Lecture # 35: 3D Wing Aerodynamics: Swept & Delta Wings – Part #4

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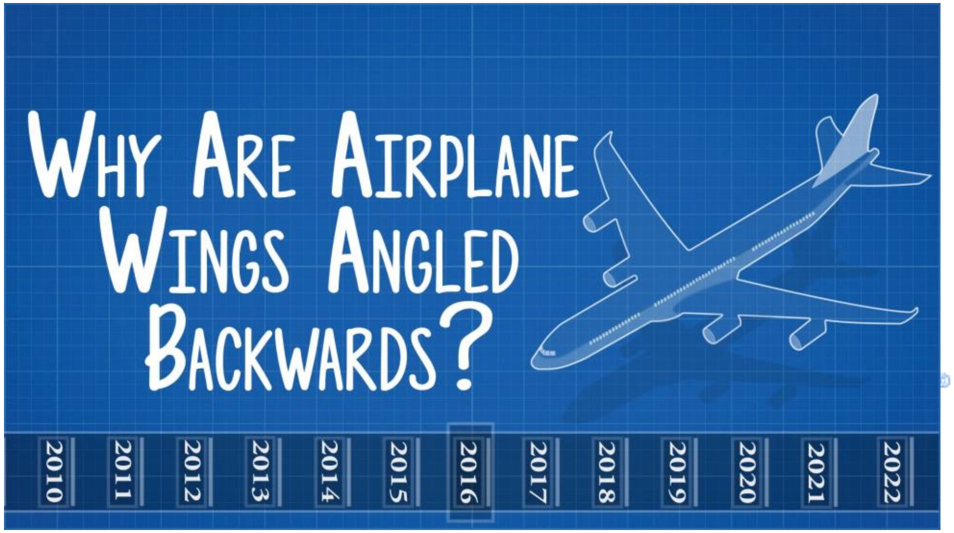
❑ 3D Wing Aerodynamics

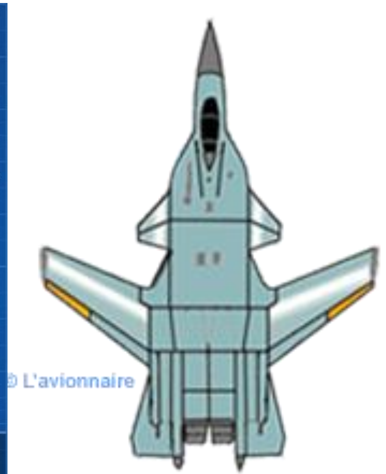
❑ ***[Wing sweep:]** Wings may be swept back, or occasionally forwards, for a variety of reasons..*

- ***Straight :** extends at right angles to the line of flight..*
- ***Swept back (aka "swept wing") :** The wing sweeps rearwards from the root to the tip.*
- ***Forward swept :** the wing angles forward from the root.*

Straight
(Curtiss P40)

Conventional tail
(Mystere IV)





Forward swept
(Sukhoï SU-47)

Variable sweep
(Dassault 3G)

❑ 3D Wing Aerodynamics

- Wing sweep reduces the wave drag by delaying formation of a shock wave over the wing surface

