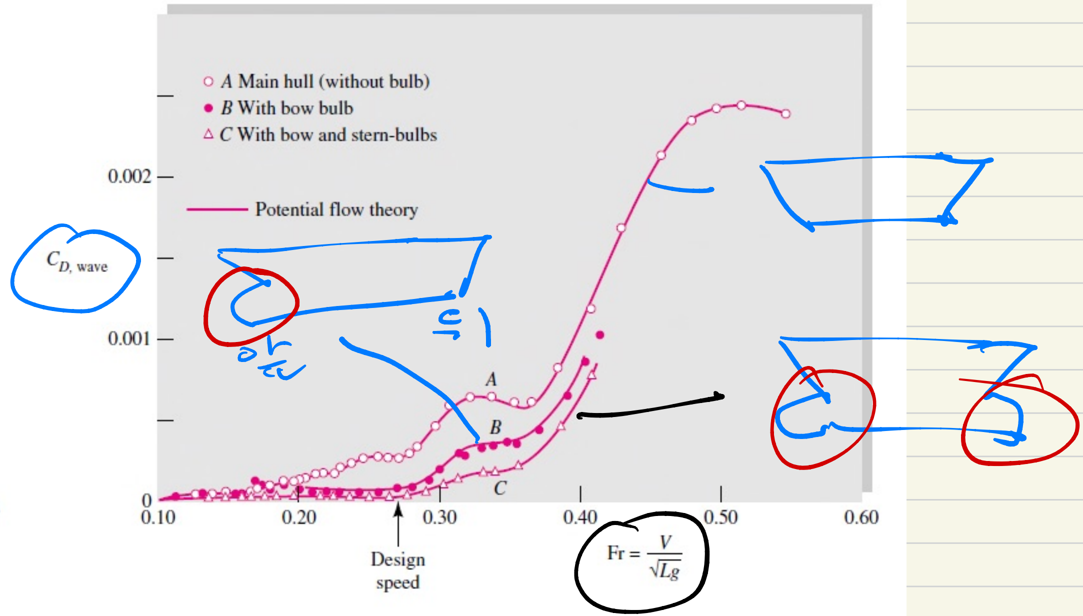
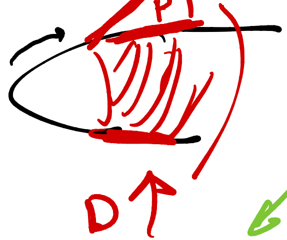



**Fig. 7.19** Wave-making drag on a ship model. (*After Inui [27].*) *Note:* The drag coefficient is defined as $C_{DW} = 2F/(\rho V^2 L^2)$.

