Wing

Airfoil selection

- Aerodynamic characteristics ($K_{\text{max}}$, $C_{L_{\text{max}}}$, stall characteristics)
- Structural reasons;
Angle of attack definition
Airfoil aerodynamic characteristics

Lift coefficient ($C_z$ or $C_L$)

Drag coefficient ($C_x$ or $C_D$)

Stall

Design $C_z$
Airfoil aerodynamic characteristics

Gliding ratio \((C_z / C_x)\)

Power factor \((C_z^3 / C_x^2) \text{ lub } C_z^{1.5} / C_x\)

Pitching moment coefficient \(C_m\)

Derivative \(dC_m/dC_z\) is an indicator of stability.

It is negative for stable aeroplanes and positive for unstable aeroplanes.
Maximum thickness – t/c

Effect of airfoil thickness on lift coefficient
Effect of airfoil thickness on lift coefficient

Effect of airfoil thickness on drag coefficient
Effect of airfoil thickness on gliding ratio

Effect of airfoil thickness on power factor
Camber

Effect of airfoil camber on lift coefficient
Effect of airfoil camber on drag coefficient

Effect of airfoil camber on gliding ratio
Effect of airfoil camber on power factor

Effect of airfoil camber on moment coefficient
Position of maximum thickness

Boundary layer development

laminar

turbulent

transition

separated

Maximum thickness

Position of maximum thickness
Effect of airfoil "laminarity" on drag coefficient

Effect of airfoil "laminarity" on lift coefficient
Effect of camber line shape on moment coefficient

Effect of camber line shape on gliding ratio
Reynolds number effect on aerodynamic coefficients

Effect of Mach number on lift coefficient
Effect of Mach number on drag coefficient

Effect of Mach number on moment coefficient
Critical Mach number

Historical values of an aeroplane airfoil thickness as a function of Mach number
Airfoil selection

Calculate Reynolds number for design airspeed

- $Re > 3,000,000$
  - Calculate Mach number for maximum airspeed
    - $M_{\text{max}} > 0.75$
    - Supercritical airfoil eg. NASA SC(2) 714
      - NASA TM X-1109
      - NASA TM X-2977
      - NASA TP 2969
    - $M_{\text{max}} < 0.75$

- $3,000,000 > Re > 500,000$
  - Wortmann catalogue
    - „Stuttgarter Profilkatalog“ Vol.1 i 2
  - Selig catalogue
    - „Summary of low speed airfoil data“ Vol.1-3
    - „Airfoils at low speeds“

- $Re < 500,000$
  - Abbot catalogue
    - „Theory of the wing section“, raport NACA 824, NASA TN D-7428

Calculate Mach number for maximum airspeed

Find characteristics for $Re_{\text{des}}$ i $M_{\text{des}}$

Calculate $C_L$ for design airspeed

Compare $C_D$ for $C_{L_{\text{des}}}$ of available airfoils and select few best airfoils

Compare $C_{L_{\text{max}}}$ of selected airfoils

Compare stall character of selected airfoils

Compare $C_M$ of selected airfoils

Select an airfoil with a combination of above features best suiting to the aeroplane mission
Remaining wing features

- Wing incidence;
- Mean aerodynamic chord mac, $\bar{c}$
- Wing area (reference area) $S$;
- Wing span $b$;
- Wing aspect ratio $A$;
- Wing dihedral;
- Wing sweep angle (leading edge $\Lambda_{LE}$, quarter chord $\Lambda_{c/4}$);
- Taper ratio $\lambda$;
- Geometrical and aerodynamic twist;
- Winglets
- Leading edges extensions;

Wing incidence angle

An angle between root chord and fuselage longitudinal axis
Taper ratio

\[ \lambda = \frac{c_T}{c_R} \]

Straight wings:
\[ \lambda = 0.4 \div 0.5 \]

Swept wings:
\[ \lambda = 0.2 \div 0.3 \]

Mean aerodynamic chord \( mac, \bar{c} \)

\[ \bar{c} = \left( \frac{2}{3} \right) c_{koot} \cdot \frac{1 + \lambda + \lambda^2}{1 + \lambda} \]

\[ \bar{Y} = \left( \frac{b}{6} \right) \cdot \left[ (1 + 2 \cdot \lambda)(1 + \lambda) \right] \]
Vortices generated by a wing

\[ A = \frac{b^2}{S} \]

\[ C_D = C_{D0} + \frac{C_L^2}{\pi \cdot A \cdot e} \]

Vortices generated by a wing and effect of aspect ratio on drag coefficient
Effect of aspect ratio (A, AR) on lift coefficient

\[ C_{l,a} = C_{l,a} \cdot \frac{A}{\left(\frac{C_{l,a}}{\pi}\right) + \left(\frac{C_{l,a}}{\pi}\right)^2 + A^2} \]

Helmbolt equation

\[ A = \frac{b^2}{S} \]

Wing dihedral angle

\[ \varphi \] – an angle between chords’ plane and horizontal plane

<table>
<thead>
<tr>
<th>Wing position</th>
<th>low</th>
<th>mid</th>
<th>high</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unswept</td>
<td>5÷7</td>
<td>2÷4</td>
<td>0÷2</td>
</tr>
<tr>
<td>Subsonic swept</td>
<td>3÷7</td>
<td>-2÷2</td>
<td>-5÷-2</td>
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<tr>
<td>Supersonic swept</td>
<td>0÷5</td>
<td>-5÷0</td>
<td>-5÷0</td>
</tr>
</tbody>
</table>
Wing sweep $\Lambda_{LE}, \Lambda_{c/4}, \Lambda_{t/c}$

$$\tan \Lambda_{LE} = \tan \Lambda_{c/4} + \left[ \frac{(1 - \lambda)}{A \cdot (1 + \lambda)} \right]$$

Line connecting quarter chords along the wing span

$\Lambda_{c/4}$ $\Lambda_{LE}$

Wing sweep

$$M_{eff} = M_{\infty} \cos(\Lambda_{LE})$$

$$M_{kryt} \sim 1/\cos^{m}(\Lambda_{LE})$$

Wing sweep reduces effective Mach number.

$$q_{eff} = q_{\infty} \cos^{2}(\Lambda_{LE})$$

$$W \sim \tan^{2}(\Lambda_{LE})$$
Wing sweep effect on $\frac{dC_L}{d\alpha}$

$$
\frac{dC_L}{d\alpha} = \frac{2 \cdot \pi \cdot A}{2 + \sqrt{4 + (A \cdot \beta)^2 \cdot \left(1 + \frac{\tan^2(A_{t/c})}{\beta^2}\right)}}
$$

$$
\beta = \sqrt{1 - M_{eff}^2}
$$

$$
M_{eff} = M_{\infty} \cos \Lambda_{LE}
$$

Wing sweep effect on separation
Wing sweep at supersonic speeds

Winglets
Wing twist

Geometric twist

Aerodynamic twist

Wing twist

Geometric twist

Aerodynamic twist
Delta wings

Leading Edge eXtensions
LEX effect on lift coefficient

Vortex generators