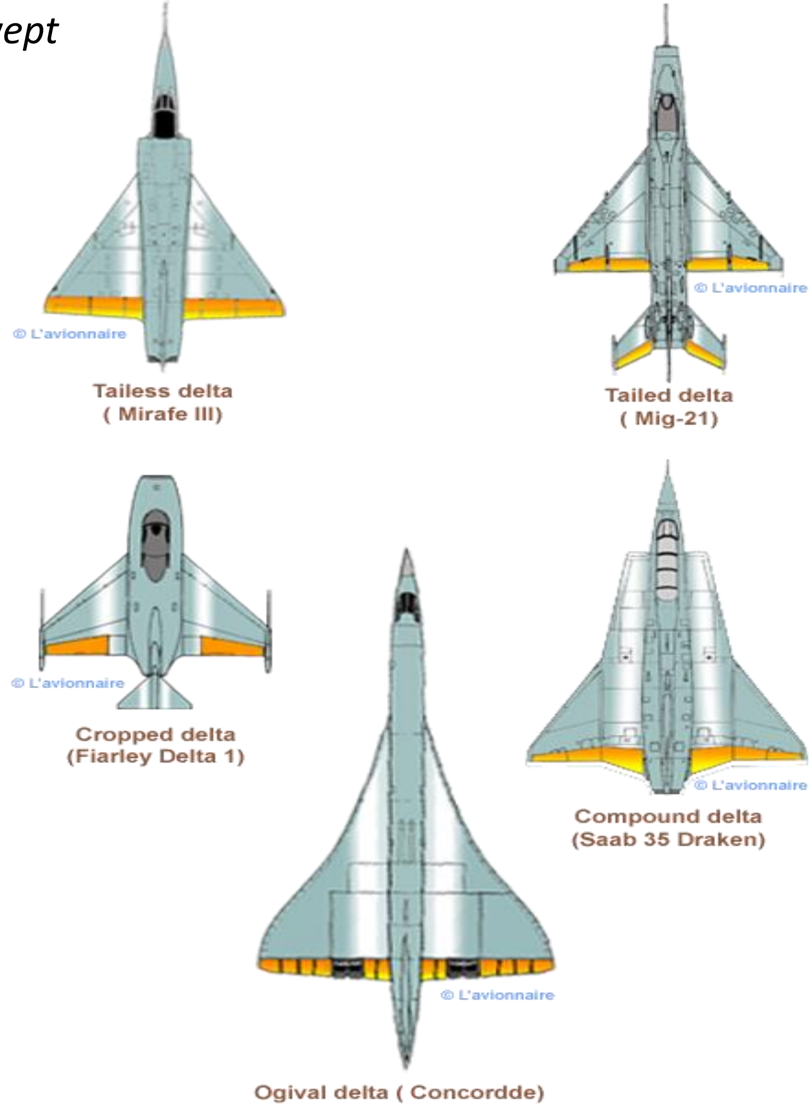
- Wave drag is the drag due to pressure drop across a shock wave (around the plane, over the wing, …)

- Swept wing is prominent for high-subsonic, transonic and low supersonic airplanes

- It comes with penalty on AR, hence higher induced drag

❑ 3D Wing Aerodynamics

- ***Wing Delta:*** *Delta triangular planform with swept leading edge and straight trailing edge. It offers the advantages of a swept wing, with good structural efficiency and low frontal area.*
- ***Tailless delta :*** *a classic high-speed design.*
- ***Tailed delta:*** *with a tailplane to improve handling.*
- ***Cropped delta :*** *wing tips are cut off to avoid tip drag at high angles of attack.*
- ***Compound delta or double delta :*** *inner section has a (usually) steeper leading-edge sweep to improve the lift at high angles of attack and delays or prevents stalling.*
- ***Ogival delta:*** *a double-curve encompassing the leading edges and tip of a cropped compound delta.*



❑ 3D Wing Aerodynamics

- At higher supersonic speeds, a delta wing has structural advantages over a simply swept wing

- Supersonic wings feature thin airfoils with relatively sharp leading edge, to minimize wave drag

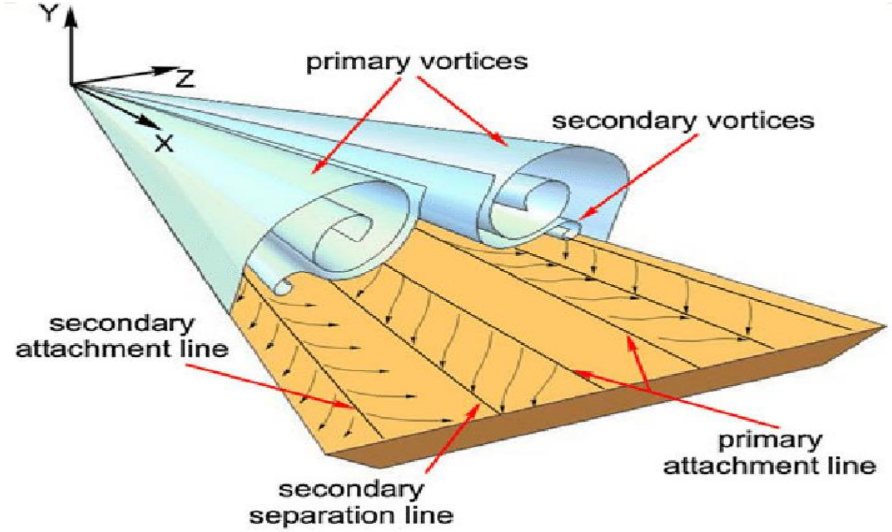
- These planes still have to fly subsonic through take-off/landing and a large portion of their mission

