Project 6 – Aircraft static stability and control

The main objective of the project No. 6 is to compute the characteristics of the aircraft static stability and control characteristics in the pitch and roll channel. The necessary computations have to be done using digital model of an aircraft, which was created within the Project No. 4 of "Aircraft Design I". The model was created using program AVL or PANUKL and the same software will be used for stability and control analysis (student must use the same program which was selected in project No. 4). Due to the different capabilities of the software, some steps of calculation can be different and the procedure depends on selected program.

Next chapters present the computation procedures for both software listed above. To recall the terms related to rotations, Figure 1 presents definitions and the sign convention of moment coefficients and angular velocities.

Student should modify the numerical model and add ailerons and elevator. Detail description of control surfaces definition is described in next chapter.

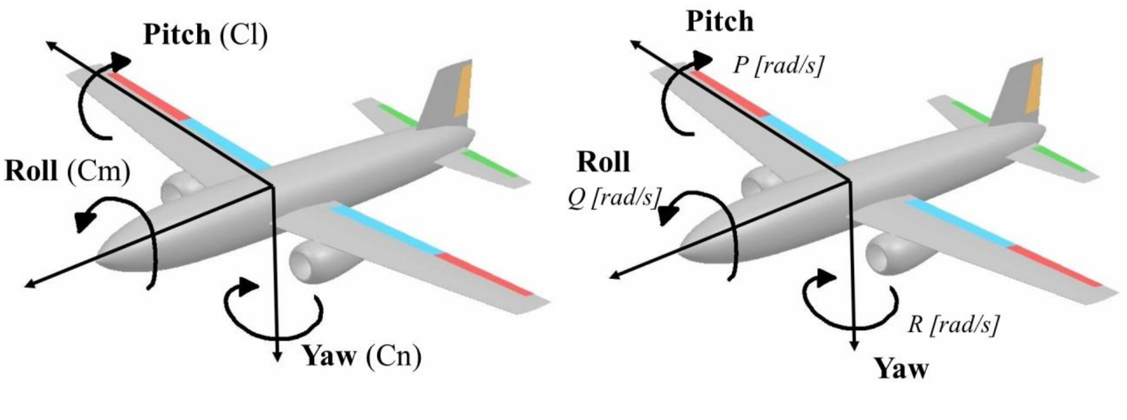

Figure 1 Moment and angular velocity components

Control surfaces definition:

AVL

Control surfaces can be defined for part or for the whole span of the wing/horizontal tail, read carefully documentation. Aileron and elevator definition, with listed variables, is shown below. Half of a wing with defined control surface is defined in **Figure 2**.

```
CONTROL
Aileron  1.0   0.7   0. 1. 0.   -1.0
CONTROL
Elevator 1.0   0.6   0. 0. 0.   1.0
```

name - name of control variable

gain - used only for mixing deflection of multiple defined controls on one surface, students should set it as 1.0

Xhinge - x/c location of hinge, see **Figure 2**

XYZhvec - vector giving hinge axis about which surface rotates

SgnDup - sign of deflection for duplicated surface, an aileron would have SgnDup = -1, an elevator would have SgnDup = 1

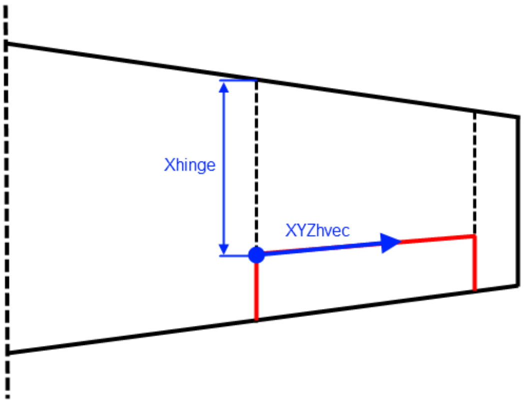

Figure 2 Wing with control surface

After loading geometry file with control surface defined, student must set angle of deflection of the ailerons/elevator (default is 0 - no deflection). In the “OPER” mode, under variables list, also names of the defined control surfaces appear. Angle of deflection, defined in degrees, must be appropriately changed to fit roll requirements. Make aerodynamic analysis and read stability derivatives needed for the roll requirements.

