3.7 – AILERON DESIGN

3.7.1 – Introduction

It's very important for preliminary design to analyze the roll and turn performances of the aircraft, paying attention on its use and category. the system used for these is the aileron, that is a classical trailing edge plain flap,so it's very important, starting from its geometry, to predict the aerodynamic characteristics that allow to estimate the roll coefficient and its derivatives in function of the aileron deflectionsδ_a and rolling velocity$P$. The ailerons on each wing deflect asymmetrically, one going up and one going downnot necessarily with same deflection, this modify the spanwise loading on the wing and generate the roll moment.

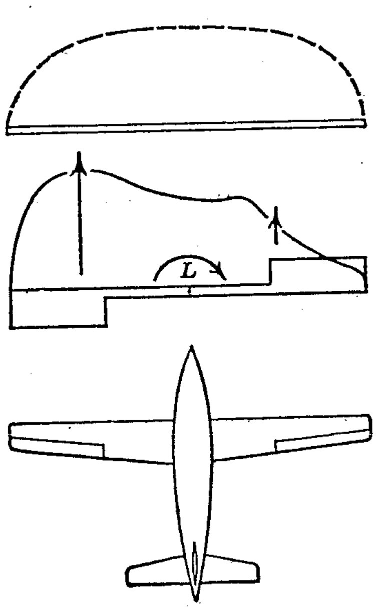


Figure 3.71 – example of spanwise loading due to aileron deflection.

As the airplane increase the rolling speed, a new spanwise loading will be created which opposes the rolling moment, this is called damping moment of the wing.
The size of the control is determined by the fulfill of two basic requirements:

- The aileron have to provide sufficient rolling moment at low speeds to counteract the effect of the vertical asymmetric gusts tending to roll the airplane.
- It have to roll the airplane at a sufficiently high rate at high speed for a given stick force.

The design criterion for the evaluating of aileron effectiveness is the non-dimensional parameter *pb/2V*, also called "Lateral Control Power".
Another step isto estimate the turn performances knowing also the characteristics of the engine system. The objective is, to satisfy the minimum maneuvering requirements, so paying attention on the bank angle, load factor, and minimum radius.

3.7.2 - Methodologies for the rolling performances

The estimation of Lateral Control Power and so the rolling performances is made by two different methodologies, one semi-empirical, based on diagram which give all the needed contribution for the calculation, and one strip integration, that can give results little higher than semi-emipirical one due to its assumptions.

3.7.2.1 Strip Integration Method

The damping moment of the wing can be calculated as follows.

$$M_d = 2\left(\frac{1}{2}\rho V^2\right)Cl_\alpha \frac{p}{V} B \qquad \textbf{(3.7.1)}$$

Where the factor B is given by: $B = \int_0^{b/2} c(y) y^2 dy$

While the aerodynamic moment due to the change of lift produced by the aileron is obtained by the following formula.

$$M_A = 2\left(\frac{1}{2}\rho V^2\right)Cl_\alpha \tau \delta_a A \qquad \textbf{(3.7.2)}$$

Where the factor A is given by: $A = \int_{y_{in}}^{y_{out}} c(y) y dy$

The y_{in} and y_{out} are the positions of aileron tips.τ is the aileron efficiency at a fixed deflection, estimated by the (3.6.1), if it is different between right and left aileron then the mean efficiency is taken. So By the equality between damping aerodynamic moment and aerodynamic moment due to the change of lift produced by aileron it’s possible to obtain the value of rolling velocity *p*.

$$M_A = M_d \qquad \Rightarrow p = \frac{A\tau}{B}\bar{\delta} V \qquad \textbf{(3.7.3)}$$

Where $\bar{\delta}$ is the mean ailerons deflections.
It’s clear that the rolling velocity grows with the airspeed linearly but this is real until the value of max couple on the wheeling steer is reached. In fact considering the hinge moments, the equilibrium of works must be kept.

$$C \cdot \Delta\psi = H \cdot \Delta\delta \qquad \textbf{(3.7.4)}$$

Where C is the couple on the steering wheel, limitated by FAR 25 at 36·Diameter and by FAR 23 at 22.5·Diameter, the and H is given as follows.

$$H = \frac{1}{2}\rho V^2 S_a \bar{c}_a C_{ha} \qquad \textbf{(3.7.5)}$$

Where the hinge moment coefficient C_{ha} can be calculated by the (3.7.6).

$$C_{ha} = 2\frac{p}{V}\left(C_{h\delta}\frac{B}{A\tau} - C_{h\alpha}\bar{y}\right) \quad \textbf{(3.7.5)}$$

So substituting the (3.7.5) in the (3.7.4) the following formula is obtained.

$$C = \rho V p S_a \bar{c}_a K\left(C_{h\delta}\frac{B}{A\tau} - C_{h\alpha}\bar{y}\right) \quad \textbf{(3.7.6)}$$

Where K is: $K = \frac{\Delta\delta}{\Delta\psi}$ (generally 1/6).$C_{h\delta}$ and $C_{h\alpha}$ are obtained from following charts.