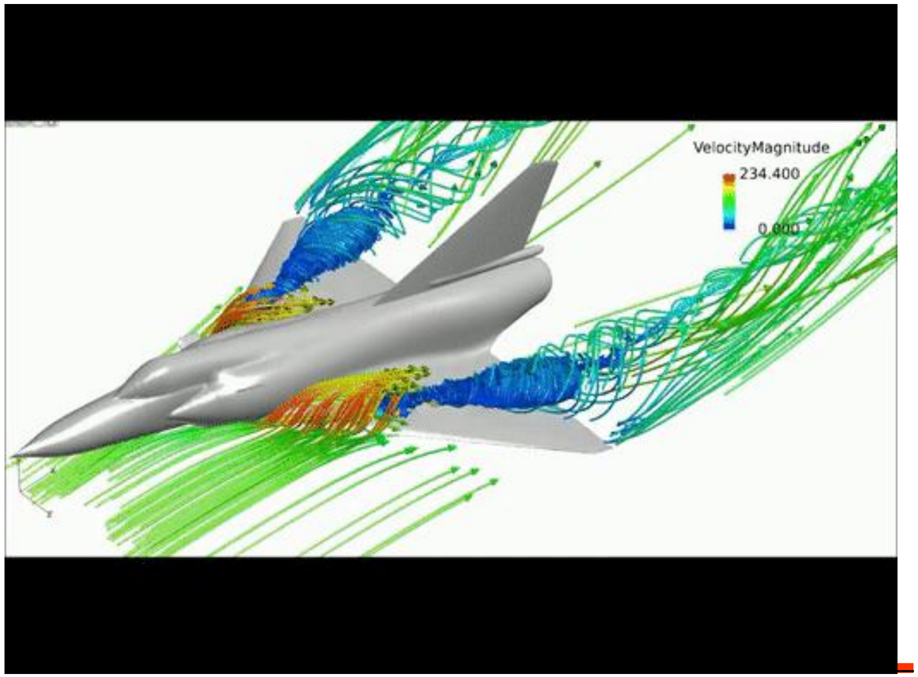
- Due to low AR, C_L is relatively low for delta wing, requiring to fly at high angle of attack in low-speed flight.

3D Wing Aerodynamics

Flow separation

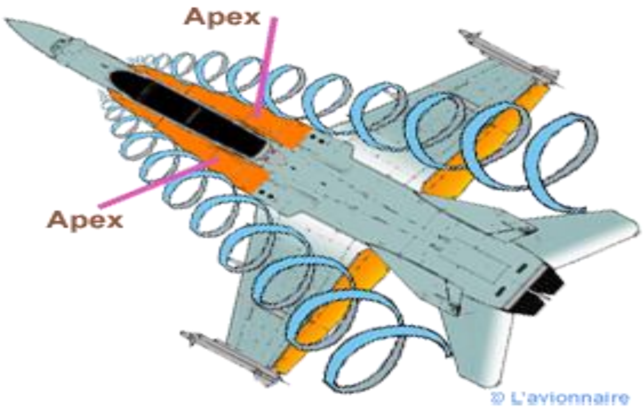
- In high angle of attack, flow separates over the wing surface
- Two primary vortices form from the leading edge and roll toward the surface
- Detached flow, reattaches on the wing, forming a loop
- These leading-edge vortices are strong and stable.



