Introduction to Aerodynamics for Flight

Oct 14 2008

Brown University

Outline

- What do we want from aerodynamics?
- Basic ideas from 2D
- Differences between 2D and 3D
- The importance of unsteadiness

What is aerodynamics?

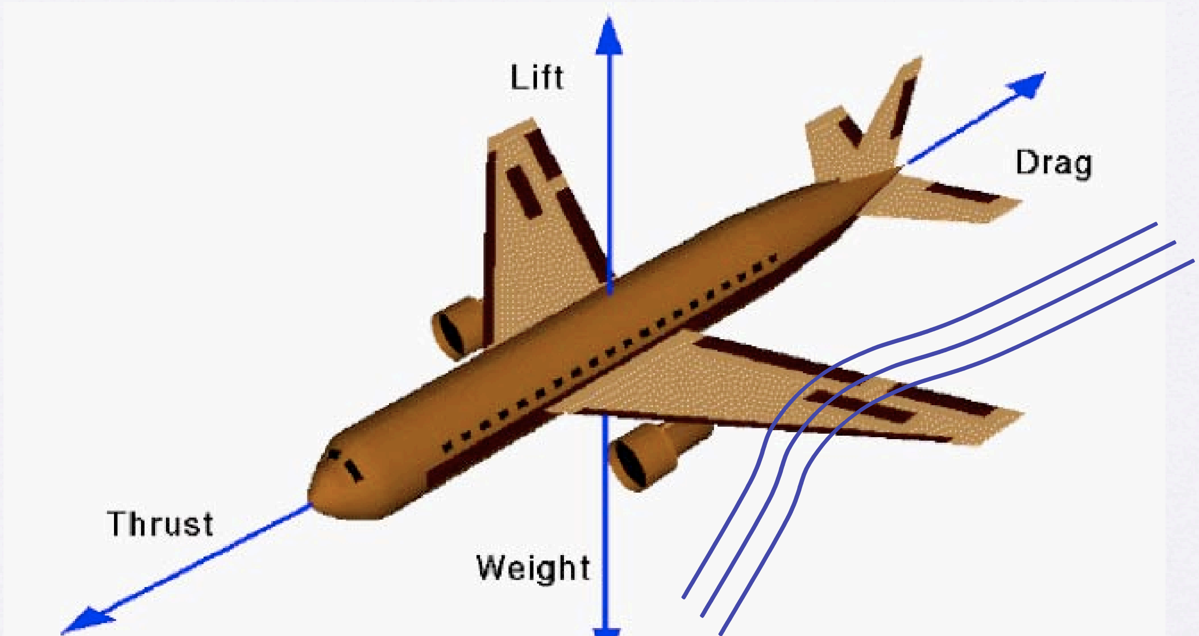
- Aero
  - Air
- Dynamics

What do we want from aerodynamics?

- Predict <u>forces</u> and <u>moments</u> on a body due to <u>motions</u> relative to <u>fluid</u>

What are the forces on an airplane?