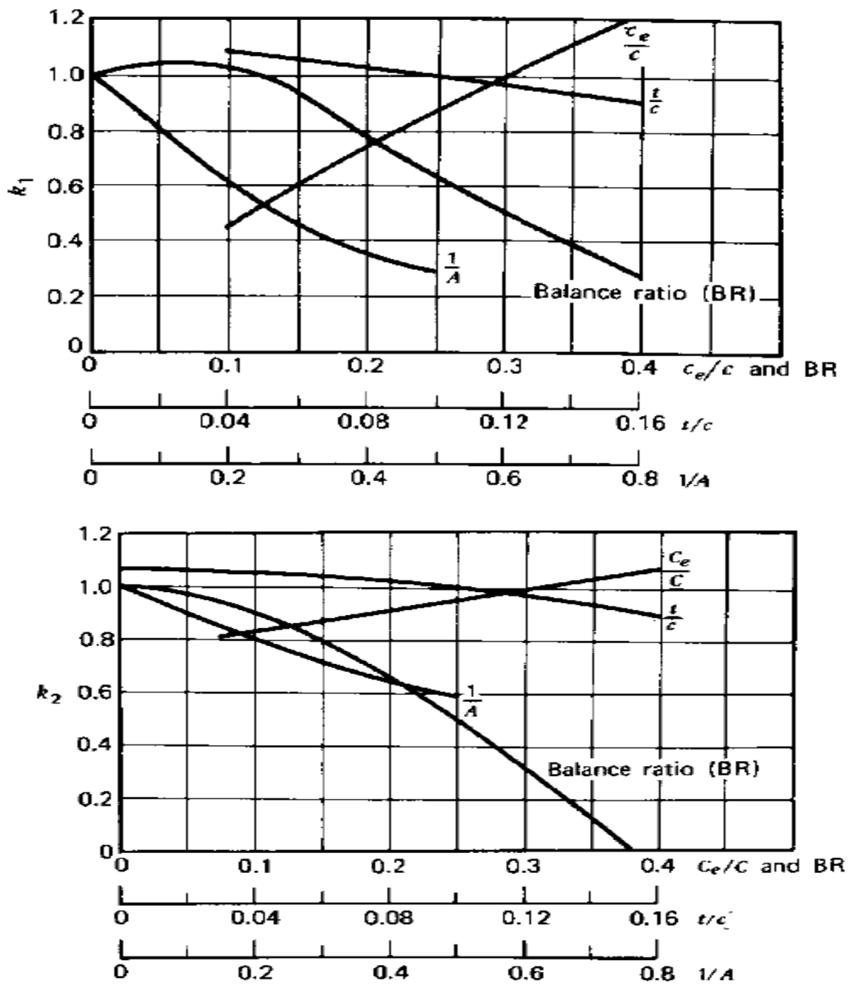


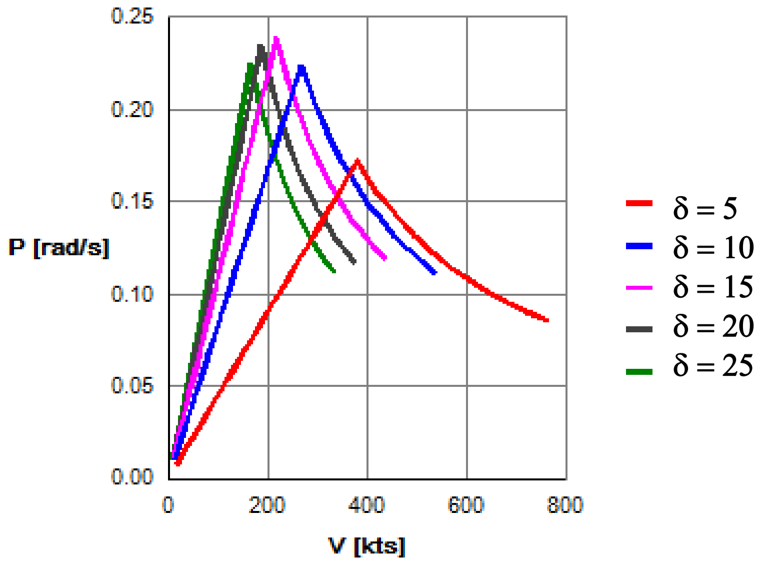
Figure 3.72 – Charts used for the estimation of $C_{h\delta}$ and $C_{h\alpha}$.

$$Ch_{\alpha} = -0.55 \cdot K1_{ce/c} \cdot K1_{t/c} \cdot K1_{1/A} \cdot K1_{BR} \quad \textbf{(3.7.7)}$$

$$Ch_{\delta} = -0.89 \cdot K1_{ce/c} \cdot K1_{t/c} \cdot K1_{1/A} \cdot K1_{BR} \quad \textbf{(3.7.8)}$$

These must be substituted in (3.7.6) with their absolute value.

Imposing the C=Cmax the value of *p* is obtained for any speed, so the intersection between this curve and the curve described by the (3.7.3) identifies the V at maximum *p*.



