Tending to restore the wing to level equilibrium position; dihedral • Easy to fabricated	• Dihedral will tend to stall higher • Used fillet to minimised the undesirable aerodynamic interference • Easy to fabricate
Mid wing 	• Provide lowest drag • For low speed airplanes, weight saving can be effected by strut braced wing • Allows placing fuselage closer to ground • No blockage of visibility. Hence, used on some military airplanes.	• Structural design complex • Wing root structure passing through the fuselage is not possible • Which leads to higher weight
Low wing 	• Easy on design • Used filet to overcome the aerodynamic problem • Wing structure can be through the fuselage	• Used fillet to minimised the undesirable aerodynamic interference • Easy to fabricate • Low ground clearance.

Table 2.3: Comparison of a straight wing and tapered wing [Anderson, 1999]

Wing type	Advantages	Disadvantages
Straight wing  	• Easy to fabricate • Tapered high, aerodynamic are benefit • Flow separated at the root chord • Minimum induced drag	• Structure long • Structure heavy compared to the tapered • Structure not benefit
Tapered wing 	• Small taper, light the wing structure • Lift shift into the wing • Moment arm from the root to the centre of pressure decrease • Structure benefit	• Exhibit undesirable flow separation and stall behaviour • Tapered ratio decreases, separation flow moved out toward the tip chord • Aerodynamic not benefit
Elliptical wing 	• High lift to drag ratio. • More versatile. • Easier on the joints due to less impact.	• Difficulty in manover • They have bad stall characteristics, because the tip stalls first, causing violent roll. • They are heavier for the same induced drag and net lift than a trapezoidal wing with nearly triangular lift distribution

2.4 Relevance between Literature Review and Current Project

It is important to understand and relate the past studies to the current work and identify how it can be contributed and improved. Although, the current and past project possess similarities in general aspect but it is worth to mention the differences between the current project and past project. Those differences are:

- The current studies investigate the most suitable design criteria based on the size and type of the components. This project specified the design of a glider that are used for the range purpose while the past studies are focus on the training and soaring glider.
- The previous studies focus on having variety type of wings while the current studies is focus on three different type of wings design
- The current studies investigate the technique of having a single fuselage that are have same size of the front fuselage and rear fuselage while the main fuselage is changeable in length. However, this project consist of a single fixed fuselage.

2.5 Glider Design Decision

Referring on the findings from the literature review and previous work, the design for this project is made up to develop a glider. The characteristic of the components selection is elaborated on the Table 1.4 at below. Plus, the table at below also define the point of choosing the components selected. The design decision is important to make because it will be used for fabrication process to develop the glider.

Table 2.4: The glider design decision based on literature review

Glider Component	Design Decision
Front fuselage or nose	Cone shape as the bullet shape is choose due to the small value of the drag coefficient by 75 % as the fabrication process of the nose is made up by using the aluminium cylinder block as the easiest ways to fabricate using the machine.
Centre fuselage	Cylinder shape has been choosing as the ways to minimise the value of the drag coefficient by 41.18 % on the skin of the fuselage surface. The material used is e-glass fibre polyester composite material as the fuselages need to minimise the weight oi it.
Rear fuselage	Cylinder shape is used to minimize the drag coefficient of the rear fuselage. The shape also easy to be used for the attachment with the centre fuselage and the tails.
Tails	Conventional tail is chosen as this type provides reasonable stability and control besides the light weight structural.
Wings	High level of wing are been chosen as it is most stable in lateral and rolling motion beside it can create lift on the lowered wing. The fabrication process of the high level wing also easy to handled.
	Three type of the wings that been choose are straight, tapered and dihedral wing because of the suitable to be used for subsonic air flow testing condition and easy to fabricate.

CHAPTER 3

THEORY

In this chapter, the equations, fundamentals and theories related to the project of the design and development of the long range glider are described. The topics that will be covered in this chapter are included with the theories of the fuselage, tail, wing and airfoil.