Ma↑ V↑ Ma>1 shock P↑

Ma<1



D↑

sonic barrier

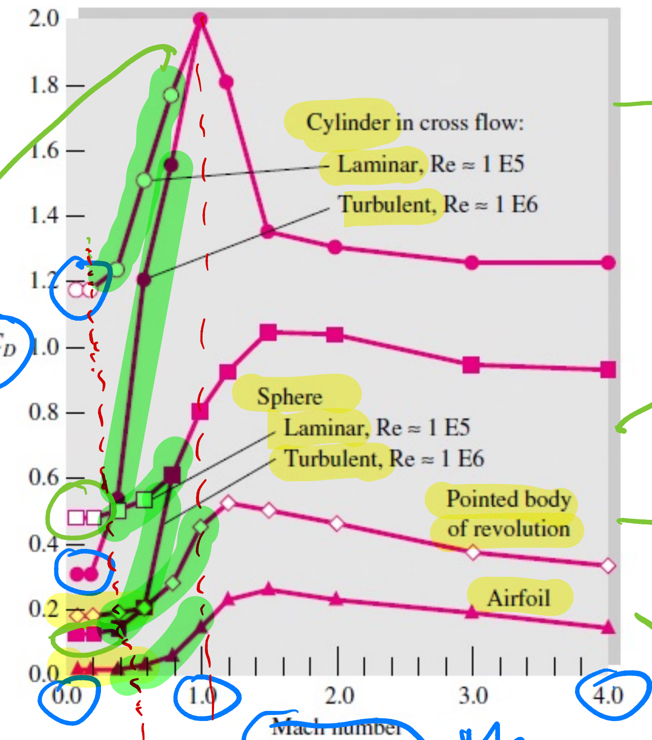


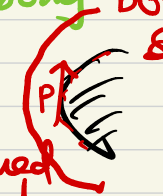

**Fig. 7.20** Effect of the Mach number on the drag of various body shapes. (*Data from Refs. 23 and 29.*)

Ma

Ch. 9

bluff body bow shock

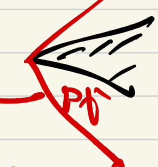
Ma>1



P↑ detached shock

D↑

oblique shock P↑



streamlined body

| Re O | Re O | Re X |
|---|---|---|
| Ma X | Ma O | Ma O |

$Ma_{crit}$

$Ma_{crit} \simeq$ 0.4 cylinder

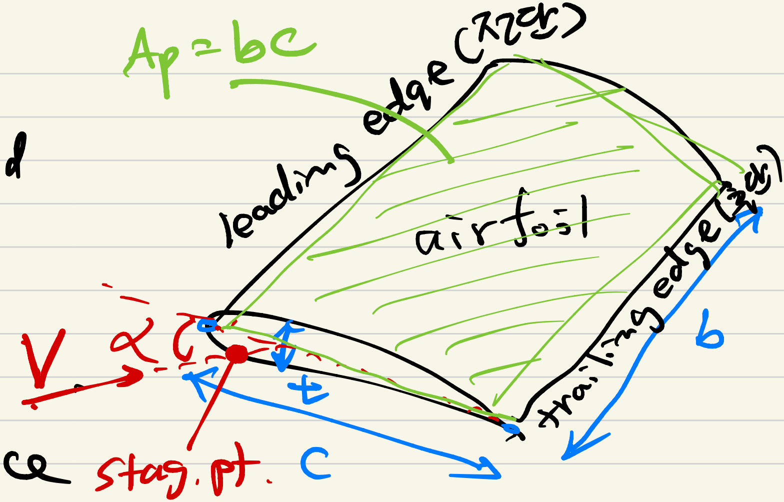
0.6 sphere

0.7 airfoil

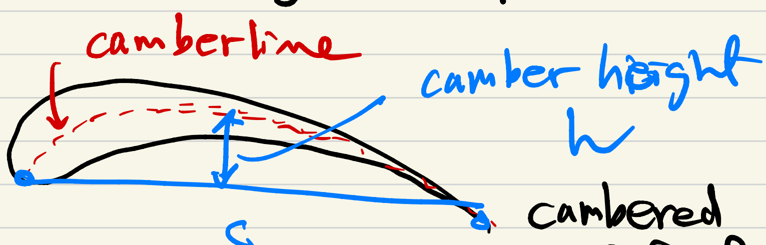
- Forces on lifting bodies

large lift $L$ } streamlined
small drag $D$ } bodies

$L/D$ : ratio of lift to drag
