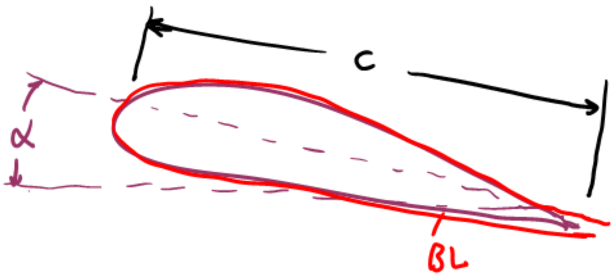
AERODYNAMIC LIFT AND INDUCED DRAG

In this lesson, we will:

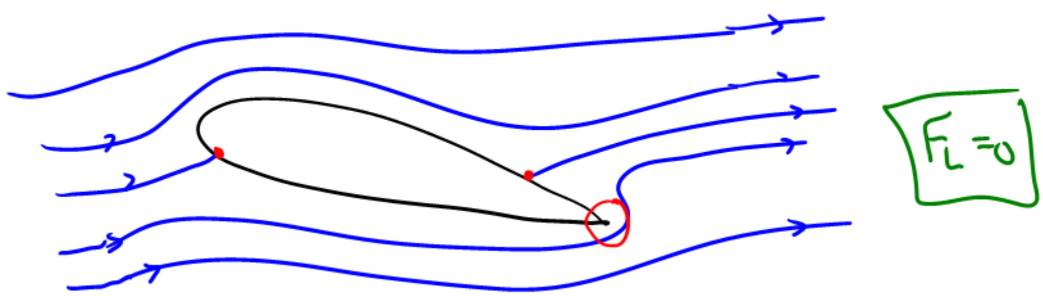
- Discuss **Aerodynamic Lift** and how to model it
- Discuss **Stall** and the purpose of **Flaps** on airplane wings
- Define **Induced Drag** and discuss its cause and how to reduce it
- Do an example problem