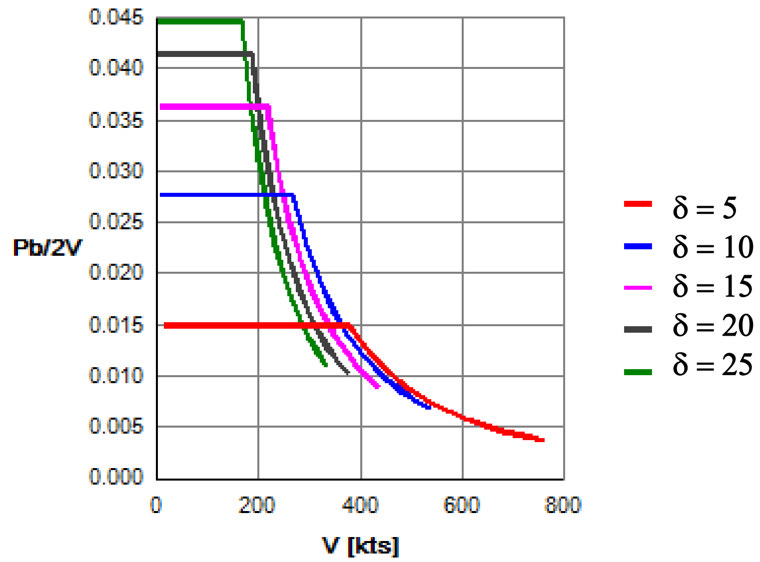


Figure 3.73 – Example of airplane rolling characteristics.

Since the rolling velocity *p*in the second part of the curve changes its trend, also the useful deflection changes, it decrease as shown by the figure 3.74.

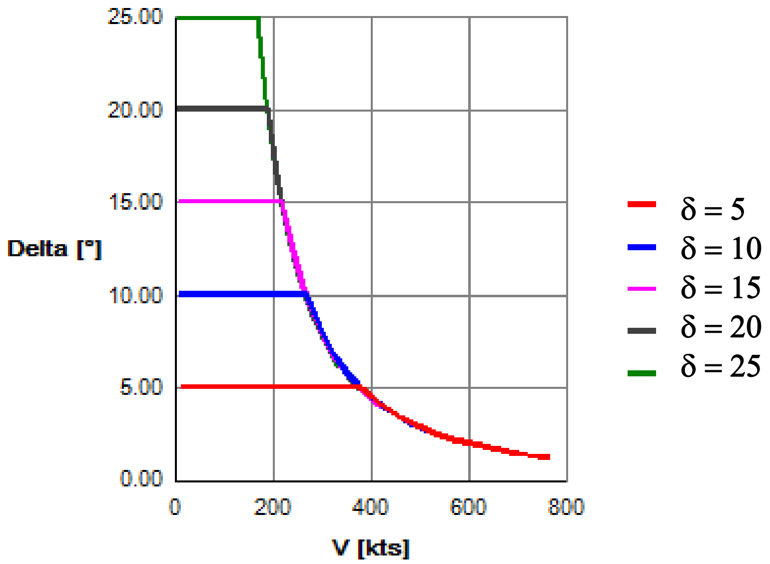


Figure 3.74 – Reduction of the required aileron deflection.

3.7.2.2 –The Semi-Empirical Method

The semi-empirical method is based on the use of various charts where it's possible to obtain directlythe value of derivative of the rolling coefficient due to aileron deflection and due to rolling velocity. From the aileron lateral coordinateη, wing sweep angle Λ, aspect ratio Aand taper ratioλ, it's possible to enter in the diagrams below to obtain the value of $Cl_{\delta a}$, the number of Mach effect can be ignored here.

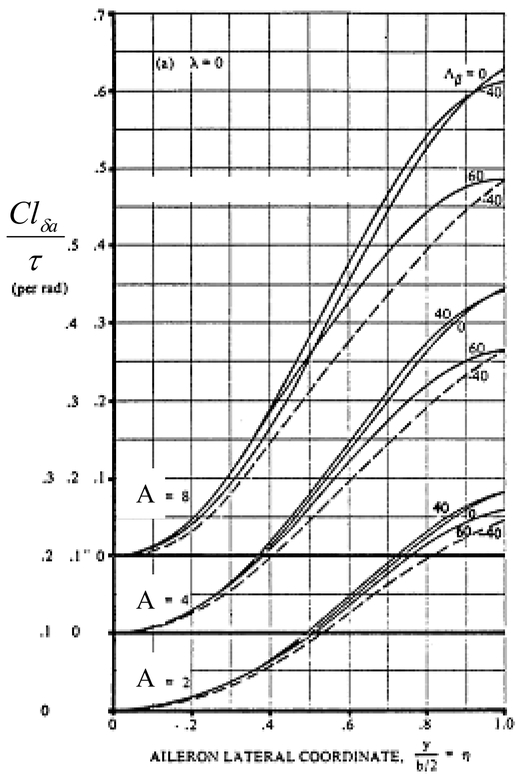


Figure 3.75 – Diagram used to estimate the $Cl_{\delta a}$.