lift-to-drag ratio
↳ aerodynamic performance

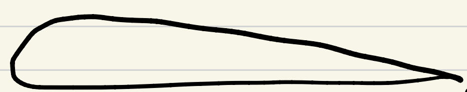



b : span
c : chord (length)
t : thickness
α : angle of attack




cambered airfoil

symmetric airfoil



asymmetric airfoil

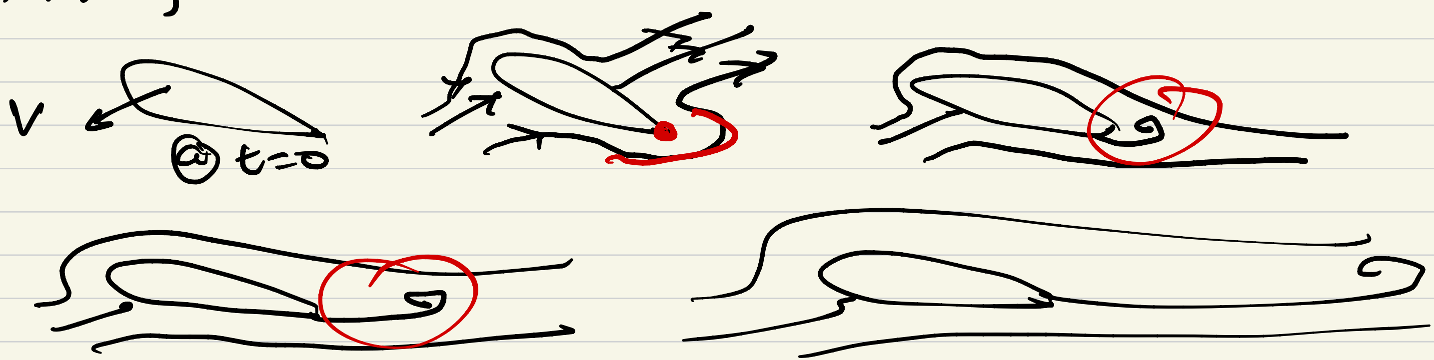
Lift coefficient $C_L = \frac{L}{\frac{1}{2}\rho V^2 A_p} = f(\alpha, Re_c)$

Drag " $C_D = \frac{D}{\frac{1}{2}\rho V^2 A_p} = f(\alpha, Re_c)$

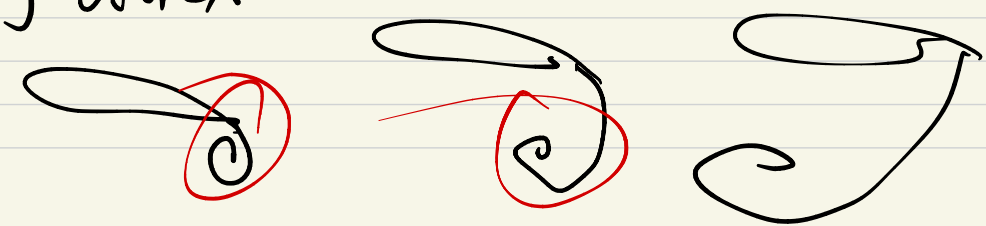
$Re_c = \frac{Vc}{\nu} = 10^5 \sim 10^7$ commonly turbulent

Ch. 8

- Starting vortex




- Stopping vortex

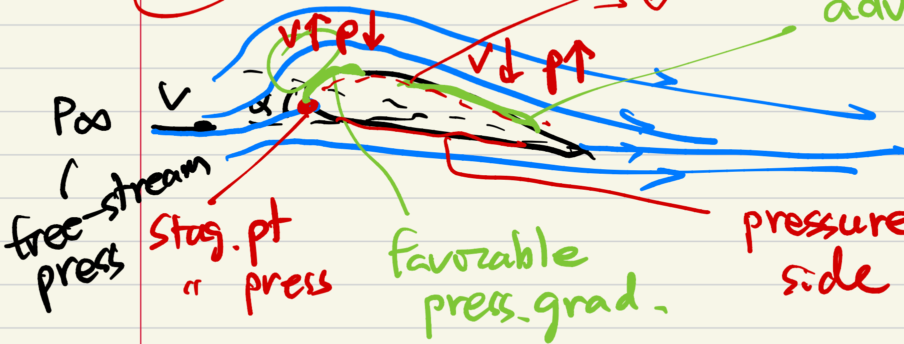


· low angle of attack

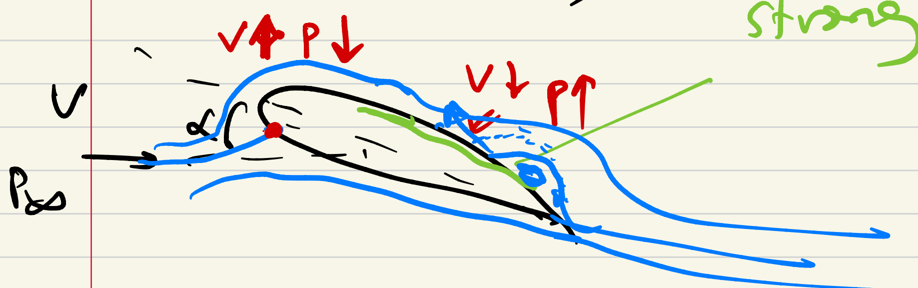
suction side

adverse press. grad.