PANUKL

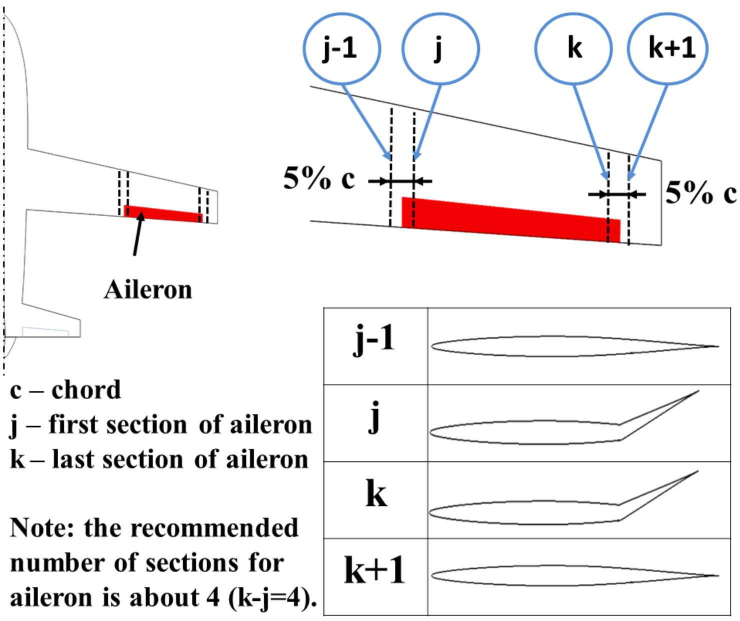

Figure 3 Aileron definition in PANUKL

In PANUKL case, the definition of wing has to be completed by aileron definition (Figure 7). The airfoils of the part of the wing with control surfaces have to be changed.

Airfoils with control surfaces deflection can be prepared in Xfoil in geometry mode "GDES" using command "Flap". Asymmetrical mesh with wake for the right and the left part of the wing has to be prepared separately and then the two halves of mesh connected. Two computational cases must be done:

1. case with aileron deflected, angle of attack and other state parameters equal to zero,
2. case with not deflected aileron, defined roll rate (e.g. 1 rad/s), other state parameters equal to zero.

The dimensionless derivatives can be computed as follows:

$$C_{l_{\delta_a}} = l_\xi = \frac{\partial C_l}{\partial \delta_a} = \frac{C_l}{\delta_a} \qquad (1)$$

$$C_{l_p} = \frac{\partial C_l}{\partial \frac{p\,b}{2V}} = \frac{C_l}{\frac{p\,b}{2}} \qquad (2)$$

where:

C_l – rolling moment coefficient (taken from [.out] file),
p – roll rate [rad/s],
b – wingspan [m],
$V = 1$

Procedure of elevator creating is similar to aileron but aircraft with elevator deflection is symmetrical object and it is not necessary generating two halves of the aircraft separately.

Longitudinal static stability

The first task is calculation of a neutral point position for the lift coefficient range corresponding with the flight envelope. Next step is estimation of a static (stability) margin for the extreme positions of the aircraft's center of gravity (the most front and the most aft position of the center of gravity for airplane configuration during flight). Basing on these calculations Student should prepare diagram of the neutral point travel versus the lift coefficient, which range has to correspond with the flight envelope (see example Figure 4).