Aerodynamic Lift on Two-Dimensional Airfoils

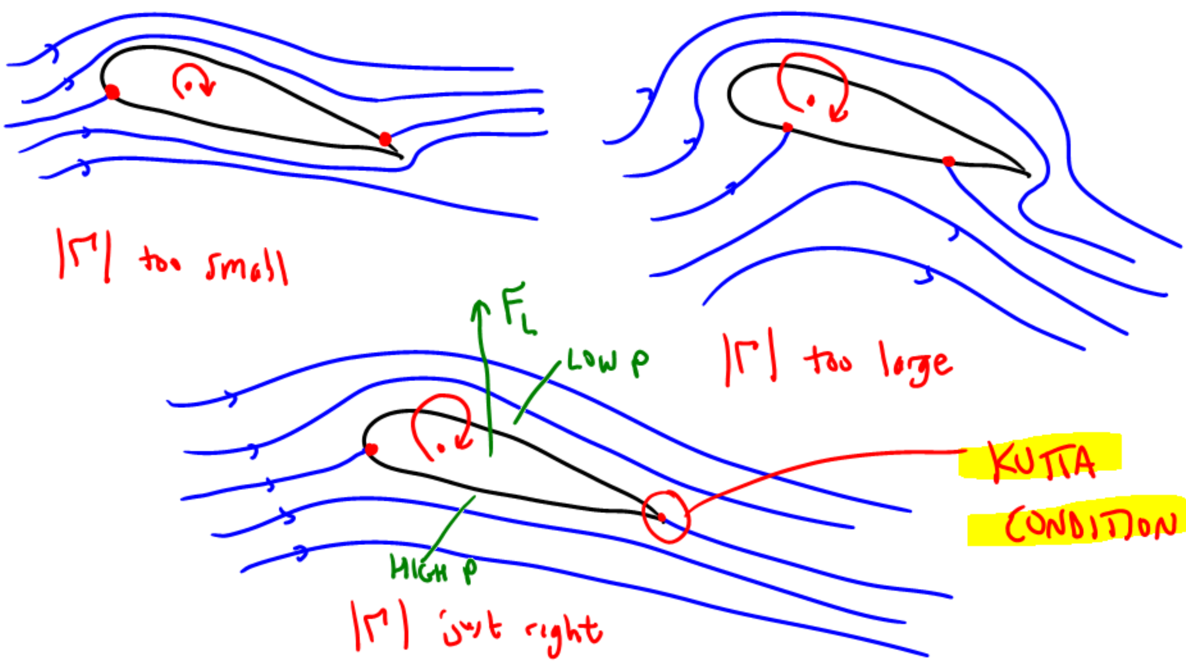


At high Re the BL thickness is extremely small

WE CAN APPROXIMATE THE FLOW OVER THE WING AS IRROTATIONAL



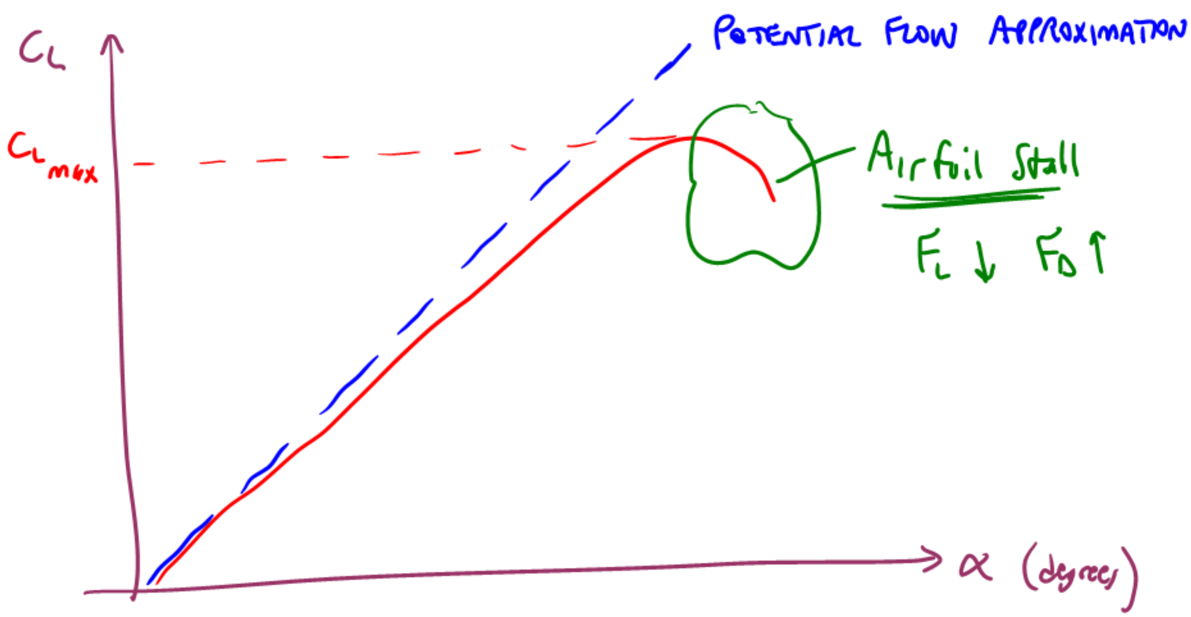
WE SUPERPOSE A LINE VORTEX (CLOCKWISE) ($\Gamma < 0$)