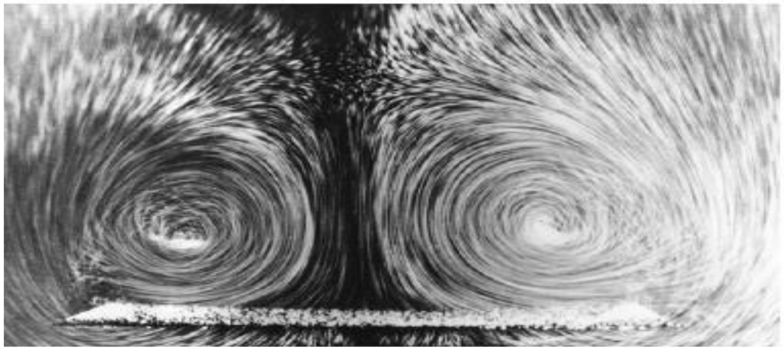


❑ 3D Wing Aerodynamics

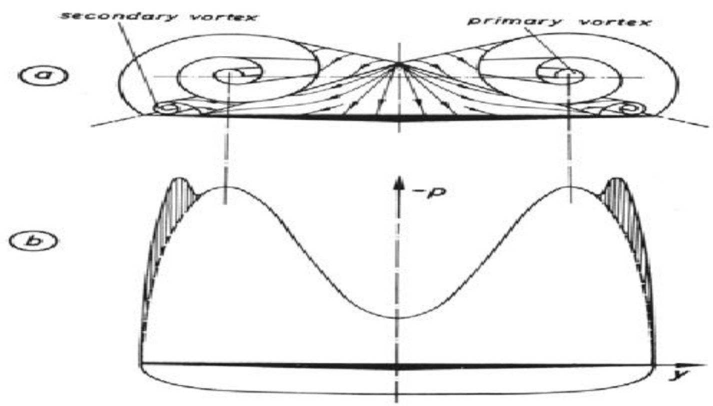
Leading edge vortices



- Near the leading edge, pressure on the top surface drops, while pressure increases over the bottom surface.



- The leading-edge vortices create a suction on the top surface near the leading edge.

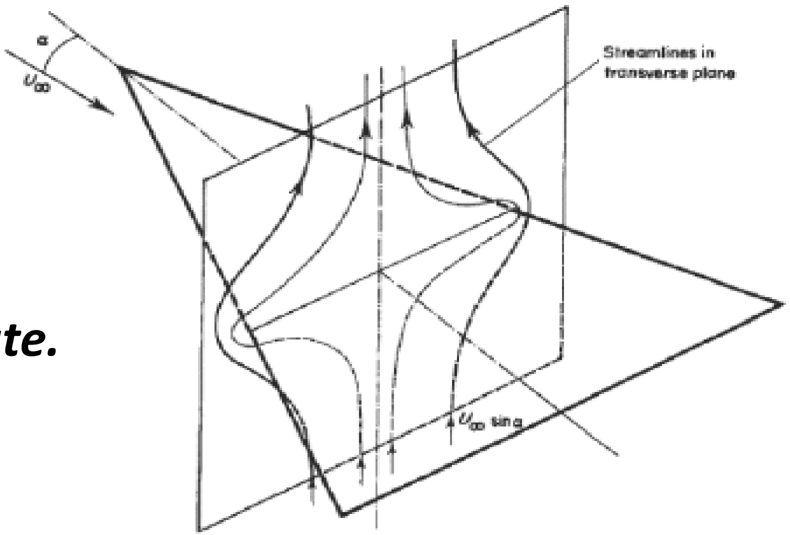


- This leads to an increased lift on the wing.

❑ 3D Wing Aerodynamics

Potential lift of a delta wing

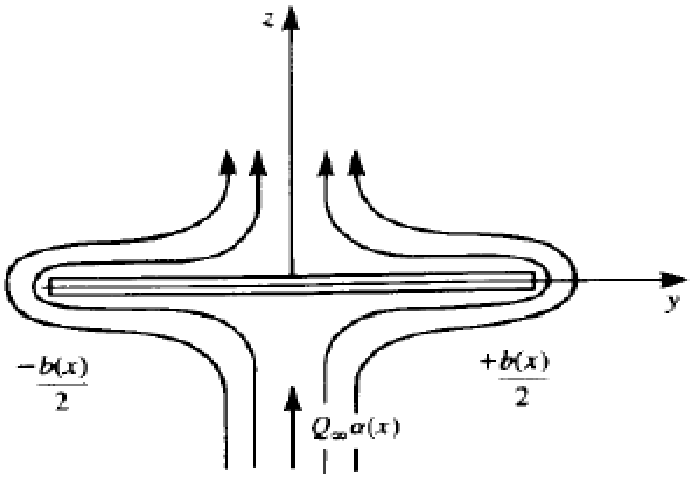
- *Using slender body theory*
- *Wing is discretized into transverse segments*
- *Each segment is modeled as a flat plate.*