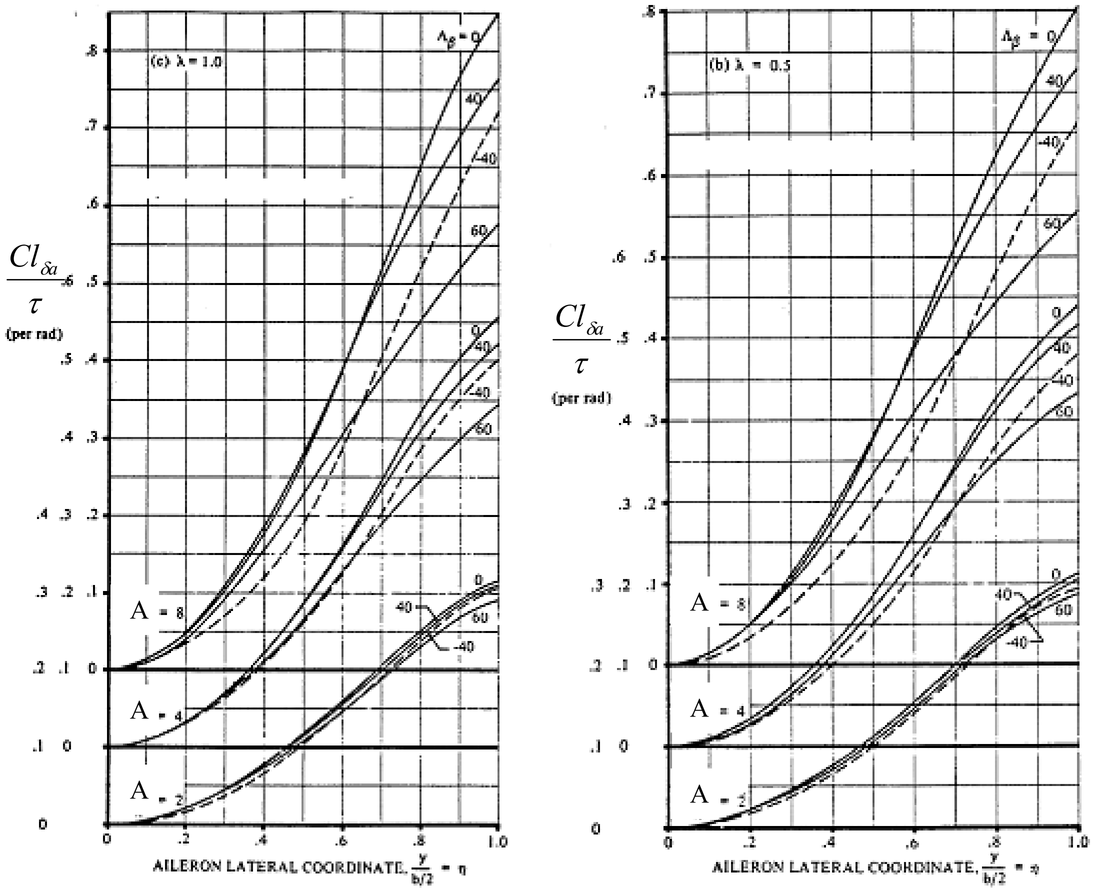


Figure 3.76 – Diagrams used to estimate the $Cl_{\delta a}$.

Then the equivalent of the factor A saw in the (3.7.2) is calculated by the following formula.

$$A = \frac{Cl_{\delta a} \cdot b}{CL_{\alpha} \cdot Sw} \qquad \textbf{(3.7.7)}$$

The contribution of the wing on Cl_{pw} is obtained by the following figure.

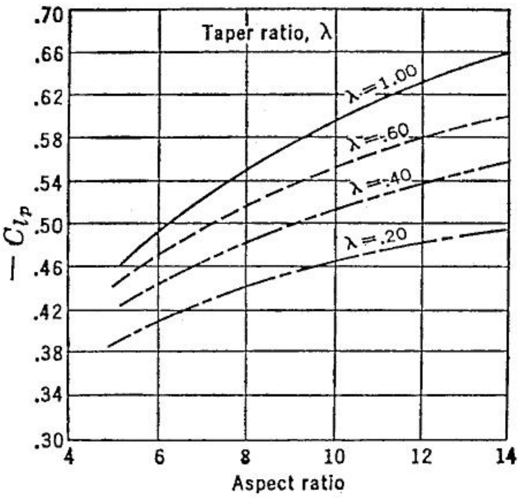


Figure 3.77 – Diagram used to estimate the Cl_{pw}.

The contribution of the presence of the dihedral angle is obtained by the formula (3.7.8).

$$K_\Gamma = 1 - 4 \cdot \frac{Zw}{b} \cdot \sin(\Gamma_w) + 12 \cdot \left(\frac{Zw}{b}\right)^2 \cdot \sin^2(\Gamma_w) \qquad \textbf{(3.7.8)}$$

The contribution due to the wing sweep angle is evaluated taking for reference the figure 3.78 and building the equation (3.7.9) or (3.7.10).

