Drag polar

Wednesday, August 23, 2017 17:00

For the glory of God

What is Drag polar ?

- The drag polar shows the relationship between the lift on an airfoil / aircraft and its drag.
- It is generally expressed by the lift and drag coefficients.
- The drag polar is a kind of packages which include or represent Aerodynamic data.
- It is usually sketched by both ways 1) C_D vs. C_L and 2) C_L vs. C_D

Drag polar Equations

For lift - dependent drag, it is given empirically.

- For airfoil, (It can be also used for 3D airplane)

Do not open k_1 and k_2 when they ask you about airfoil. (In an airfoil, k_2 is something related to camber effect and k_1 is about drag itself)

$$C_d = K_1 C_l^2 + K_2 C_l + C_{d,0}$$

; where $C_{d,0}$ = Zero - lift drag coefficient

C_d = Sectional drag coefficient

C_l = Sectional lift coefficient

K_1, K_2 = Aerodynamic constant (Determined by Experiment)

; where $K = \frac{1}{\pi e AR}$ (This is only for 3D)

$K_2 C_l$: usually, for 3D it is very small and negligible (like interference)

- In general, (Do not use this for airfoil, this is for complete airplane)

$$C_D = C_{D,0} + \frac{C_L^2}{\pi e AR}$$

$\frac{C_L^2}{\pi e AR}$ → $C_{D,i}$ (Induced drag coefficient)

; where $C_{D,0}$ = Parasite drag coefficient at zero lift

C_D = Drag coefficient for the complete aircraft

C_L = Total lift coefficient (wing + tail + ⋯)

AR = Aspect Ratio

e = Oswald efficiency factor

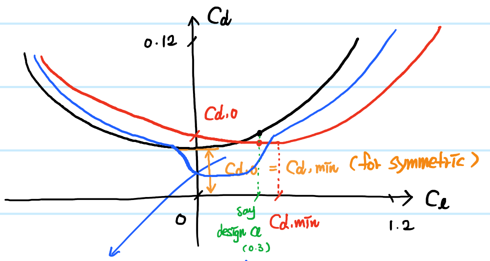
Plotting the Drag polar

- C_d is plotted versus C_l

cf. what if design $C_l = 0.3$, between Symmetric and camber, which one would you choose ? camber (∵ less C_d)

Then, how would you make the flow is laminar ? : Delay transition point (Related to delay flow separation)

If we have a multiple line, it should be a function of Re



- Symmetric airfoil
- Lockheed C-141 A (cambered)
- Jet airliner (Laminar airfoil)

Laminar as much as possible

Drag bucket (lowest drag) : This would be $C_l = 0$ location if symmetry

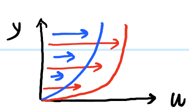
For cruise condition, α small, C_{Df} important than C_{Dp}

($C_{f,turbulence} > C_{f,Laminar}$)

cf. $C_f = \frac{\tau_w}{\frac{1}{2}\rho_\infty u_\infty^2}$; where $\tau \propto \frac{du}{dy}\Big|_{y=0}$

- The drag polar for an actual airplane exhibits a subtle difference
- Also, $C_{d,0}$ is not the minimum drag coefficient but rather is displaced slightly above.

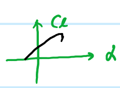
$\alpha = 0$ so that easy to have laminar flow



- Laminar
- Turbulent

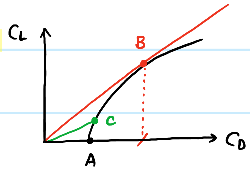
⇒ This is because the airplane is pitched slightly downward at this orientation.

∴ The minimum C_d occurs when the airplane is more aligned with the relative wind, that is, when α is slightly larger than $\alpha_L = 0$.



Maximum L/D point at the Drag polar

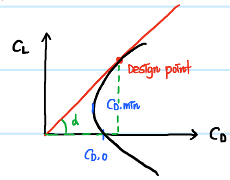
- A line drawn from the origin tangent to the drag polar identifies the L/D_{max} of aircraft.
  - It could be a design point.

(+) 

A = zero-lift drag point

B = Design point → why is it maximum?