3.1 Airfoil

Airfoil is a solid section of the wing in term of 2D and also known as infinite wing. Any section of the wing cut by a plane parallel to the plane is called an airfoil [Anderson, 2005]. The lift of the airfoil are due mainly to the pressure distribution,. The geometrical shape of the airfoil would be useful in the preliminary stage design because it influence the airflow. The first patented airfoil shapes were developed by Horatio F. Phillips in 1884 followed by Wright brothers in 1902 that tested out by using a wind tunnel [Anderson, 2005]. On December 17, 1903 Wrigth brother first flight successful with 12 seconds above sand dunes of California as shown at Figure 3.1. However, early 1930s NASA embarked an experiment of the series of airfoil shape that called as NACA that are used until now as well-known standard.

Figure 3.1 shows the airfoil sequence from the early stage, NACA and modern (supercritical and supersonic) types of airfoil. The NACA identified different airfoil shapes with a logical numbering system (4-digit, 5-digit and 6-digit). For an example for 4-digit numbering system, the first digit is the maximum camber of the chord, the second digit is the location of the maximum camber along the chord from the leading edge and the last two digits gives the maximum thickness of the chord.

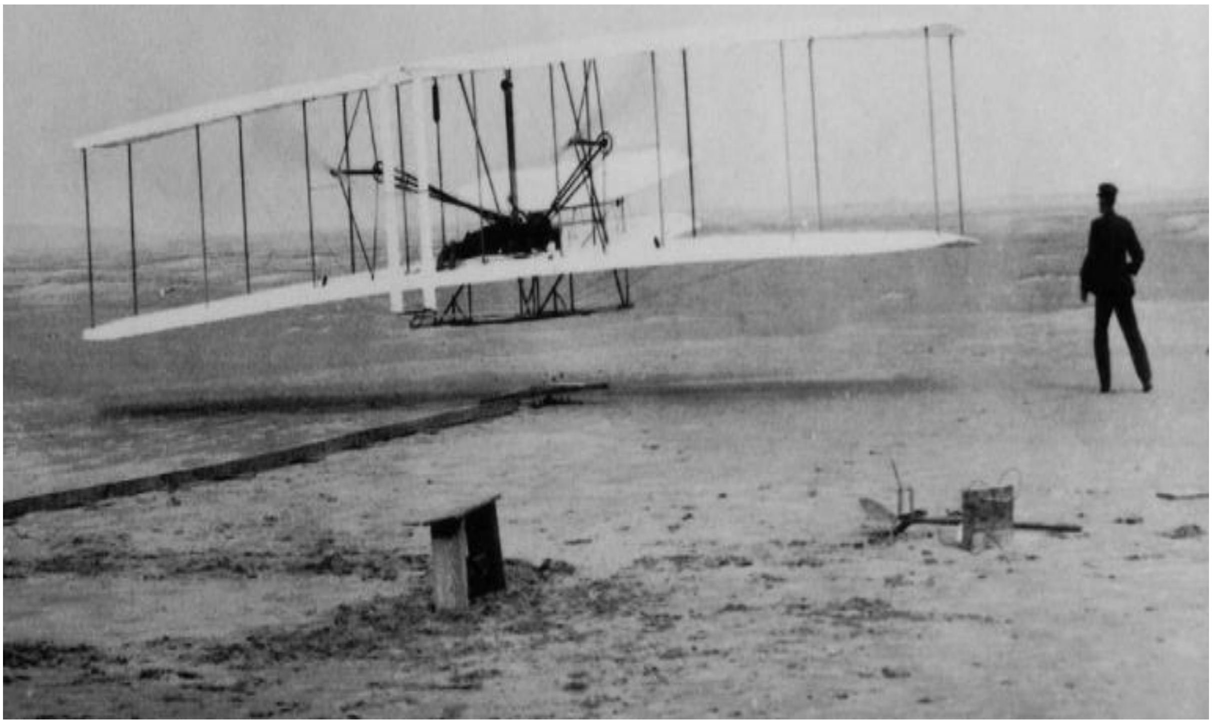


Figure 3.1: The first flight made by Wringth Brother [NASA, 2015]

Figure 3.2 shows the airfoil nomenclature sketched that consist of the mean camber line that is the locus of points halfway between upper and lower surfaces as measured perpendicular to itself. Leading and trailing edge is where most forward and rearward points of the mean camber line. Next, chord line is located on the straight line connecting the leading and trailing edges. Chord is precious distance from leading to trailing edge measured along the chord. Next, camber is maximum distance between the mean camber line and chord line, perpendicular to the chord line. Finally, the thickness is the distance between upper and lower surface.