weak – no separation




As α increases,



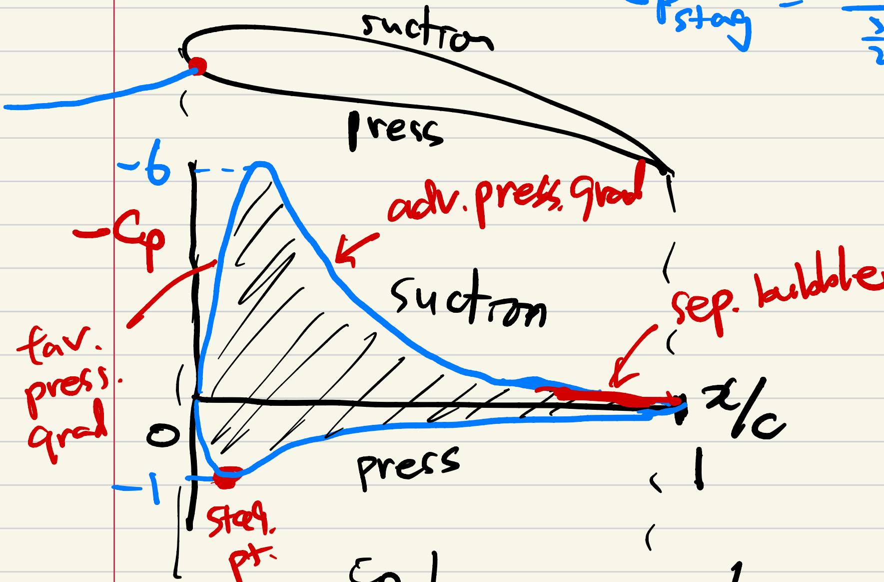

strong adv. press. grad.

→ separation

As α ↑, separation bubble moves forward to the leading edge.

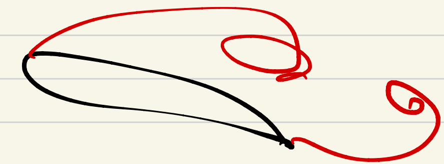
$$C_p = \frac{P - P_\infty}{\frac{1}{2}\rho V^2} \quad : \text{press. coefficient}$$