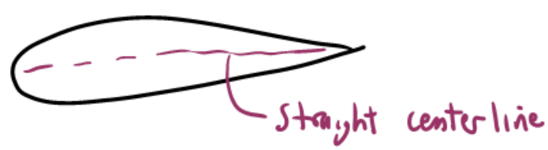


Recall

$$C_L = \text{LIFT COEFFICIENT} = \frac{F_L}{\frac{1}{2}\rho V^2 A}$$

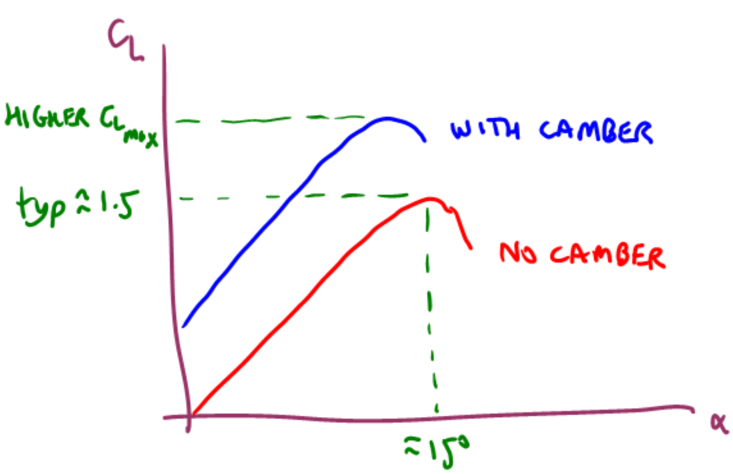
A = PLANFORM AREA



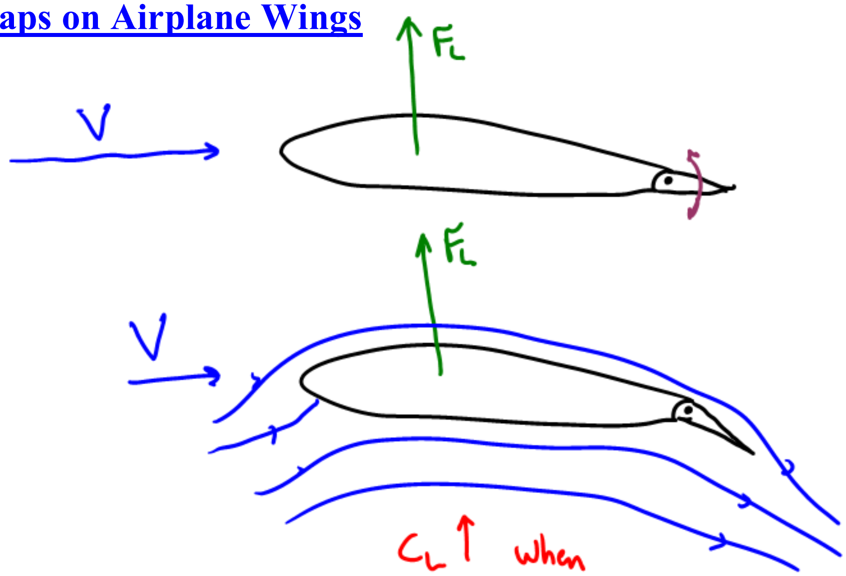


NO CAMBER

NON-ZERO CAMBER



Flaps on Airplane Wings



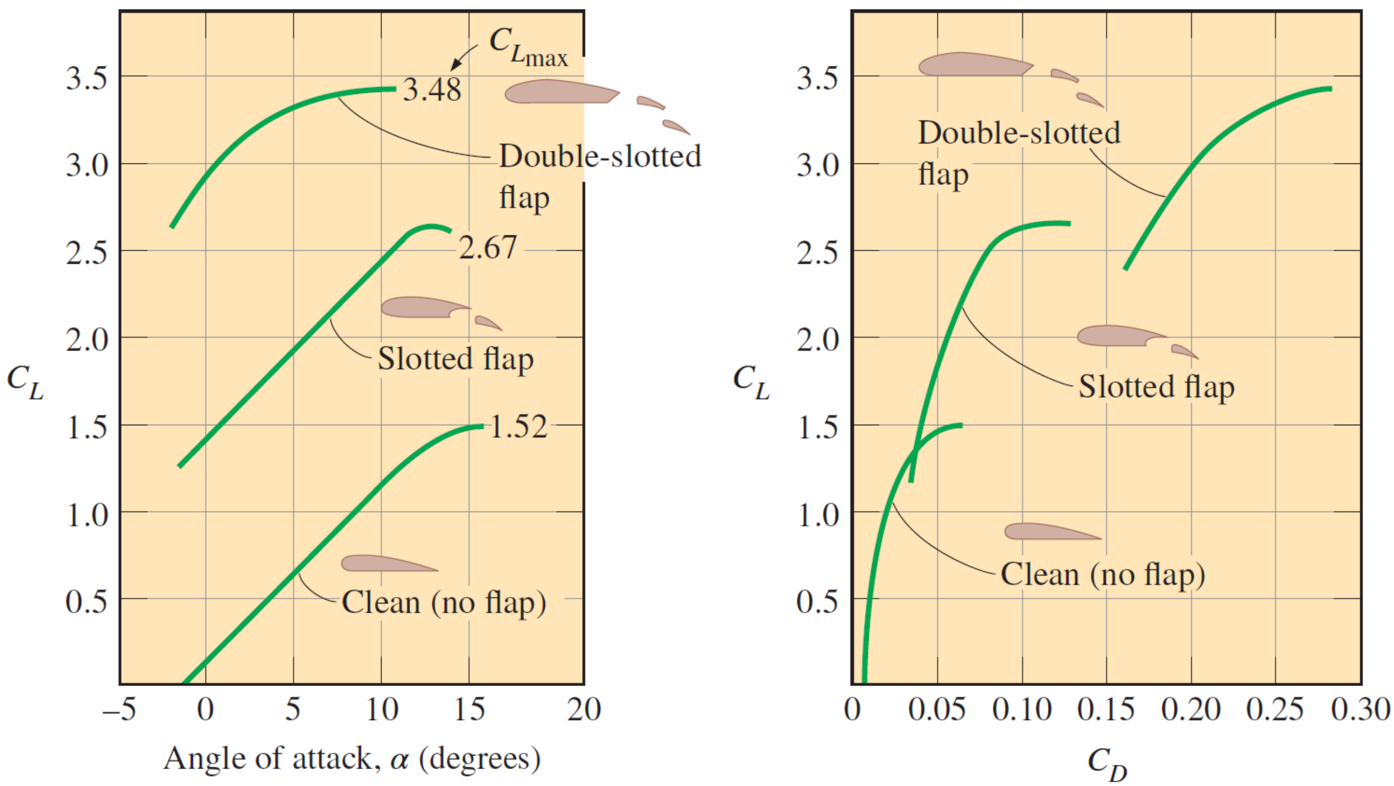
FLAP STRAIGHT FOR CRUISING FLIGHT

FLAP DOWN FOR TAKEOFF & LANDING

$C_L \uparrow$ when flap is down like this