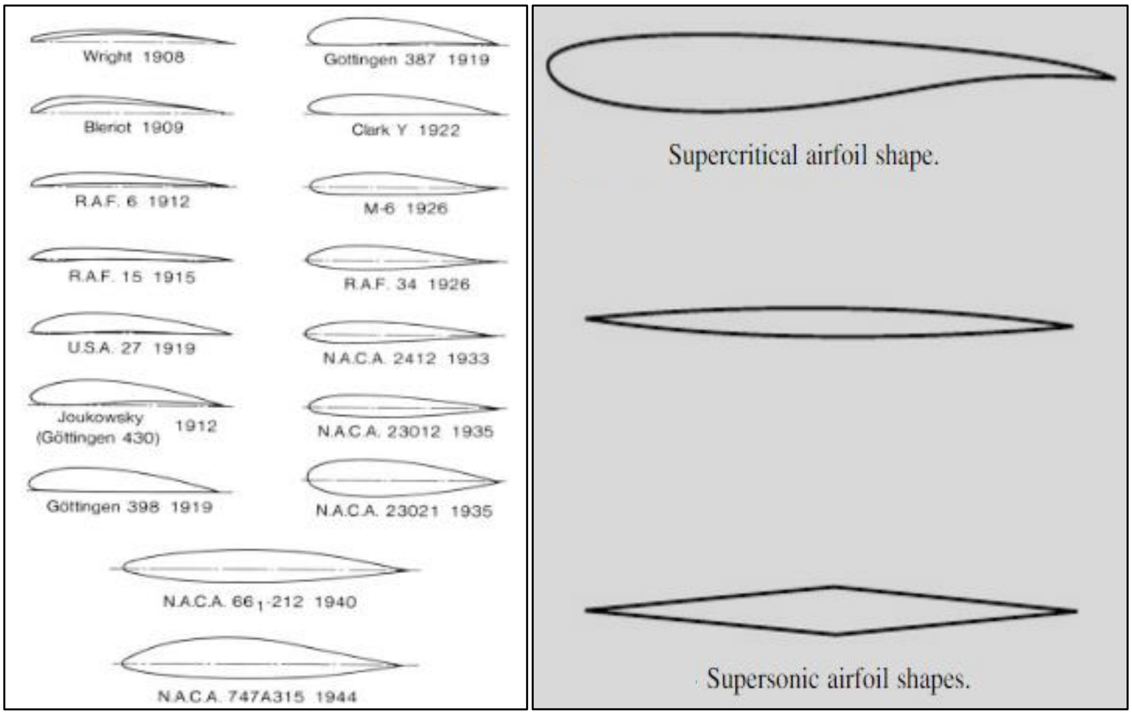


Figure 3.2: The airfoil sections sequence [Anderson, 2005]

There are many types of the airfoil that can be used. The airfoil chooses are based on the activity involved of the aircraft or glider. For training gliders, the camber airfoils are preferred. Angle of attack (α) is defined as the angle between the relative direction of the air flow and the chord line of the airfoil. Thus, it will affect the lift (L), drag (D) and aerodynamic force that created by the pressure and shear stress distribution over the surface, which relative direction of the air flow (V_∞).