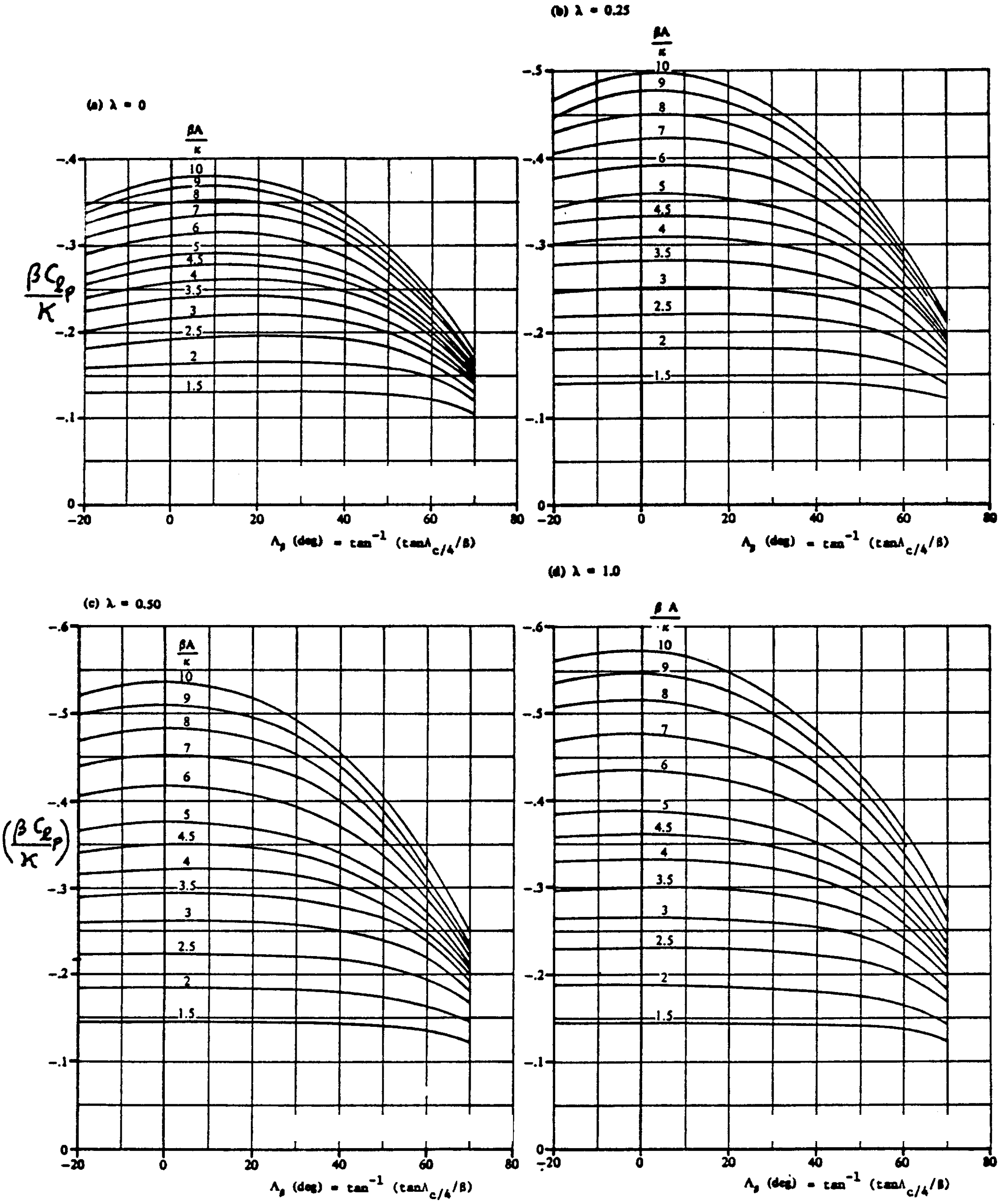


Figure 3.78 – Diagram used to estimate the contribution of the sweep angle on Cl_p.

For AR<=12 : $K_\Lambda = 0.0036 \cdot AR^2 - 0.0331 \cdot AR + 0.78$ **(3.7.9)**

For AR>12 : $K_\Lambda = 0.05 \cdot AR + 0.3$ **(3.7.10)**

So the value of rolling coefficient derivative due to *p* is given by the following equation.

$$Cl_p = Cl_{pw} \cdot K_\Gamma \cdot \cos(\Lambda \cdot K_\Lambda) \qquad \textbf{(3.7.11)}$$

At this value can be added the contribution of vertical tail and horizontal tail, which have minor effect.
The horizontal Tail is evaluated in the same way of the wing, described above, for the contribution $(Cl_p)_h$ which is used in the following formula.

$$Cl_{ph} = 0.5(Cl_p)_h \frac{S_h}{S}\left(\frac{b_h}{b}\right)^2 \qquad \textbf{(3.7.12)}$$

The vertical Tail instead is calculated as follows.

$$Cl_{pv} = 2 \cdot \left(\frac{Z_v}{b}\right) C_{Y\beta v} \qquad \textbf{(3.7.13)}$$

Where Z_v is defined by the following figure.