❑ *For a triangular wing:*

$$C_L = \frac{\pi AR}{2} \sin\alpha \cos\alpha$$

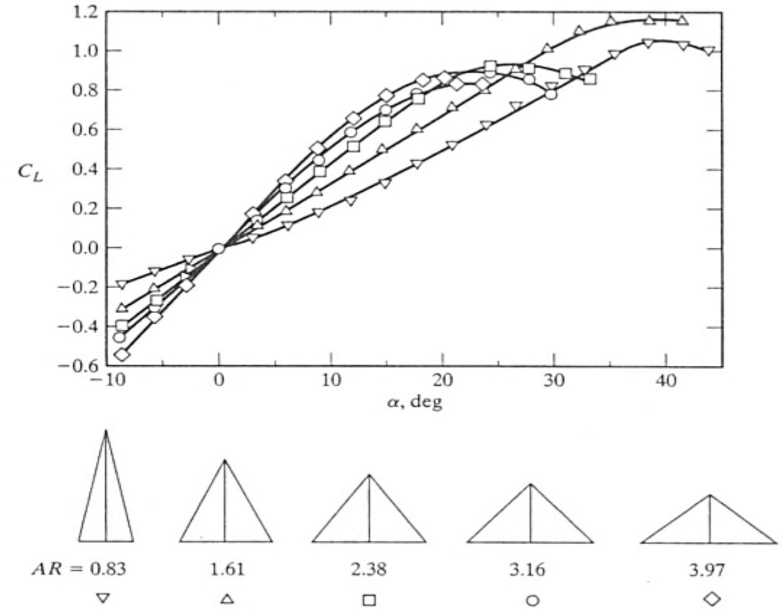
$$C_D = C_L \sin\alpha$$

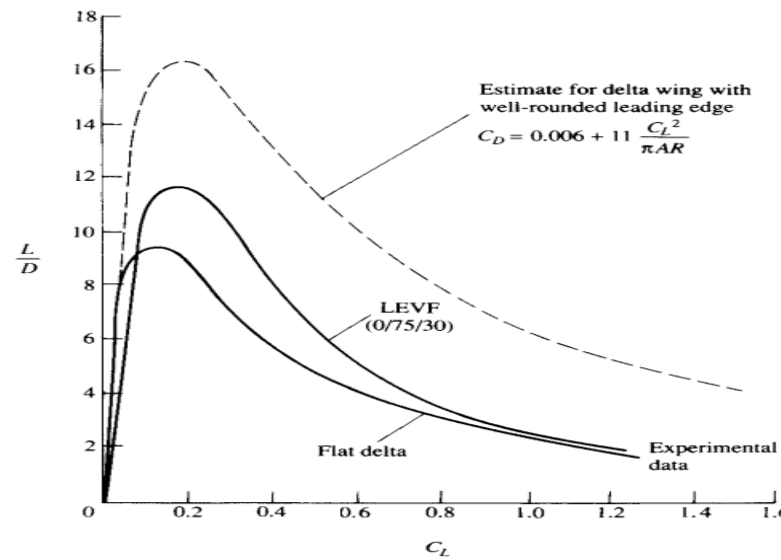


3D Wing Aerodynamics

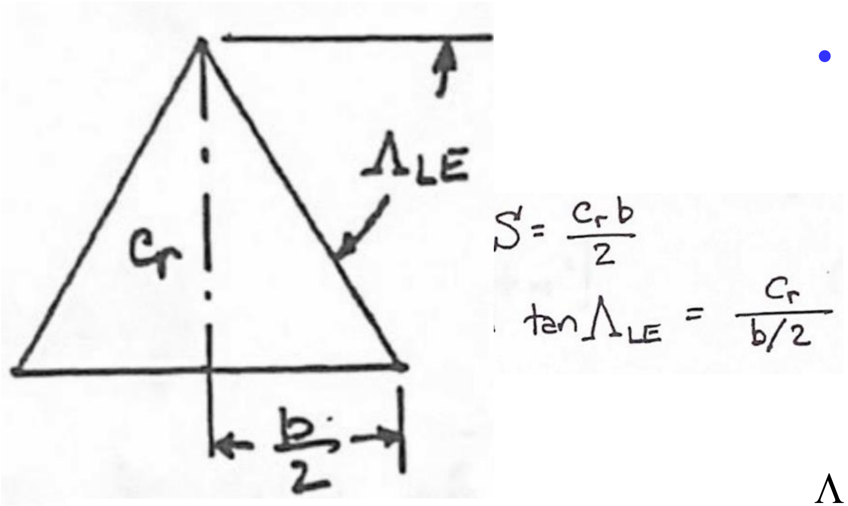
Delta wing efficiency at low speed

- The lift coefficient is still small, but the wing generates lift at higher angle of attacks.
- The increased lift comes with penalty of increased drag