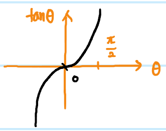
C = one point out of L/D points



$\tan\alpha = \frac{C_L}{C_D}$

↳ In order to get maximum C_L/C_D, the angle (α) should be increased.

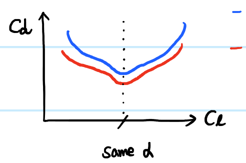
→ Hence, the maximum case would be tangent to the curve.

cf. 

(+) C_L is usually shown because negative lift situation is not frequently encountered in Aerodynamic analysis.

Reynolds number effects on Drag polar

- For drag coefficient,



; Here, Cd decreases as Re increases.

↳ This is because Re ↑ ∝ viscous force ↓

(In terms of airfoil, $C_{Df} > C_{Dp}$)

→ Basically, the shape of drag polar can be changed when;

- Change in flight regime (⇔ Reynolds number)
- Different vehicle configuration

Otherwise,

$Re_1 = \frac{\rho_\infty U_\infty C_1}{\mu}$ vs. $Re_2 = \frac{\rho_\infty U_\infty C_1}{\mu}$

- Here, μ = const

  $C_1 = C_2$ = Same (∵ Same airfoil)

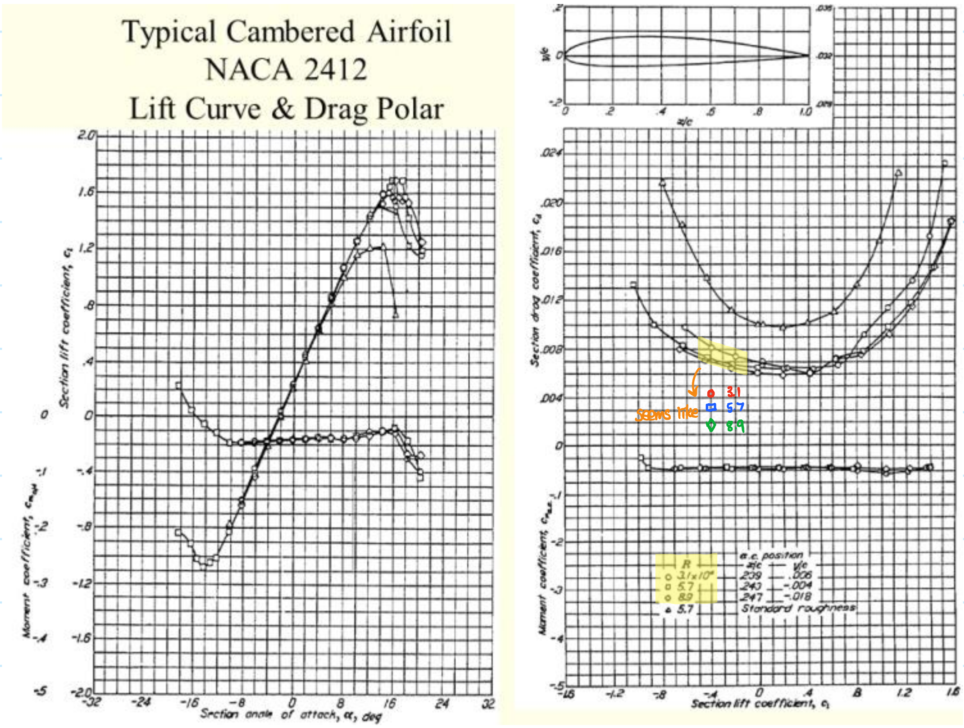
- Therefore,

  The higher Reynolds number, the more q_∞ $(= \frac{1}{2}\rho_\infty U_\infty^2)$

  ↗ It would be good for database choosing. i.e. Army, Same missile.

- Thus, ↓ $C_D = D/q_\infty S$ ↑

cf. $D = C_D q_\infty S \Leftrightarrow D = f q_\infty$; where f = Equivalent flat plate drag area



cf. · $L/D = C_L/C_D$ only for same Reference area and ρ_∞, U_∞ conditions.

→ Induced drag.

· When aircraft is taking off, Supersonic aircraft has greater Lift-dependent drag than subsonic.

↳ This is because supersonic aircraft usually has low AR, which results in increase in $C_{D_i} \uparrow = \frac{C_L^2}{\pi A R e} \downarrow$