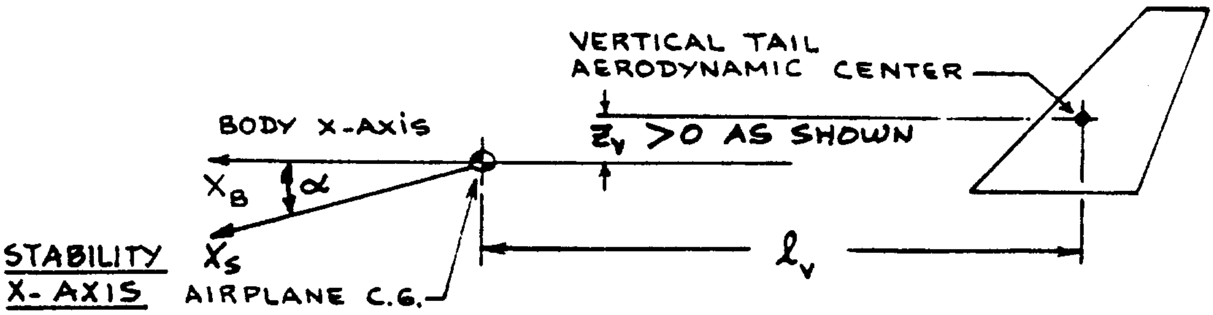


Figure 3.79 – Diagram used to estimate the contribution of the sweep angle on Cl_p.

The $C_{Y\beta v}$ is given by following formula.

$$C_{Y\beta v} = -K_v \cdot Cl_{\alpha v} \cdot \eta_v \left(1 + \frac{\partial\sigma}{\partial\beta}\right)\frac{S_v}{S} \qquad \textbf{(3.7.14)}$$

Where K_v is obtained by the following chart.

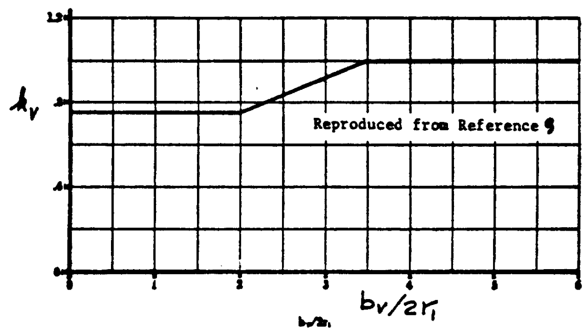


Figure 3.79 – Chart used to obtain the value of Kv.

r_1 is the local equivalent radius of the fuselage at the vertical tail position and b_v is the span.

While the sidewash is estimated as follows.

$$\left(1+\frac{\partial\sigma}{\partial\beta}\right)\eta_v = 0.724+3.06\left[\frac{\left(\frac{S_v}{S}\right)}{\left(1+\cos\left(\Lambda_{c/4_W}\right)\right)}\right]+0.4\frac{Z_W}{Z_f}+0.009AR_w \qquad \textbf{(3.7.15)}$$

Where Z_w is taken as shown by the figure 3.80.

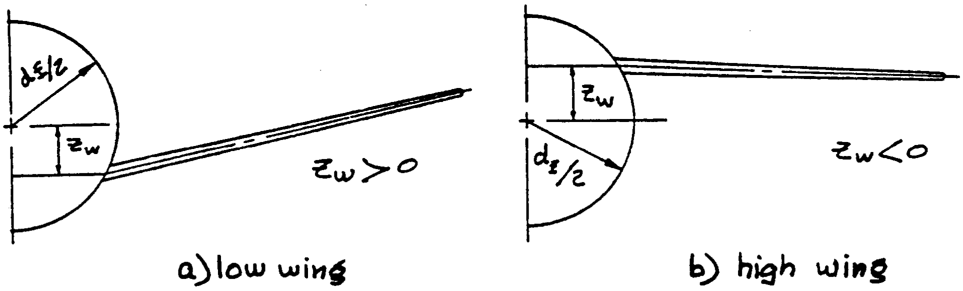


Figure 3.80 – Definition of Wing-Fuselage parameter Z_w.

$S_v$is the effective vertical tail area, defined by the following figure.