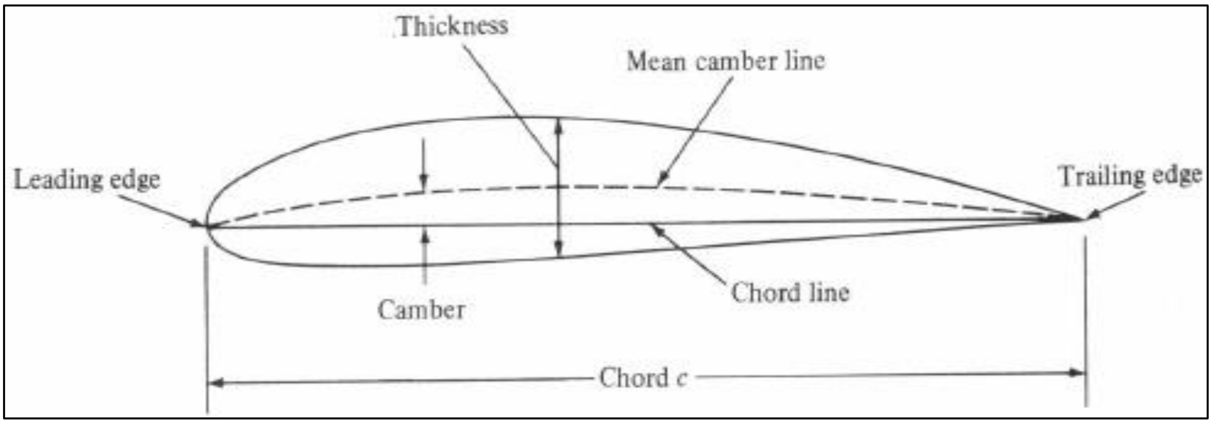
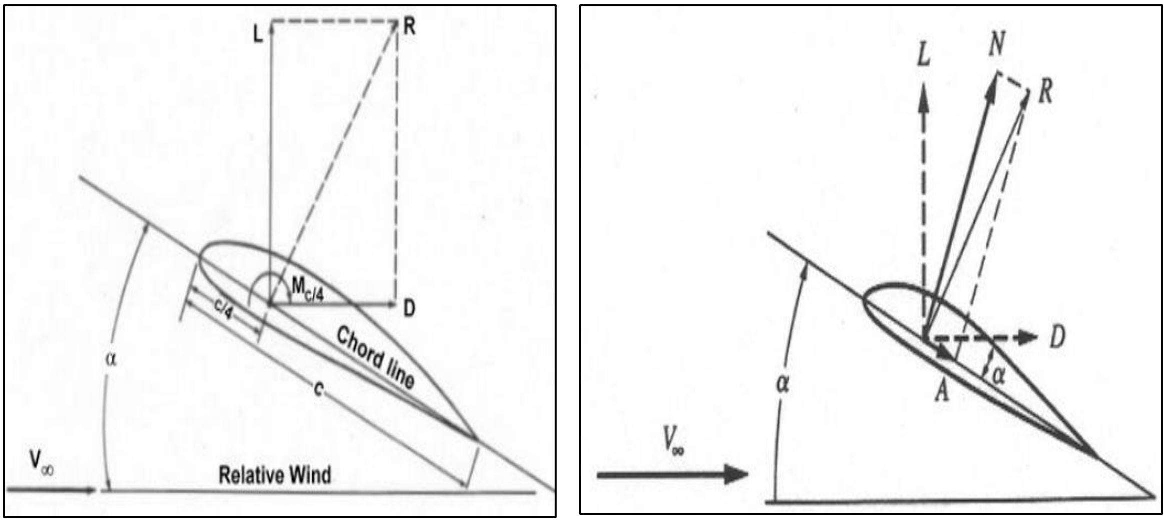


Figure 3.3: Airfoil nomenclature [Anderson, 2005]



(a) *(b)*

Figure 3.4: The forces that act on the airfoil (a)lift, drag, moment, angle of attack and relative wind; (b) normal and axial force [Anderson, 2012]

The lift and drag can be split into two directions as it is perpendicular and parallel to the relative velocity. The possible flight should be when L is equal to the W which refers to the weight. The lift, drag and moment can be expressed by the equation of [Anderson, 2012]:

$$L = C_l . \left(\frac{\rho}{2}\right) . S . V^2 \tag{3.1}$$

$$D = C_d . \left(\frac{\rho}{2}\right) . S . V^2 \tag{3.2}$$

where, the C_l and C_d is called as lift and drag coefficient or call as non-dimensional coefficients, respectively. These coefficients can be obtained by conduction the wind tunnel experiment test. Based on the lift and drag, it tends to be a ratio for considered the wing choosing thus it now known as lift drag ratio$\left(\frac{L}{D}\right)$. The lift drag ratio of the airfoil can be determined as follows:

$$\frac{L}{D} = \frac{C_l}{C_d} \tag{3.4}$$

Lift drag ratio should be maximum value to reduce the drag. The increasing of the efficiency related to the increasing of the wing span. There is the requirements need to be considered to choose the airfoil. It is not necessary to find an airfoil that fulfils all these requirements, some of them offset each other. The considerations are as follow:

1. Maximum value of the lift coefficient $C_{l\,max}$. This is the factor that directly influences the minimum velocity.
2. Maximum value of lift drag ratio, $\frac{Cl}{Cd}$. As we have previously seen, this is of utmost importance, especially for gliders.
3. Maximum value of the power factor. $\frac{Cl^{3/2}}{Cd}$. This index measures the quality of climb and the velocity of sink. The higher the value, the lower the power required to maintain flight. Therefore, the higher the value the lower the sink velocity V_y.
4. Minimum value of the moment's coefficient for zero lifts C_{M0}. This factor is the index of stability of the airfoil, and it gives the movement of the center of pressure. If its value is negative, it means that the airfoil is stable.

3.2 Wing

Wing is a solid section of the airfoil in the term of 3D or called as finite wing. Wing is important as to generate the lift of the glider. There are many types of the wings such as straight, elliptical, tapered, dihedral and delta wing as Figure 3.4. Different types of wing produce different types of vortices at the wing-tip and drag where influent the lift of the glider.

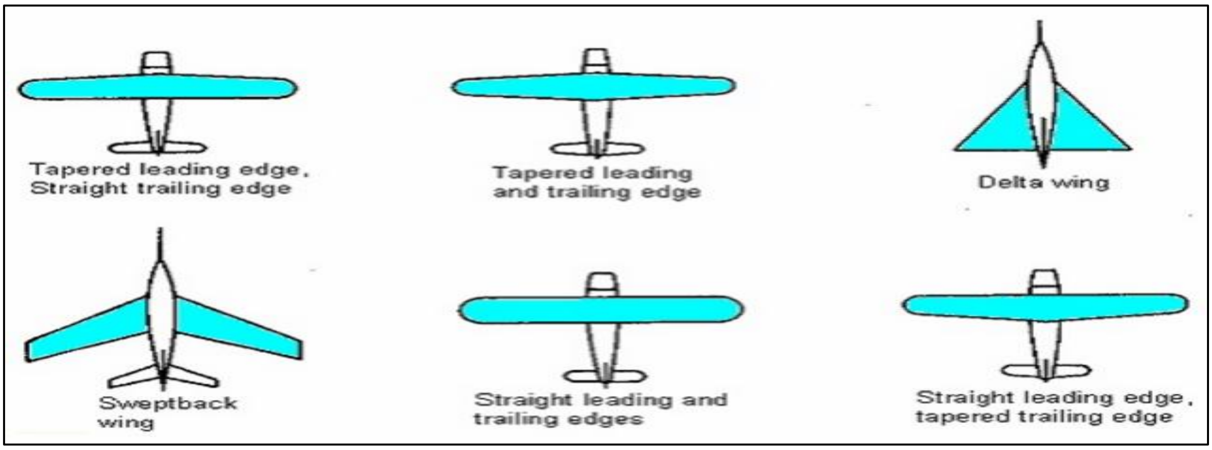


Figure 3.5: Types of the wing [P. Venkatesh, 2014]

The important point need to be highlighted is the aspect ratio which labelled as AR. The increasing of the aspect ratio give advantages [Anderson, 1999]:

1. reducing the induce drag with the subsequent increase in lift drag ratio
2. movement towards attitudes of greater lift with minimum drag
3. tip vortices weak, and hence at given angle of attack, the lift coefficient increase

The value of AR where, the b is refers to the wing span while the S is the size of the wing that can be obtained by [Roskam, 1997] as Equation 3.5. Tapered ratio (λ) is used for the tapered wing where the chord, (c) of the tip is devided with the root as Equation 3.6. The area, S of the tapered wing can be determine using the Equation 3.7 and the Equation 3.8 can be used to determine the mean aerodynamic chord, $\bar{c}$.

$$AR = \frac{b^2}{S} \tag{3.5}$$

$$\lambda = \frac{c_{tip}}{c_{root}} \tag{3.6}$$

$$S = bc_{root}\left(\frac{1+\lambda}{2}\right) \tag{3.7}$$

$$\bar{c} = \frac{2}{3} c_r \left(\frac{1 + \lambda + \lambda^2}{1 + \lambda} \right) \tag{3.8}$$