C_D also $\uparrow$ in this configuration

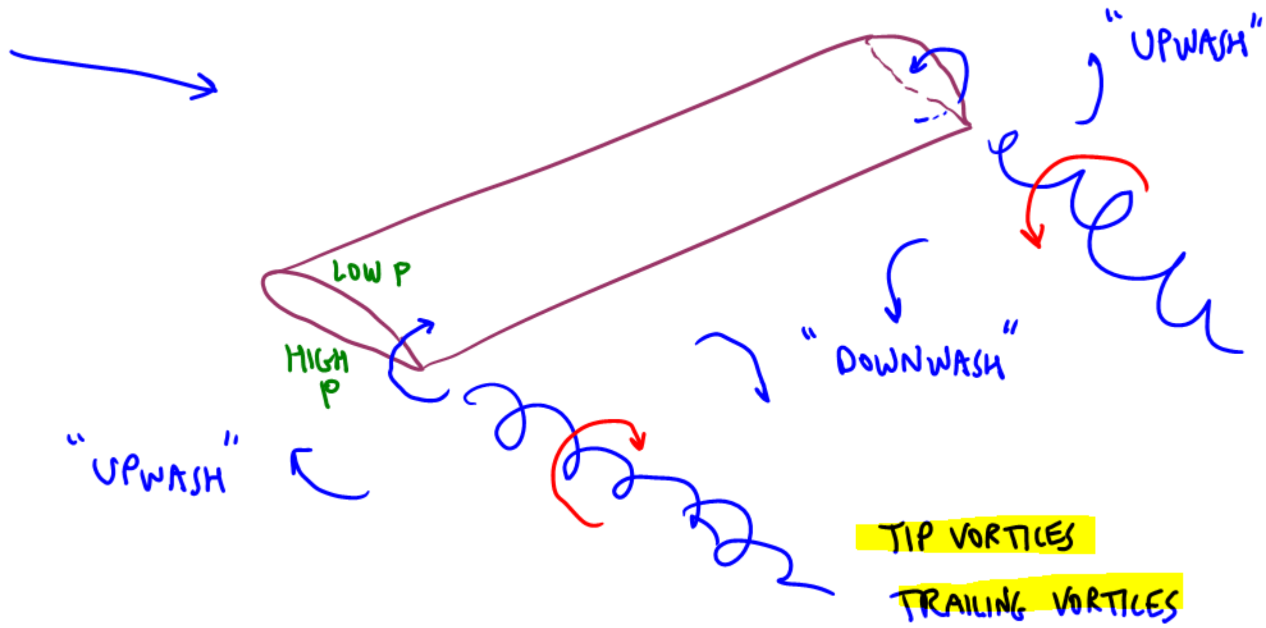
$$F_L = \frac{1}{2}\rho V^2 C_L A$$ ✱



All figures from Çengel and Cimbala, Ed. 4.

Three-Dimensional Wings and Induced Drag

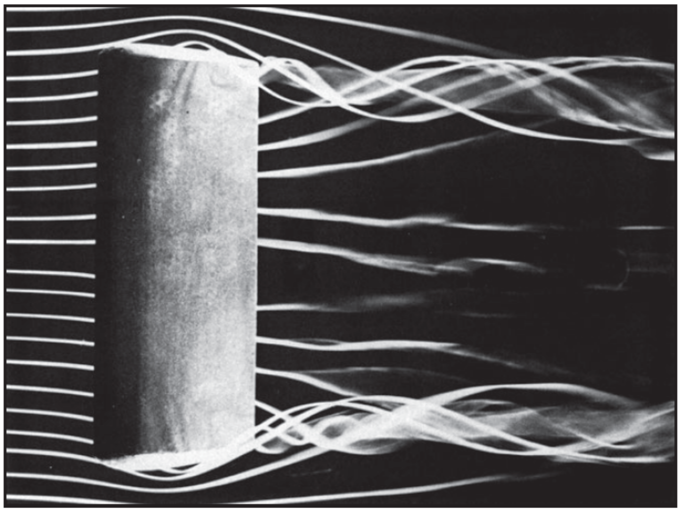
Real airplane wings have finite span (not infinite span → 2-D)



WHY ARE TIP VORTICES UNDESIRABLE?

- Reduce lift
- Increases drag **INDUCED DRAG** (drag induced by the tip vortices & wing lift)