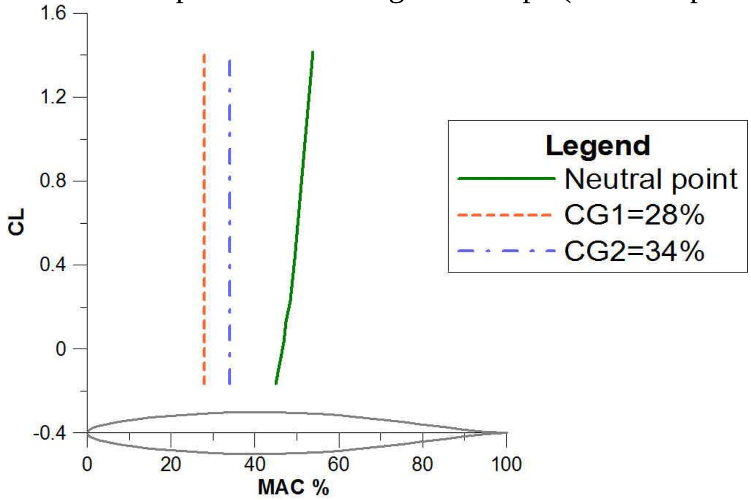

Figure 4 Diagram of neutral point travel

If the aircraft is unstable, the sufficient modification of geometry or of gravity center position should be done. Figure 5 presents diagram illustrating various conditions of longitudinal static stability.

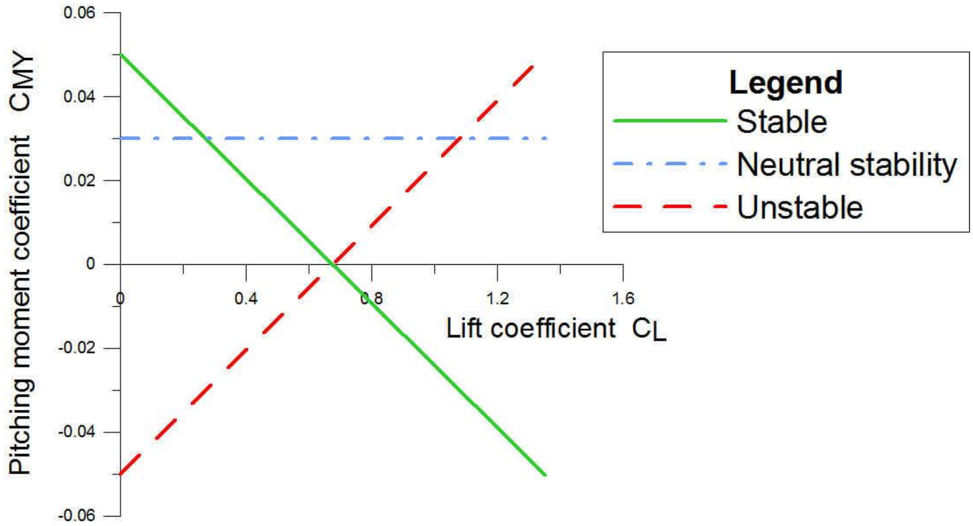

Figure 5 Longitudinal aircraft stability

AVL

The neutral point position should be calculated by AVL software for the lift coefficient range corresponding with the flight envelope. Position of neutral point can be obtained by *"ST"* command in oper mode. Next step is recalculation the position of neutral point from meters to percent of the mean aerodynamic chord.

ATTENTION: Check the position of the reference coordinate system in numerical model.

The static margin can be calculated:

$$(h_n)_\alpha = (X_N)_\alpha - X_{C.G} \quad (3)$$

h_n – static margin [%]
X_N– neutral point position [MAC%]
$X_{C.G.}$ – center of gravity position [MAC %]

If aircraft was unstable and geometry was modified, the aerodynamic analyses have to be repeated for the new configurations.