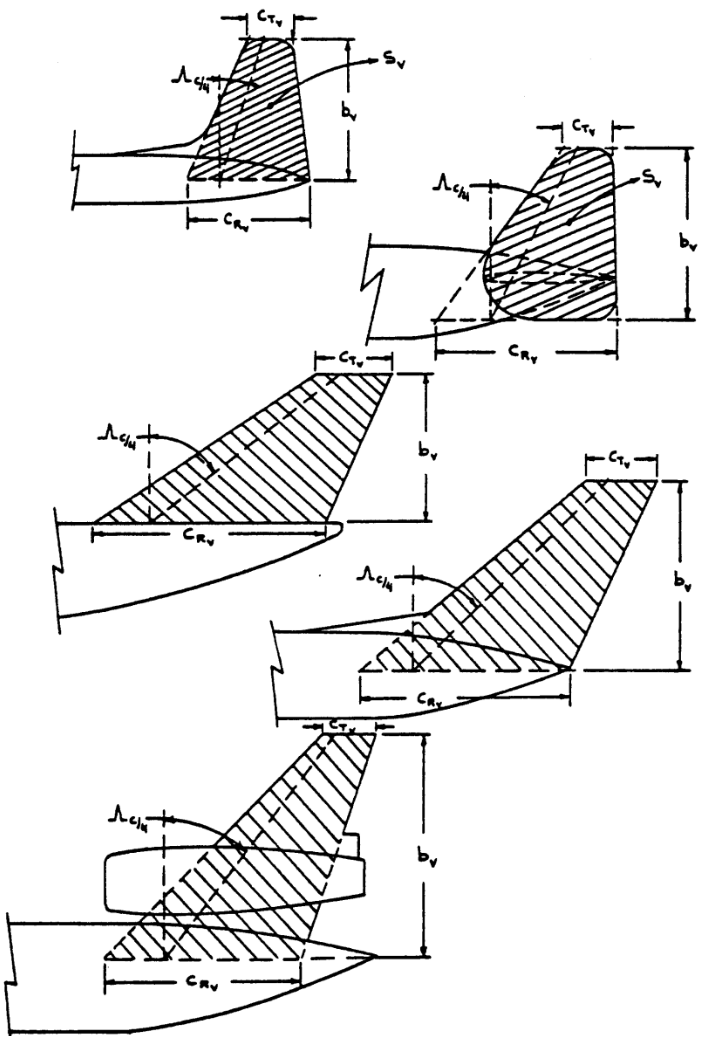


Figure 3.81 – Definition of effectivevertical tail area.

Finally the total $Cl_p$is obtain by the sum of all the contribution.

$$Cl_p = Cl_{pw} + Cl_{ph} + Cl_{pv} \tag{3.7.15}$$

The factor B shown in (3.7.1) can be obtained now from the following formula.

$$B = -\frac{Cl_p S_w b^2}{2Cl_\alpha} \tag{3.7.16}$$

Then the methodology is the same shown for the strip integration method.

3.7.2.3 - Turn Performances

To evaluate the turn performances is necessary know some engine data and Polar curve data. During a constant altitude turn it's possible to divide the calculation in two region, since the available power is greater than the required power at CL_{max}that is the "First Region". If the available power is lesser then required power at CL_{max} that is the "Second Region".
The required power is given by the (3.7.17) while the available power is given by the engine model for the chosen aircraft.

$$\Pi_r = D \cdot V \tag{3.7.17}$$

In the First Region it's possible to use the following formulas.

$$CD = CD(CL_{max}) \left(= CD_0 + \frac{CL^2}{e\pi AR} \text{ if parabolic}\right) \tag{3.7.18}$$

$$D = \frac{1}{2}\rho V^2 S \cdot CD \tag{3.7.19}$$

$$L = \frac{1}{2}\rho V^2 S \cdot CL_{\max} \tag{3.7.20}$$

Then is possible evaluate the load factor.

$$n = \frac{L}{D} \tag{3.7.21}$$

The most important value for the turn performances studies are the angle of bank Φ, the turn radius *R*and Time to turn *T*.

$$\Phi = \arctan(1/n) \tag{3.7.22}$$

$$R = \frac{V^2}{g\sqrt{n^2 - 1}} \tag{3.7.23}$$

$$T = \pi \frac{R}{V} \tag{3.7.24}$$

In the second region the Power is equal to Power available, so the CD is the following.

$$CD = \frac{\Pi_a}{\frac{1}{2}\rho V^3 S} \tag{3.7.25}$$

The value of CL is obtained from the drag polar, for example from the parabolic form, then the other value is calculated by the equations (3.7.33) (3.7.23) (3.7.24).
So it's possible to draw the following charts.