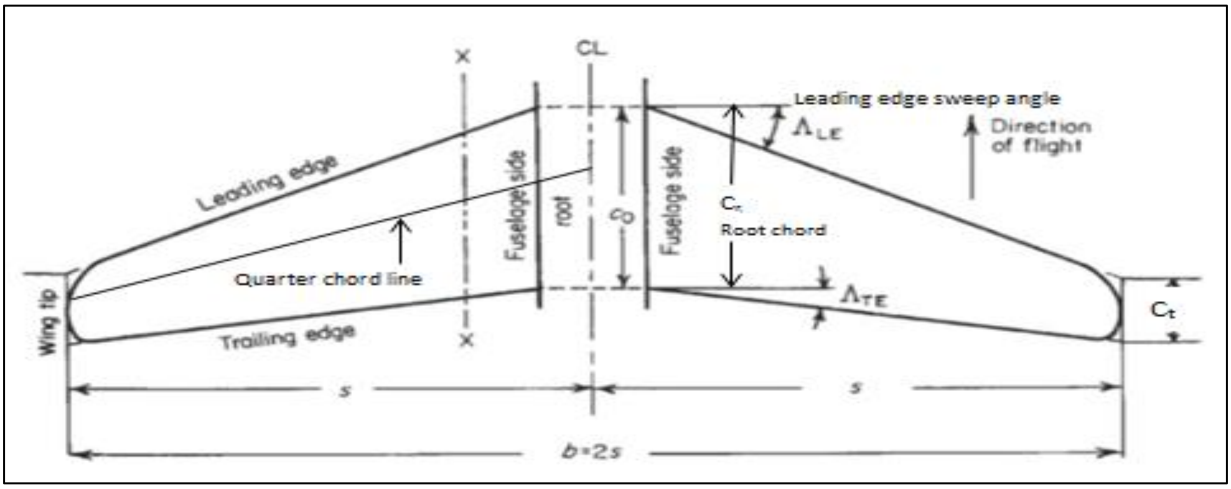


Figure 3.6: Wing geometry [Roskam, 1997]

For structural reasons, the wing is usually thick at the connection with the fuselage. It is here that the greatest forces of bending and shear are applied. As we move toward the wing tips, the airfoil is much thinner to reduce drag. Thus, the calculations to determine the value of lift coefficient of finite wing are depending on the weight, *W* and angle of attack, α as state on Equation 3.9 and Equation 3.10.

$$C_{LW} = 1.05\ C_L = C_{L\alpha W}(\alpha - \alpha_{0L}) \tag{3.9}$$

$$C_L = \frac{W}{qS} \tag{3.10}$$

$$q = \frac{1}{2} \rho V^2 \tag{3.11}$$

3.3 Fuselage

Fuselage is a part of an aircraft or a glider where the wings and empennages are joined at the central structural membrane. The structure of the fuselage simply must be strong, rigid and light in weight. Fuselage contribute about 30% of zero lift drag also known as parasite drag coefficient and induce skin friction coefficient (wetted area) [F. Nicolas, 2016]. Fuselage is divided into three different parts from the whole fuselage that consists of nose, main body ant boot tail. Usually the main body can be in the form of cylinder with uniform cross section area. For an example, in case of the long fuselage, the empennage area are smaller, thus it low the weight and drag. However, it is offset by the larger weight of the fuselage and higher drag that is due to the increase surface friction. However, nose and tail can be same in geometry but opposite direction. There are many shapes of the nose design that mention in Figure 3.6 [S.F. Horner, 1965]. However, this project is limited to parabolic nose shape because this shape is suitable for subsonic airflow.