PANUKL

To obtain a neutral point of stability, calculations should be made for two different angles of attack equidistant from the point (angle of attack) under consideration. Then the position of neutral point can be obtained from formula:

$$\left(X_N\right)_\alpha = \left.\frac{dC_m}{dC_L}\right|_\alpha \times 100\% \approx \frac{\left(C_m\right)_{\alpha+1} - \left(C_m\right)_{\alpha-1}}{\left(C_L\right)_{\alpha+1} - \left(C_L\right)_{\alpha-1}} \times 100\% \qquad (4)$$

where:
X_N – neutral point position [MAC%]
C_m –pitching moment coefficient of the whole aircraft
C_L– lift coefficient of the whole aircraft
In presented formula, these two equidistant points are α-1 and α+1.

ATTENTION: The coordinate system used in PANUKL, differs from system presented on Figure 1. The “X” axis is directed backward and the origin is defined by user during defining of the aircraft geometry. The moment coefficients are computed with respect to point defined by user or computed automatically by program – usually ¼ of MAC. The coordinates of this point are saved in results file [.out]. X_N is computed with respect to the same point as moment coefficients.

The static margin, like in AVL case, can be computed using Eq. (3). If aircraft was unstable and geometry was modified, the aerodynamic analyses have to be repeated for the new configurations.

Information about aircraft’s component moment coefficient contribution can be obtained by unchecking the horizontal stabilizers active flag during the mesh generation.

Angle of horizontal tail setting:

In this part of the project student should define an angle of horizontal tail setting. Using numerical software student should find configuration of tail which fulfils the following condition:

Aircraft with no elevator deflection should be in equilibrium state for cursing flight condition.

Trim analysis:

In this part of project student should modify geometry of the numerical model and add the elevator. Next student should make numerical aerodynamic calculation for model with elevator deflected. Result of this part of project should be the diagram of ruder deflection versus to flight velocity which is necessary to obtain trim condition (CM=0) – see example Figure 6

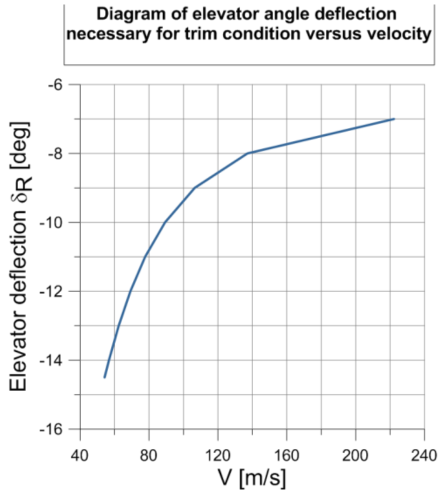

Figure 6 Diagram of δ_R(V)

Directional static stability

Next task is directional stability calculation. This calculation should be prepared for asymmetrical model (Check asymmetrical settings; for AVL model check iYsym parameters; for PANUKL all symmetry flags). Result of this part should be a diagram of yaw moment coefficient referred to side slip angle β. The calculation should be computed for angle of attack equal 0. The calculation should be computed for two points: β=0 and β≠0, in both cases the angle of attack has to equal 0. Directional characteristics should be compared with roll rate response criteria and roll controllability criteria described in the next chapter.