- The leading edge separation can be decreased with a round leading edge
- Round leading edges however have higher wave drag at supersonic speeds
- Leading Edge Vortex Flap is a design to balance the two effects.





❑ 3D Wing Aerodynamics



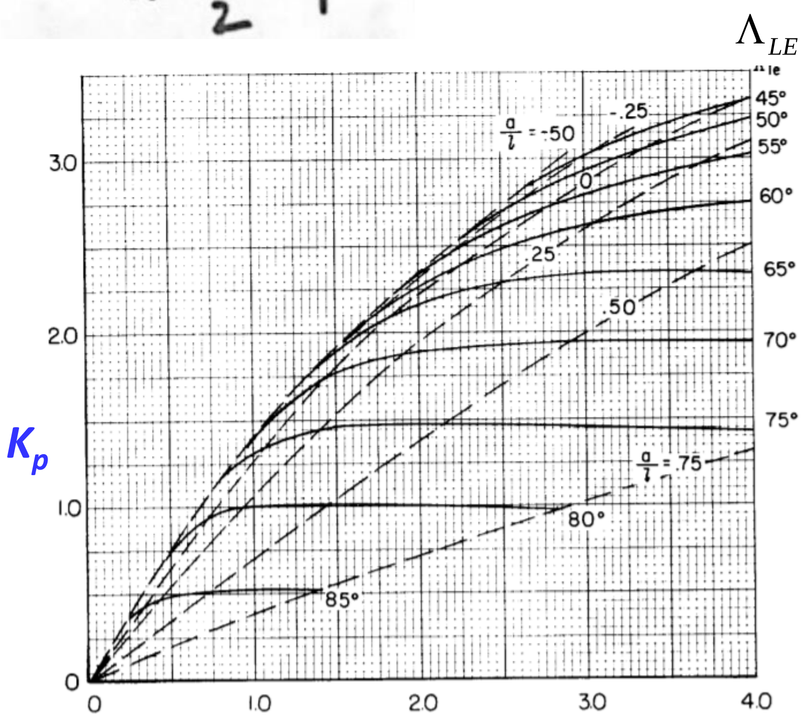
- ***Lift coefficient***

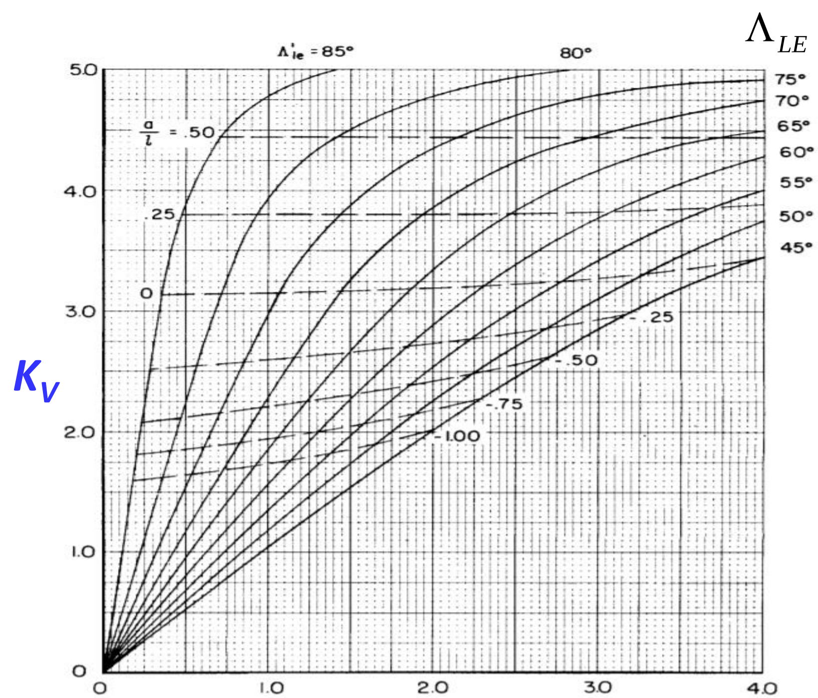
$$C_L = K_p \sin\alpha \cdot \cos^2\alpha + K_v \sin^2\alpha \cdot \cos\alpha$$