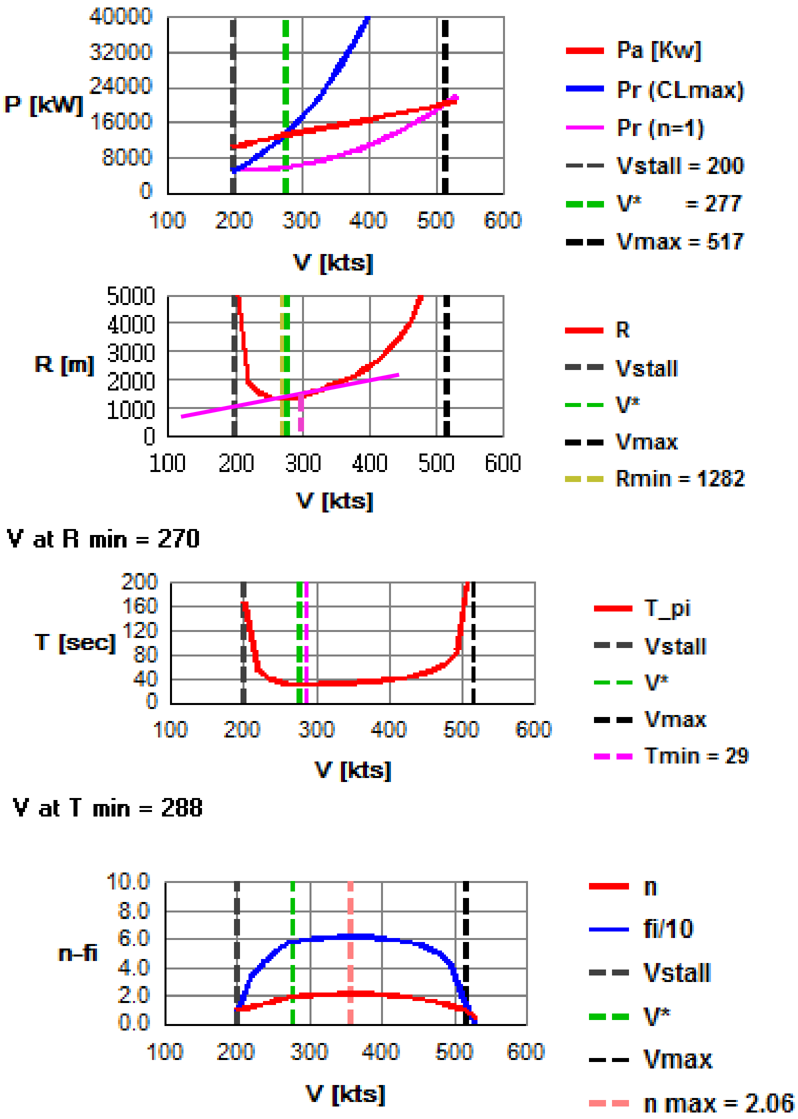


Figure 3.82 – Turn Performances plots.

To note that the minimum T is located at the point of contact between the curve of R and the tangent starting by the origin of the axis.

With increasing the load factor the curve of the required power shift over as shown in the figure 3.83.

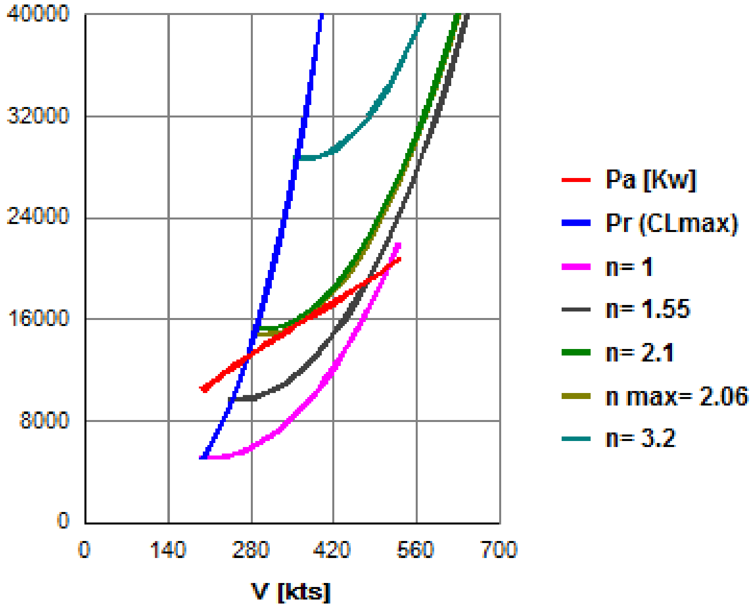


Figure 3.82 – Power vs speed with varying of load factor *n*.

The radius obtained by the 3.7.23 with stall speeds and maximum speeds give the follows plot.

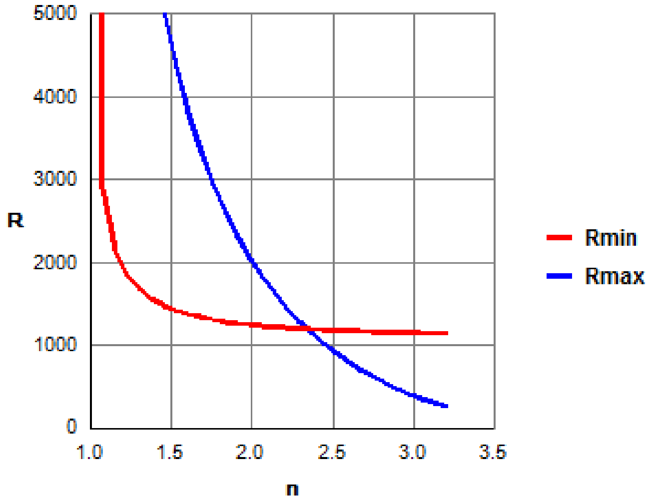


Figure 3.82 – Minimum and maximum radius obtained by the stall speeds and maximum speeds.