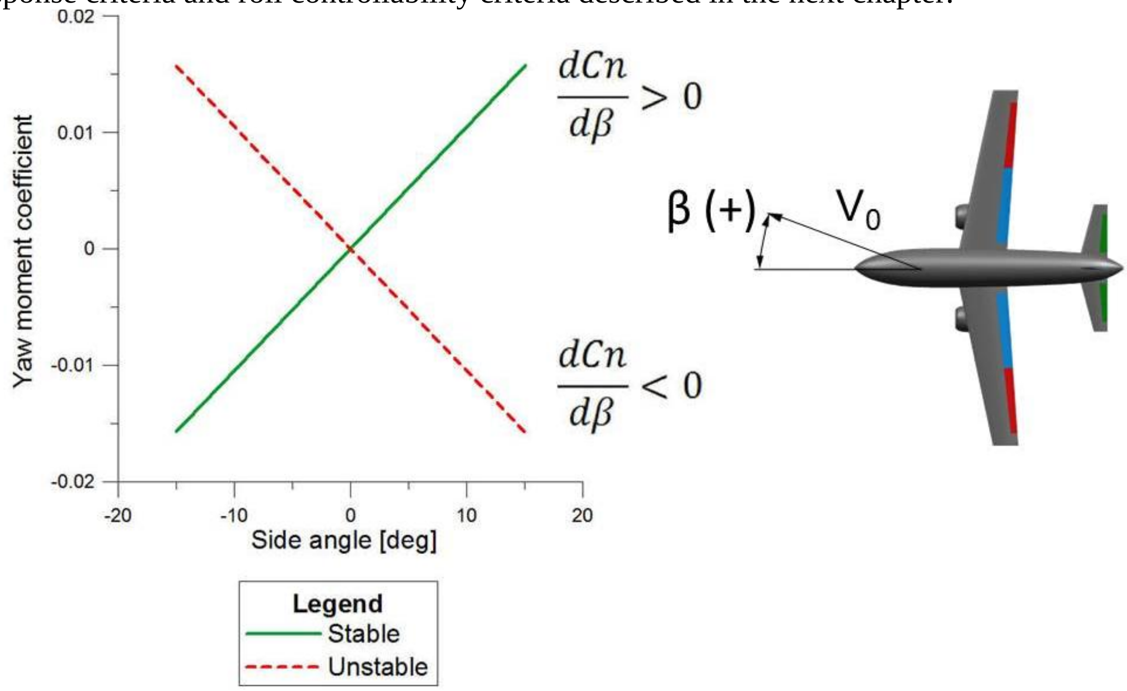

Figure 7 Static directional stability

Roll control characteristics

In this part of project student must add control surfaces to the main wing, which will work as an aileron to obtain $C_{l_{\delta_a}}$ derivative and define roll rate to obtain C_{lp} derivative.

Simplified Roll Rate criterion

Two factors are used to rate flying qualities in roll:

- time constant T_R of inertial module, which describes roll characteristics using the first order transfer function:

$$G_R(s) = \frac{p(s)}{\delta_a(s)} = \frac{k_R}{T_R \cdot s + 1} \tag{5}$$

where:

p(t) – roll rate,

$\delta_a(t)$ – aileron deflection.

- roll time T_φ to perform roll angle φ after aileron deflection δ_a.

Basic terms for derivatives calculation

Analysis bases on the linear differential equation:

$$\dot{\Phi}(t) = -\left[\frac{L_{\delta a}\,\delta_a}{L_p}\right]\left(1 - e^{L_p t}\right) \quad , \tag{6}$$

where dimensional stability derivatives are defined as follows:

- derivative of rolling moment with respect to aileron deflection:

$$L_{\delta_a} = \frac{q\,S\,b\,C_{l_{\delta_a}}}{I_{XX}} \tag{7}$$

- derivative of rolling moment with respect to roll rate

$$L_p = \frac{q\,S\,b^2 C_{l_p}}{2\;I_{XX} V} \tag{8}$$

Dimensionless derivatives are defined as follows:

$$C_{l_{\delta_a}} = l_\xi = \frac{\partial C_l}{\partial \delta_a} \qquad\qquad C_{l_p} = \frac{\partial C_l}{\partial \dfrac{p\,b}{2V}} \tag{9}$$

AVL: Both derivatives C_{lp} and $C_{l_{\delta_a}}$ could be directly computed by AVL package.

PANUKL: Both derivatives C_{lp} and $C_{l_{\delta_a}}$ could be estimated basing on results from PANUKL.