- ***Drag coefficient:***

$$C_{D,i} = C_D - C_{D0} = C_L \tan\alpha$$

$$C_D = C_{D0} + C_{D,i} = C_{D0} + K_p \sin^2\alpha \cdot + K_v \sin^3\alpha$$



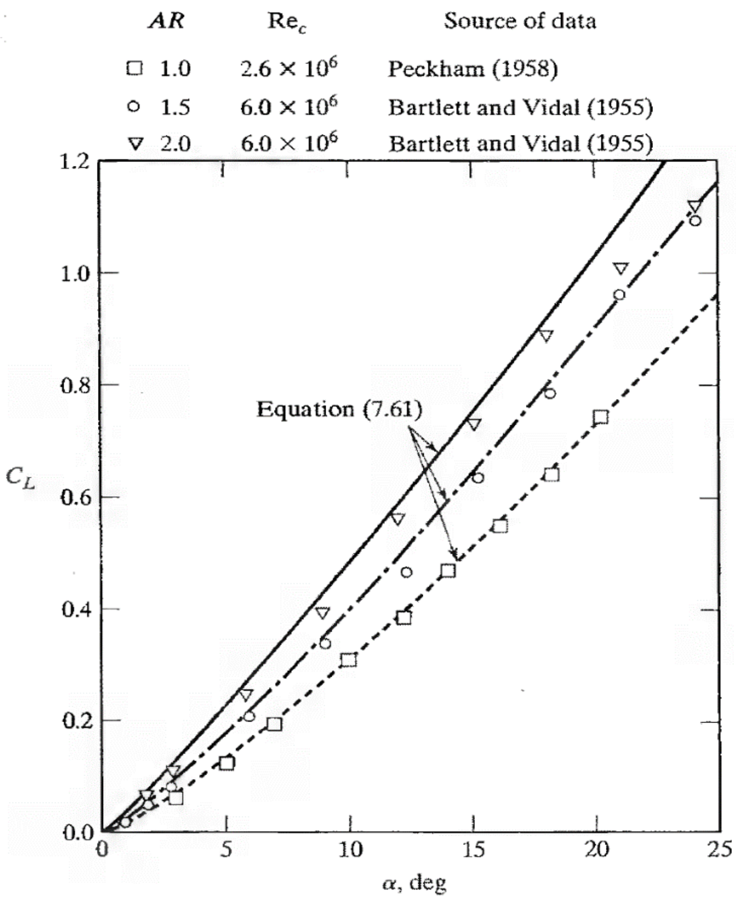


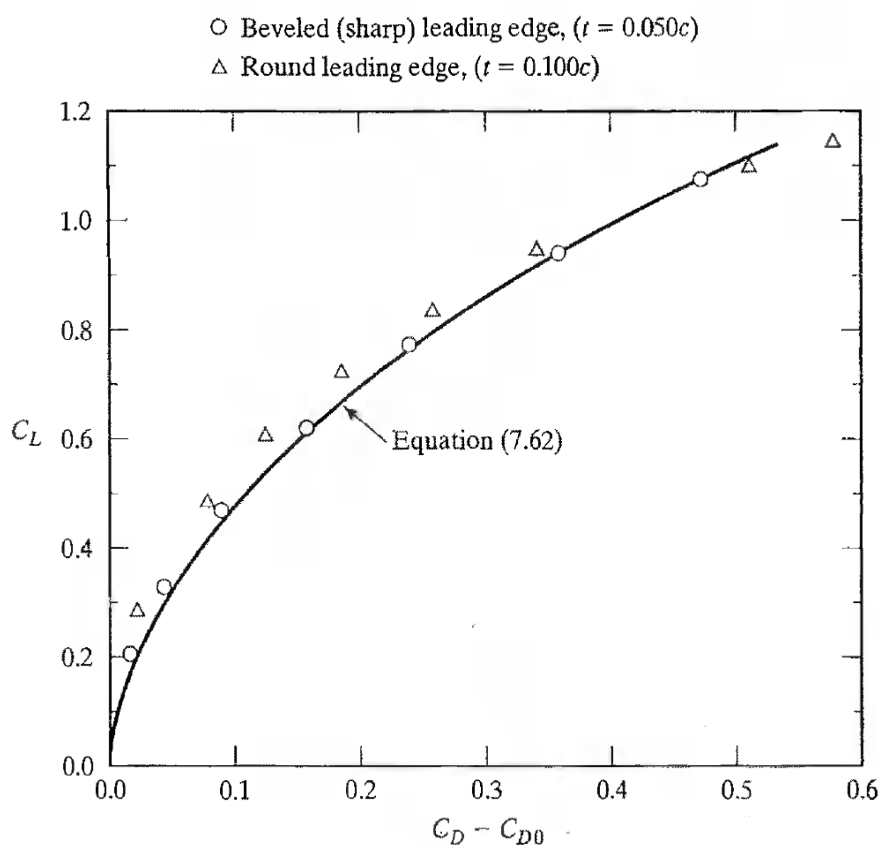
3D Wing Aerodynamics

Example #1

- ***For a delta wing of aspect ratio 1.5, please calculate the lift and drag coefficients at α = 15°.***

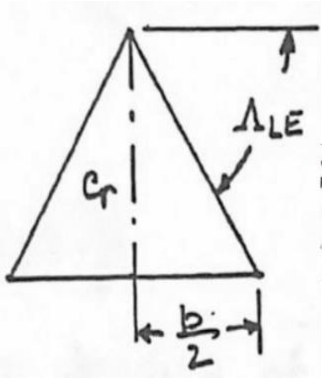
- ***Compare the result with the experimental data plotted in figure below.***





❑ 3D Wing Aerodynamics

❑ *Example #1*



$S = \frac{c_r b}{2}$

$\tan\Lambda_{LE} = \frac{c_r}{b/2}$

Combining these two relations: $S = \frac{b^2}{4}\tan\Lambda_{LE}$; $\tan\Lambda_{LE} = \frac{4}{AR}$

Since the AR (aspect ratio) is 1.5, $\Lambda_{LE} = 69.45°$.