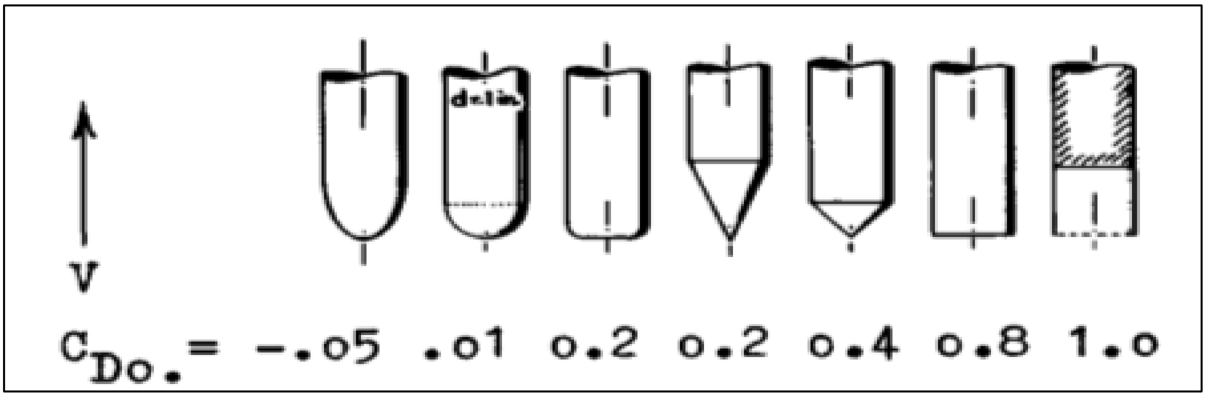


Figure 3.7: The variety of nose shape [S.F. Horner, 1965]

If the dynamic stability is considered, the long fuselage is preferable. The reason is the longitudinal inertia moments are increased and the tail is less influenced by the wing turbulence because the wing is much farther away, thus it is more effective. Moreover aircraft longitudinal and directional stability characteristics are strictly related to the fuselage contribution [F. Nicolosi, 2016]. Fuselage lift coefficient is not presented, due to the very low relevance in isolated fuselage geometry design. However, fuselage effect on aircraft lift coefficient has to be carefully evaluated and taken into account during the design phase, especially in the wing integration in term of the shape [F. Nicolosi, 2016]. According to the Roskam , 1990 the best fineness ratio *FR* to be used is 8 where can be used to the equation of length diameter ratio of the fuselage as Equation 3.12 where length of fuselage is l_f and diameter fuselage is d.

$$FR = \frac{l_f}{d} \tag{3.12}$$

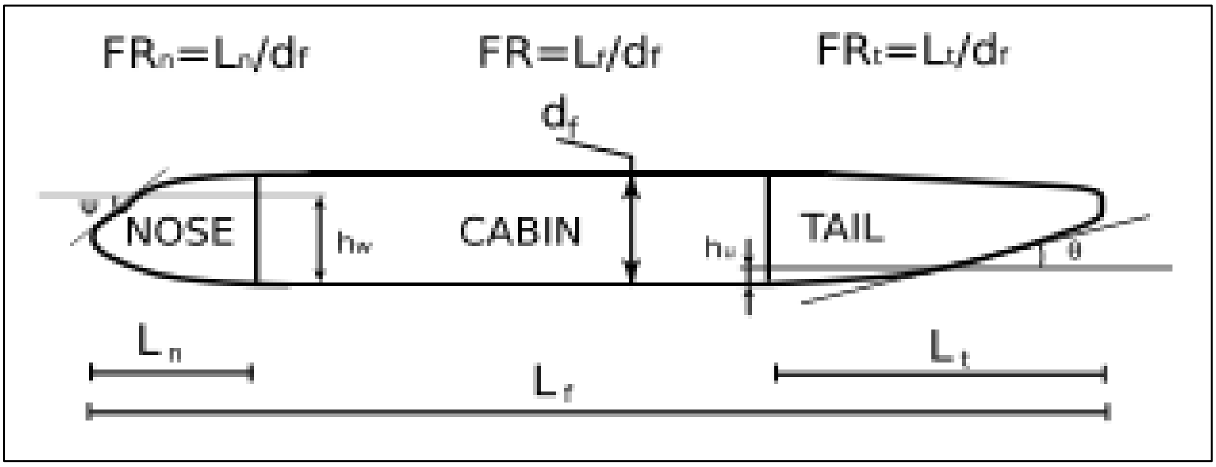


Figure 3.8: Fineness ratios [F. Nicolosi, 2016]

3.4 Tail (Empennages)

Tail or called as empennages consist of two part, (i) horizontal tail-longitudinal stability and (ii) vertical tail-directional stability. There are many types of tail such as conventional, T-tail and cruciform tail shape as shows on Figure 3.8.