Roll characteristics

Roll characteristics are defined as follows (basing on the model defined by Eq. 6):

- Time constant of roll mode $T_r = \frac{-1}{L_p}$. it is time necessary to perform roll rate:

$$\left(1 - e^{-1}\right)\dot{\Phi}_{ss} = 0.63\dot{\Phi}_{ss} \qquad (10)$$

where:

$\dot{\Phi}_{ss}$ is steady value of roll rate

- Roll controllability:

$$T(\phi, \delta_a) = -\frac{\phi}{\delta_a}\frac{b}{2V}\left\{\frac{\dfrac{\partial C_l}{\partial \dfrac{pb}{2V}}}{\dfrac{\partial C_l}{\partial \delta_a}}\right\} \qquad (11)$$

where $T(\phi,\delta_a)$ - time necessary to roll from angle 0^o to angle equal to ϕ after aileron is deflected on δ_a.

Acceptance levels

The acceptance levels are defined by different regulation in different ways. The MIL-F8587C can be used if there are not clear criterions in airworthiness regulation. Necessary highlights are below:

Time constant of roll mode

Flight phase	Aircraft class	Acceptance level		
		1	2	3
		Time constant T_R [s] cannot be greater than		
A	I, IV	1.0	1.4	-
A	II, III	1.4	3.0	-
B	all	1.4	3.0	10
C	I, IV	1.0	1.4	-
C	II, III	1.4	3.0	

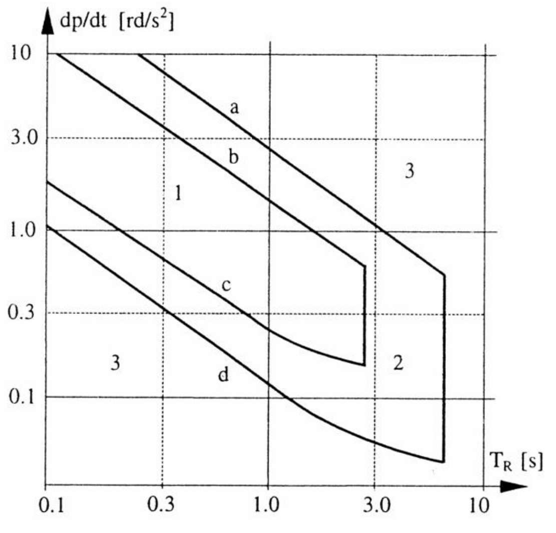

Figure 8 Simplified Roll-Rate response criterion for transport aircraft

Areas:

1. recommended
2. acceptable
3. unacceptable

Lines:

a) max roll rate 120°/s
b) max roll rate 60°/s
c) time to perform roll angle 60° - 6.5s
d) time to perform roll angle 60° - 10.5s

Roll controllability

Aircraft class	Flight phase	Acceptance level		
		1	2	3
		(φ-T) – roll angle φ[°] performed in time T [s]		
I	A	60° in 1.3 s	60° in 1.7 s	60° in 2.6 s
	B	60° in 1.7 s	60° in 2.5 s	60° in 3.4 s
	C	30° in 1.3 s	30° in 1.8 s	30° in 2.6 s
II	A	45° in 1.4 s	45° in 1.9 s	45° in 2.8 s
	B	45° in 1.9 s	45° in 2.8 s	45° in 3.0 s
	C	30° in 2.5 s	30° in 3.5 s	30° in 5.0 s
III	A	30° in 1.5 s	30° in 2.0 s	30° in 3.0 s
	B	30° in 2.0 s	30° in 3.0 s	30° in 4.0 s
	C	30° in 3.0 s	30° w 4.0 s	30° in 6.0 s
IV	A	90° in 1.3 s	90° in 1.7 s	90° in 2.6 s
	B	60° in 1.7 s	60° in 2.5 s	60° in 3.4 s
	C	30° in 1.0 s	30° in 1.3 s	30° in 2.0 s

Remarks:

1. In case of aircraft of IV-th class, for 1st level, stick and pedals should be free during test.
2. Otherwise rudder may be used to reduce sideslip, however only if it causes decreasing of the roll angle; any use of rudder, which increases roll angle is forbidden.