- Persist for long distances
  - CAUSE OF NUMEROUS ACCIDENTS
  - CAUSE AIRPORT CONGESTION (reason we must wait between takeoffs)

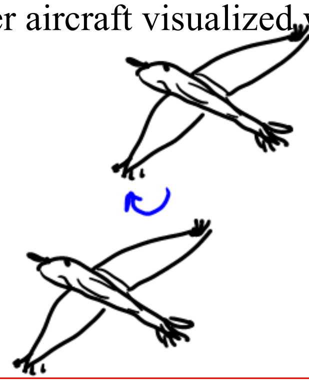
Examples of Trailing Vortices



Smoke streaklines showing tip vortices.

Four contrails merge into two trailing vortices.

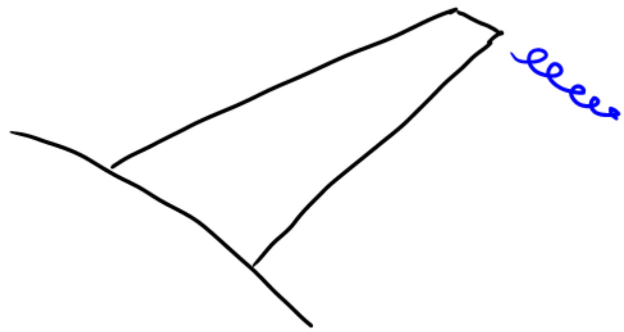
Tip vortex from a crop duster aircraft visualized with colored smoke.