Using Fig. 7.39, $K_p = 1.76$ and using Fig. 7.40, $K_v = 3.18$ as the "constants" in equation (7.61)

$$C_L = K_p \sin\alpha \cos^2\alpha + K_v \sin^2\alpha \cos\alpha$$

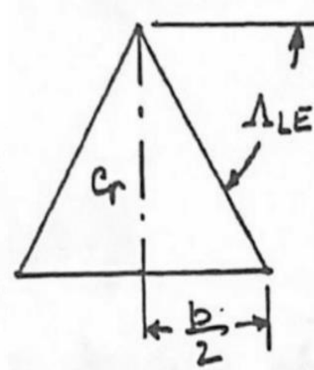
we have:

α	0°	5°	10°	15°
C_L	0.000	0.176	0.391	0.631

These calculations reproduce those represented by the broken line of Fig. 7.41

3D Wing Aerodynamics

Example #1



$S = \frac{c_r b}{2}$

$\tan \Lambda_{LE} = \frac{c_r}{b/2}$

7.14] Taking the coefficients found in the previous problem, i.e., $K_p = 1.76$ and $K_v = 3.18$, and substituting them into equations (7.61) and (7.62)

$$\Delta C_D = C_D - C_{D0} = C_L \tan \alpha$$

and using the results from the previous problem:

α	0°	5°	10°	15°
C_L	0.000	0.176	0.391	0.631
ΔC_D	0.000	0.015	0.069	0.169

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