$$C_{p_{stag}} = \frac{P_{stag} - P_\infty}{\frac{1}{2}\rho V^2} = 1$$

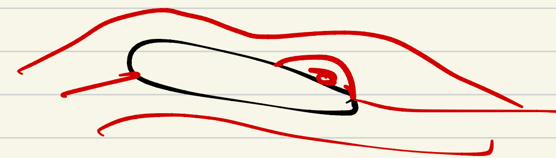


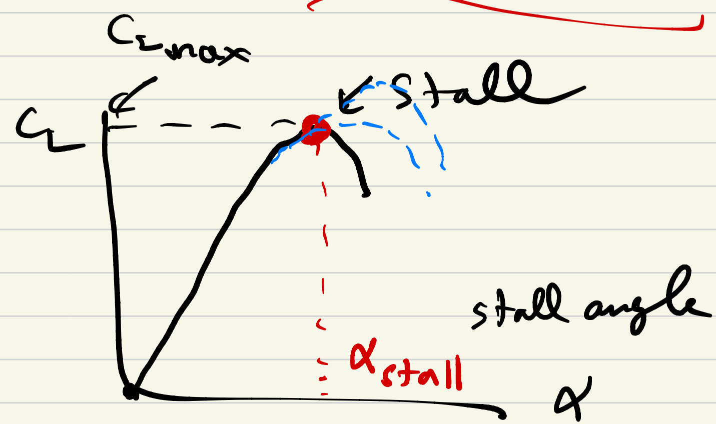

low Re airfoil

$O(Re \lesssim 10^6)$



high Re airfoil




As $\alpha$ ↑,

drag ↑,

lift ↗ ↓

- Stall speed $V_s$ : minimum speed for supporting its weight

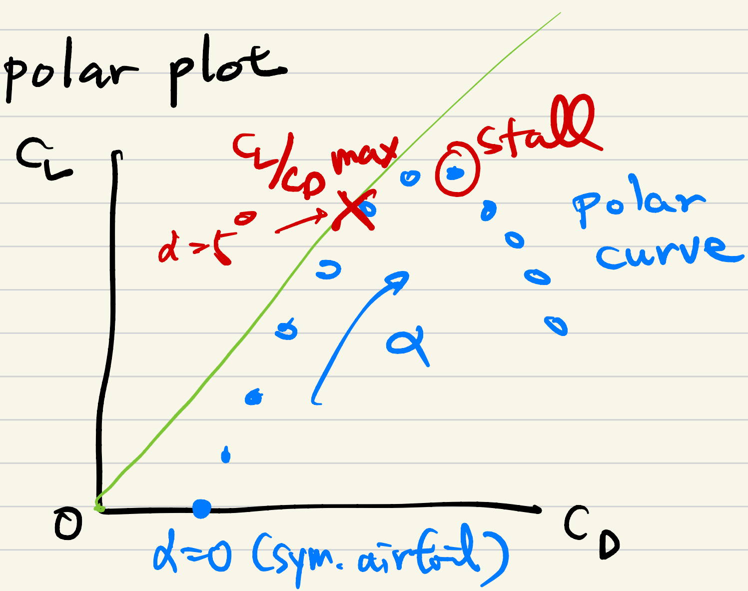
$$C_L = \frac{L}{\frac{1}{2}\rho V^2 A_p} = \frac{W}{\frac{1}{2}\rho V^2 A_p} \rightarrow W = \frac{1}{2}\rho V^2 A_p C_L$$

$$\rightarrow V = \sqrt{\frac{2W}{\rho A_p C_L}}$$

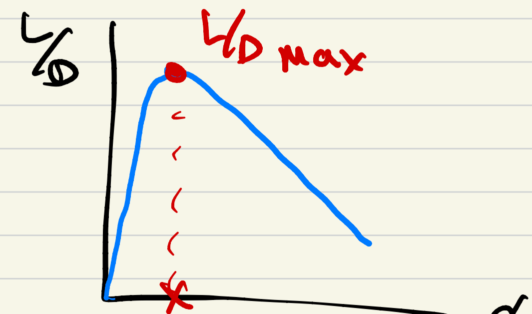
$$\Rightarrow V_s = \sqrt{\frac{2W}{\rho A_p C_{L\max}}}$$ : stall speed

18 ~ 60 m/s typical aircraft

polar plot




$$\frac{C_L}{C_D} = \frac{L}{D}$$



NACA 0009

sym

$\frac{\text{thickness}}{\text{chord}} = 9\%$

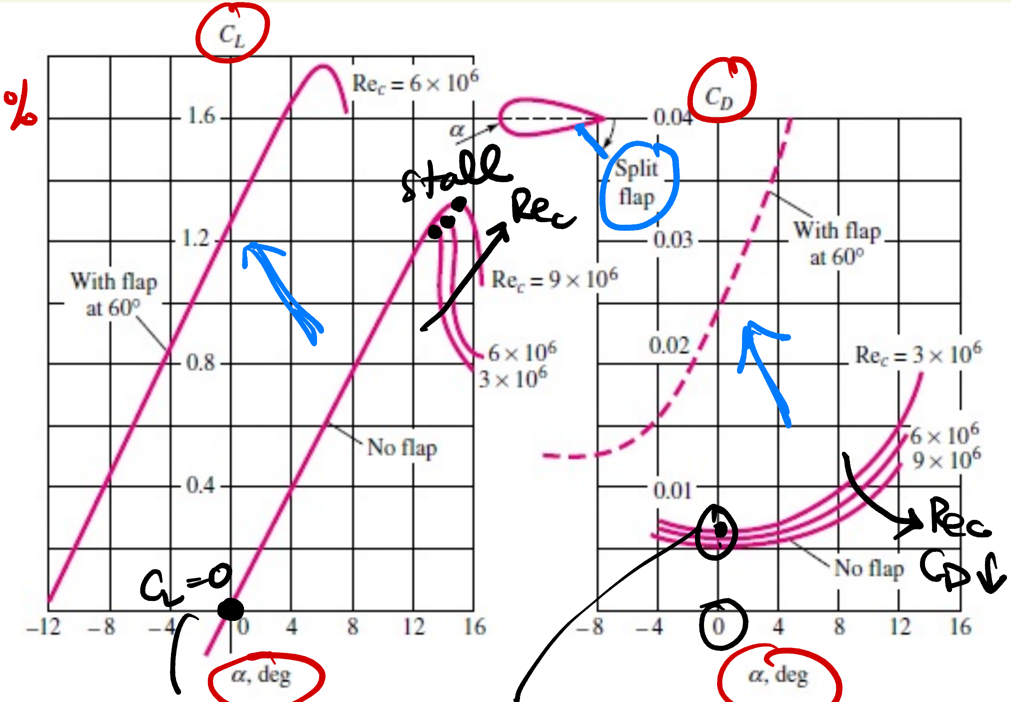
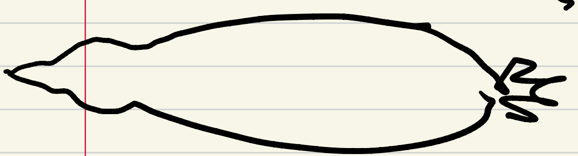