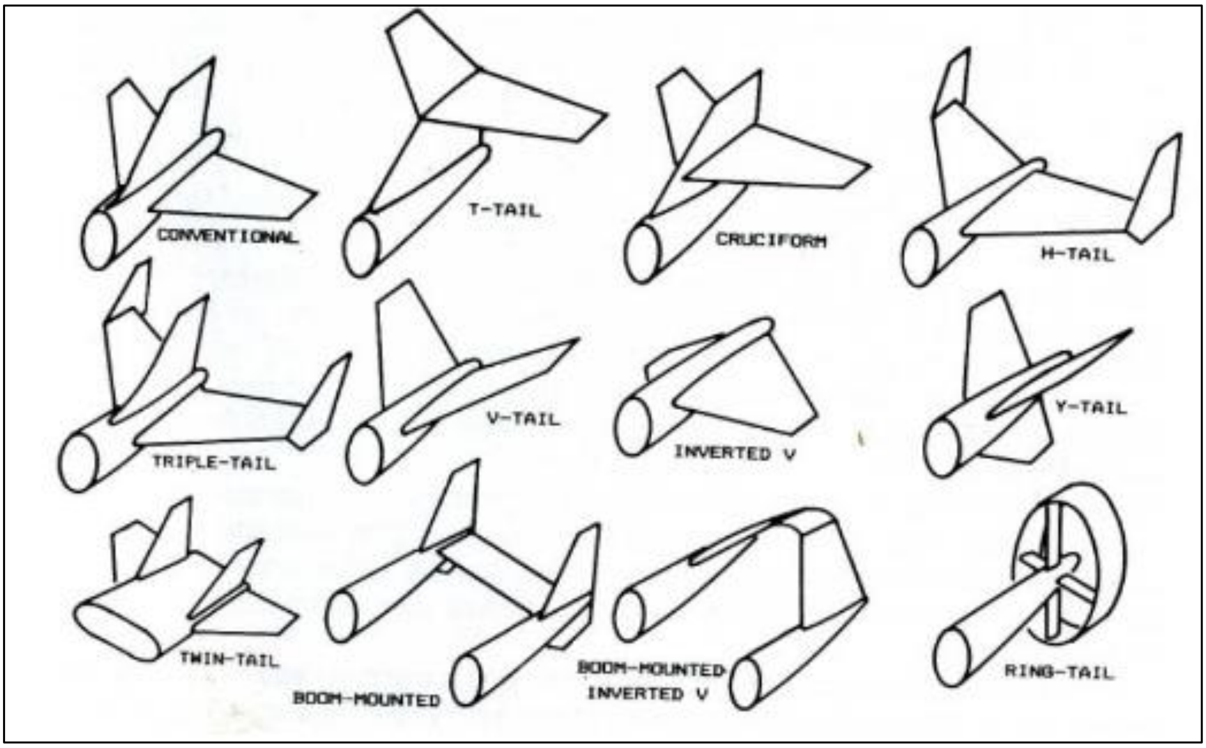


Figure 3.9: Types of the empennage [Raymer, 1992]

Tail is important to maintain the good stability within area. The location of the tails will affect the effectiveness of it. Generally the thickness of the empennage goes from 10% to 12% where it attaches to the fuselage at the tip. Both the vertical and horizontal section must be linear in variation. The area of the tail can be determined using the Equation 3.13 and Equation 3.14 which represent horizontal, V_{HT} and vertical tail, V_{VT} [Anderson, 1999].

$$V_{HT} = \frac{l_{HT} S_{HT}}{\bar{c} S} \tag{3.13}$$

$$V_{VT} = \frac{l_{VT} S_{VT}}{b S} \tag{3.14}$$

The value of l_{HT} is represent the distance between c.g. of the airplane and aerodynamic centre of the horizontal tail while, l_{VT} represent the distance between c.g. of the airplane and aerodynamic centre of the vertical tail. S is the wing planform area, S_{HT} area for