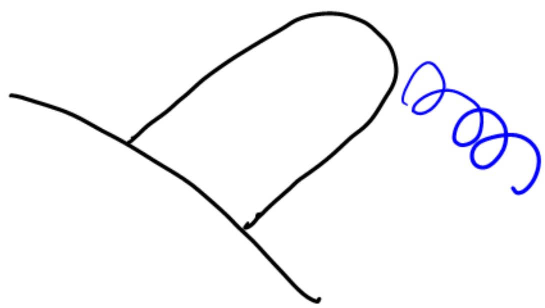
Geese and aircraft taking advantage of the upwash from the trailing vortices

How to Reduce Tip Vortices

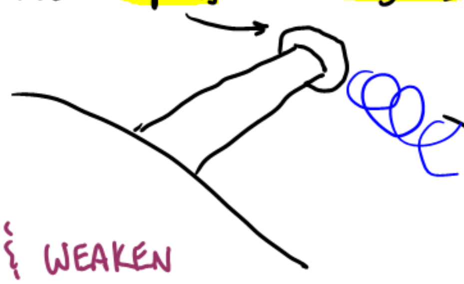
- Taper the wings

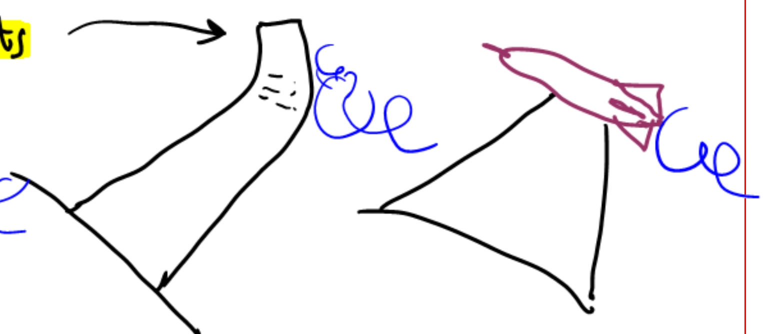


- Round off the tips



- Add endplates or winglets





DISRUPT & WEAKEN THE TIP VORTICES — REDUCE INDUCED DRAG

Winglets on a sailplane.

Bald eagle with fanned-out wing tip feathers.

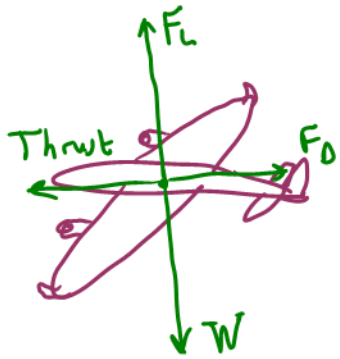
Example: Minimum Aircraft Speed to Avoid Stall at Takeoff

Given: A commercial passenger airplane is taking off from a runway. Here are some values:

- Total airplane mass at takeoff is 62,120 kg
- Planform area of the wings is 142.5 m^2
- Air density is 1.158 kg/m^3
- Maximum lift coefficient is 1.81

To do: Calculate the minimum airplane speed to avoid stall while taking off.

Solution:



At constant cruising speed,

$$\sum \vec{F} = 0$$

$$\therefore F_L = W$$

$$F_D = \text{Thrust}$$

At takeoff, $F_L \approx W = mg$

$$C_L = \frac{F_L}{\frac{1}{2}\rho V^2 A} \Rightarrow F_L = \frac{1}{2}\rho V^2 C_L A$$

$$V_{min} = \sqrt{\frac{2mg}{\rho C_{L,max} A}}$$

★ ANS IN VARIABLES

$$V_{min} = \sqrt{\frac{2(62{,}120 \text{ kg})(9.807 \text{ m/s}^2)}{(1.158 \frac{\text{kg}}{\text{m}^3})(1.81)(142.5 \text{ m}^2)}} = 63.9 \frac{\text{m}}{\text{s}}$$

V_{min} ★:
63.9 m/s
230 km/h
143 mph

- THIS IS WHY RUNWAYS ARE LONG
- IN WINTER, $\rho \uparrow$, so $F_L \uparrow$ if all else the same