**Fig. 7.25** Lift and drag of a symmetric NACA 0009 airfoil of infinite span, including effect of a split-flap deflection. Note that roughness can increase $C_D$ from 100 to 300 percent.



$C_D = 0.005 \sim 0.007$

flat plate $C_D = 0.031 / Re_L^{1/7} = 0.0037$ $(Re_L = 3 \times 10^6)$

$0.037 \times 2 = 0.0074$ (both sides)

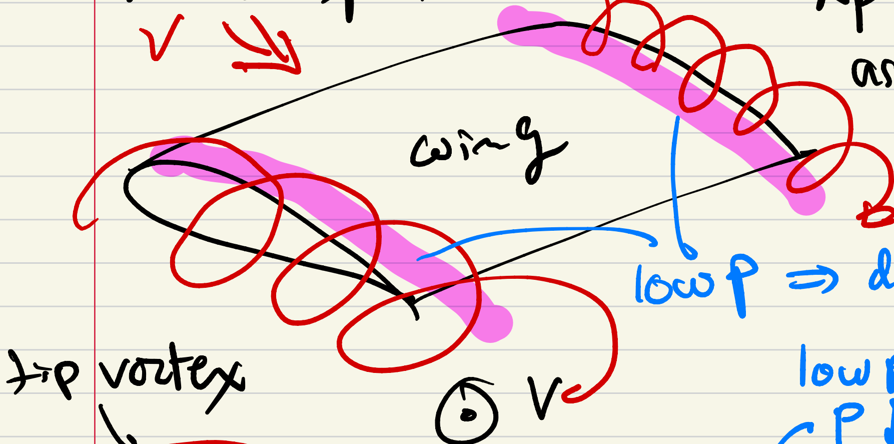
lower than that of a flat plate

- Finite aspect ratio

$A_p = bc$

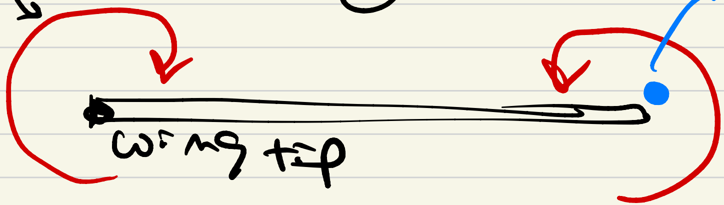
aspect ratio

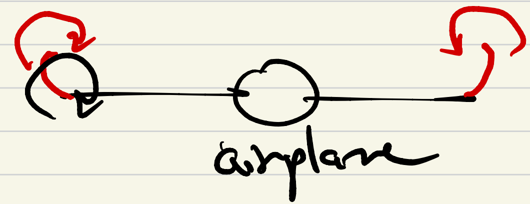
$$AR \equiv \frac{b^2}{A_p} = \frac{b^2}{bc} = \frac{b}{c}$$