Project requirements:

Project's report should include:

- all student's assumptions (reference values should be also included);
- result of static stability margin calculation (diagram and table with values), angle of horizontal tail setting, diagram of $\delta_R(V)$ for trim condition;
- diagram of $Cn(\beta)$ for $\alpha=0$;
- plot of pressure distribution for model with aileron deflected (example Figure 9);
- results of roll characteristic calculation which present that requirements for roll for all phases of flight are fulfilled;
- plot of lift distribution versus wing span with ailerons deflected – example Figure 10 (AVL – T Trefftz Plane plot command, PANUKL – from "spanwise distribution" file [.czy]);
- draw scheme with dimension of wing with ailerons and tail with elevator;

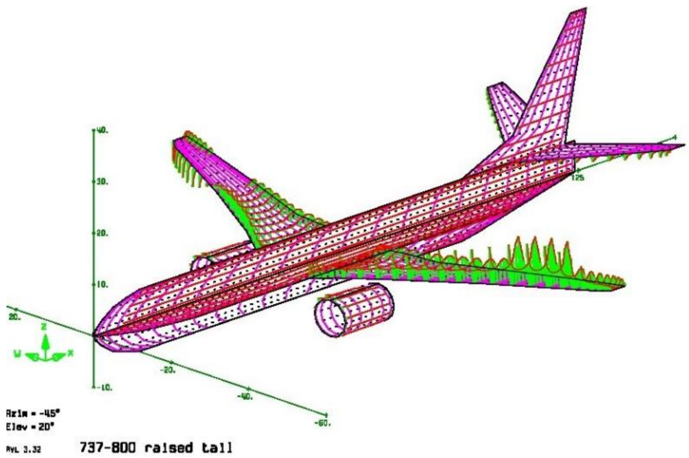

Figure 9 Example of the pressure distribution for model with aileron deflected (on the right) results of AVL example calculation

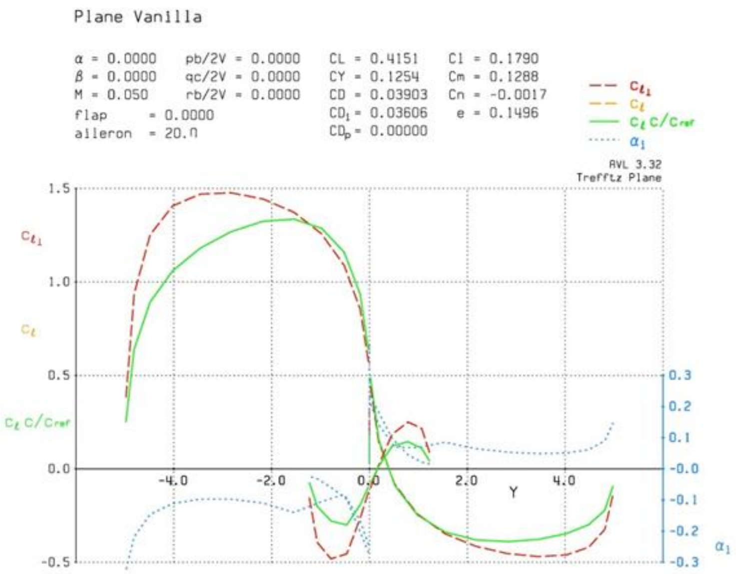

Figure 10 Example of the lift distribution versus wing span results of AVL example calculation.

Bibliography

[1] R.C. Nelson: Flight Stability and Automatic Control (second edition), McGraw-Hill, 1998
[2] Ajoy Kumar Kundu: Aircraft Design, Cambridge University Press, 2010
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[4] AVL user Guide (http://web.mit.edu/drela/Public/web/avl/avl_doc.txt)
[5] PANUKL user Guide (http://itlims.meil.pw.edu.pl/zsis/pomoce/PANUKL/2012/PanuklMan_eng.pdf)

[1],[2],[3] are available in Main or Faculty Library or in E-books on WUT Main Library e-resources