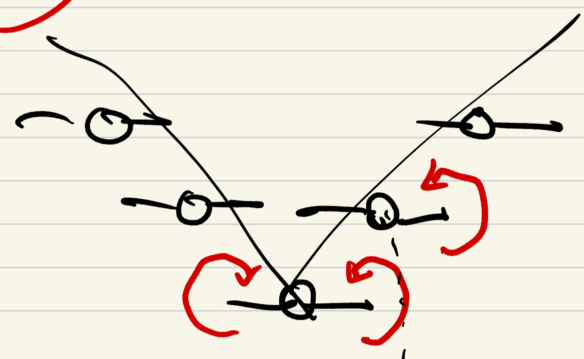


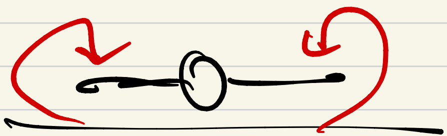

low p ⇒ drag ↑ ⇐ induced drag

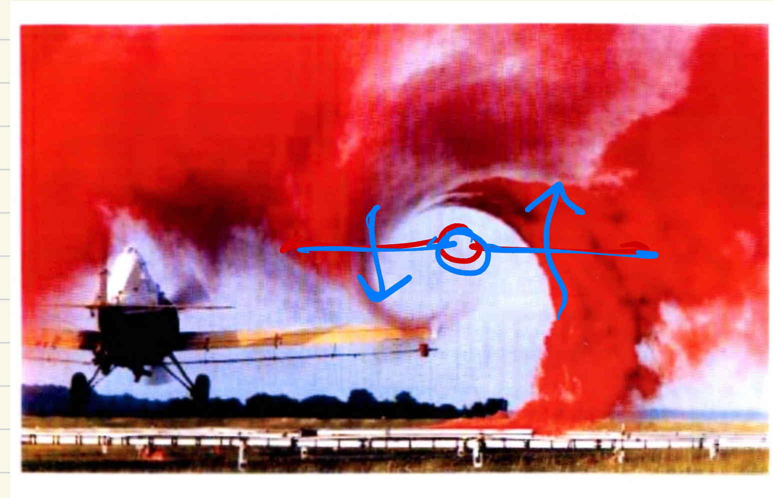
low press
p ↓

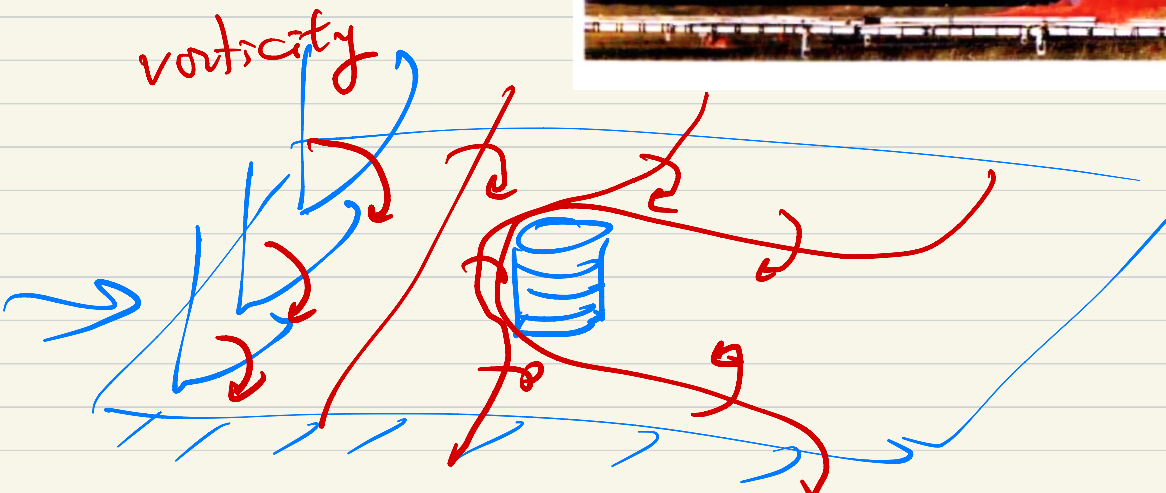




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