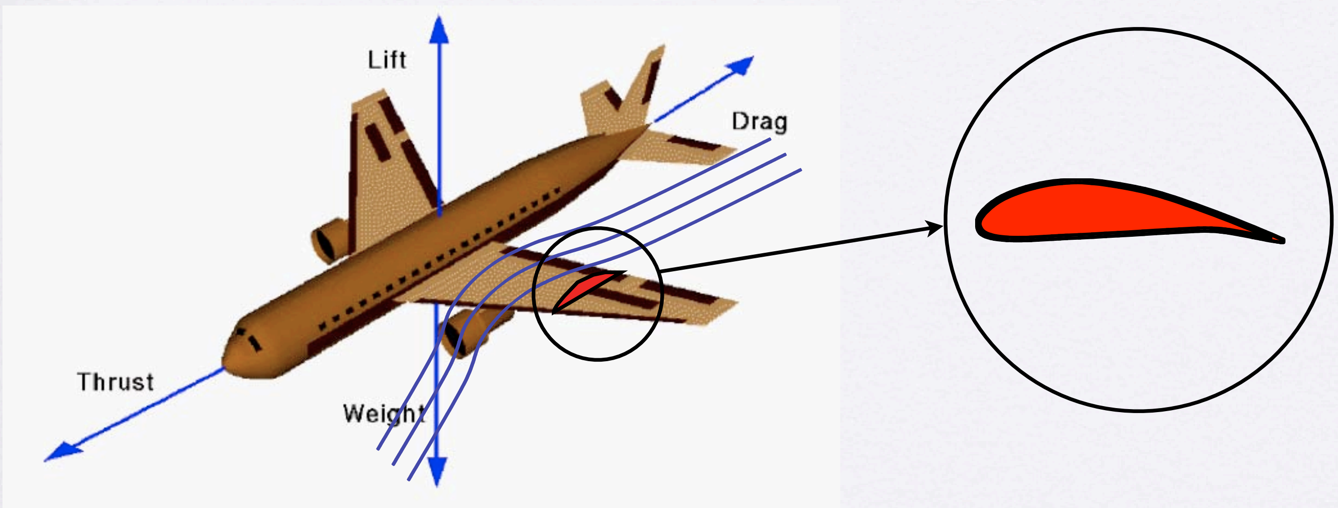
Four forces on an airplane

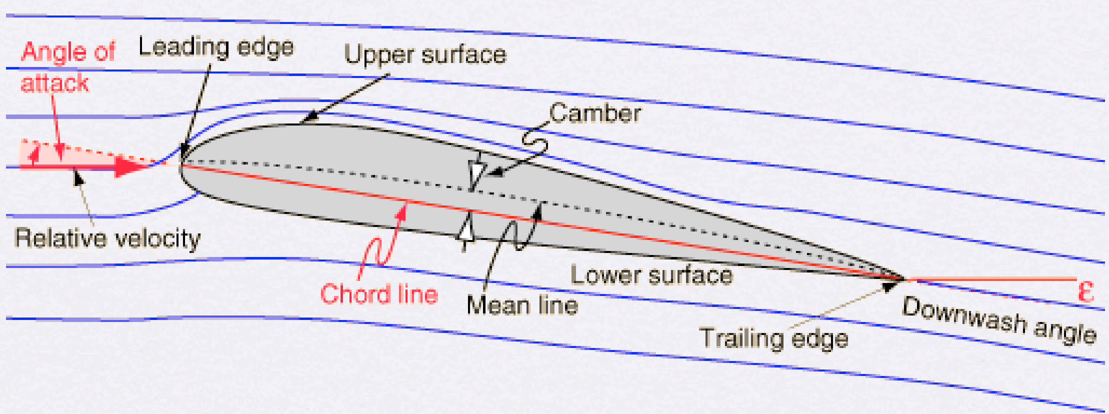


NASA Glenn Research center

What is the most important part that identifies the type, performance, and purpose of an airplane?

2D Airfoil


Lift
Drag
Thrust
Weight


Angle of
attack
Leading edge
Upper surface
Camber
Relative velocity
Chord line
Mean line
Lower surface
Trailing edge
Downwash angle
ε

Vectors

- Direction
- Magnitude

Governing principles

- Conservation of mass
- Conservation of momentum
- Conservation of energy

Physics laws nothing in nature that violates.

Thrust

Newton's 1st law

applied to airplanes

Isaac Newton
(1643-1727)

- "Every object persists in its state of rest or uniform motion in a straight line unless it is compelled to change that state by forces impressed on it."

If Thrust == Drag, airplane holds constant airspeed
If Thrust ↑ , airspeed ↑ , then drag ↑
When Drag == thrust, airplane holds a new, higher constant airspeed

Newton’s 2nd law

applied to airplanes

Isaac Newton
(1643-1727)

- *Force* = mass * *acceleration*

Excess Thrust = Thrust - Drag
Forces on the fluid causes acceleration

Lift

- What cause it?
- How to explain it?

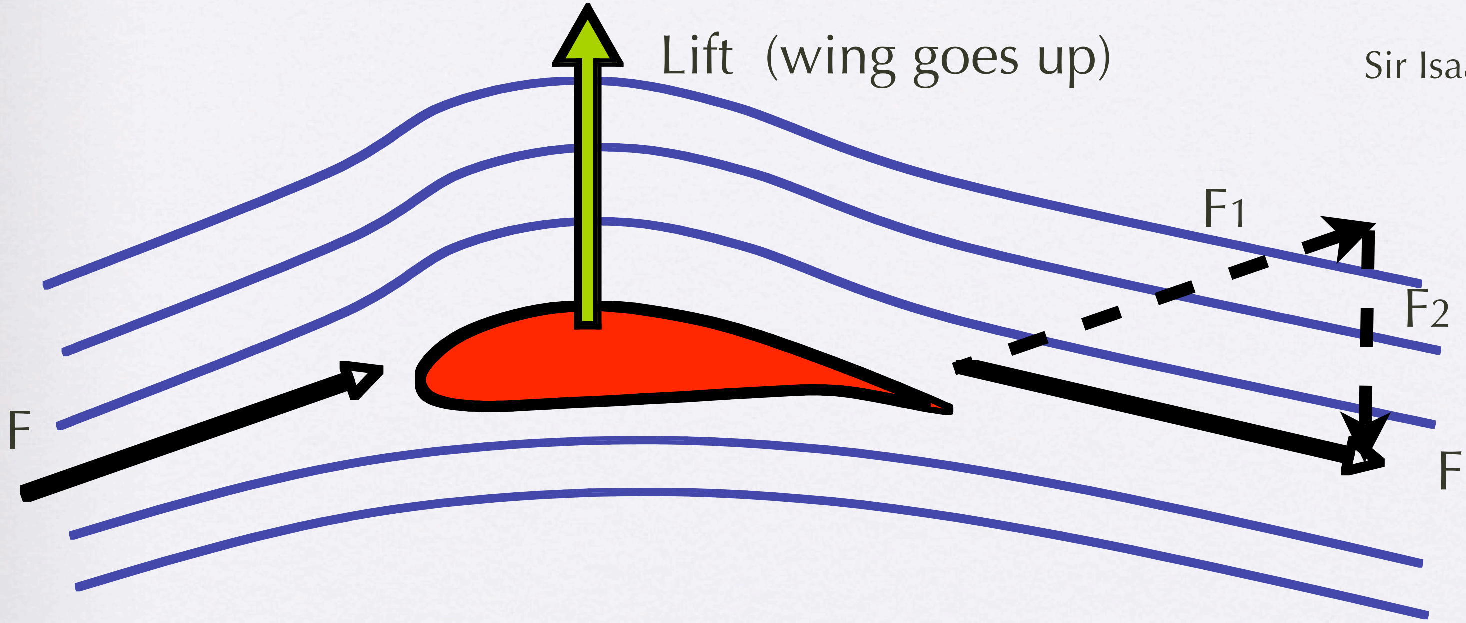
Air and motion

Newton's laws
Bernoulli's principle

Motion effects on lift (1)

- Change in momentum


Sir Isaac Newton



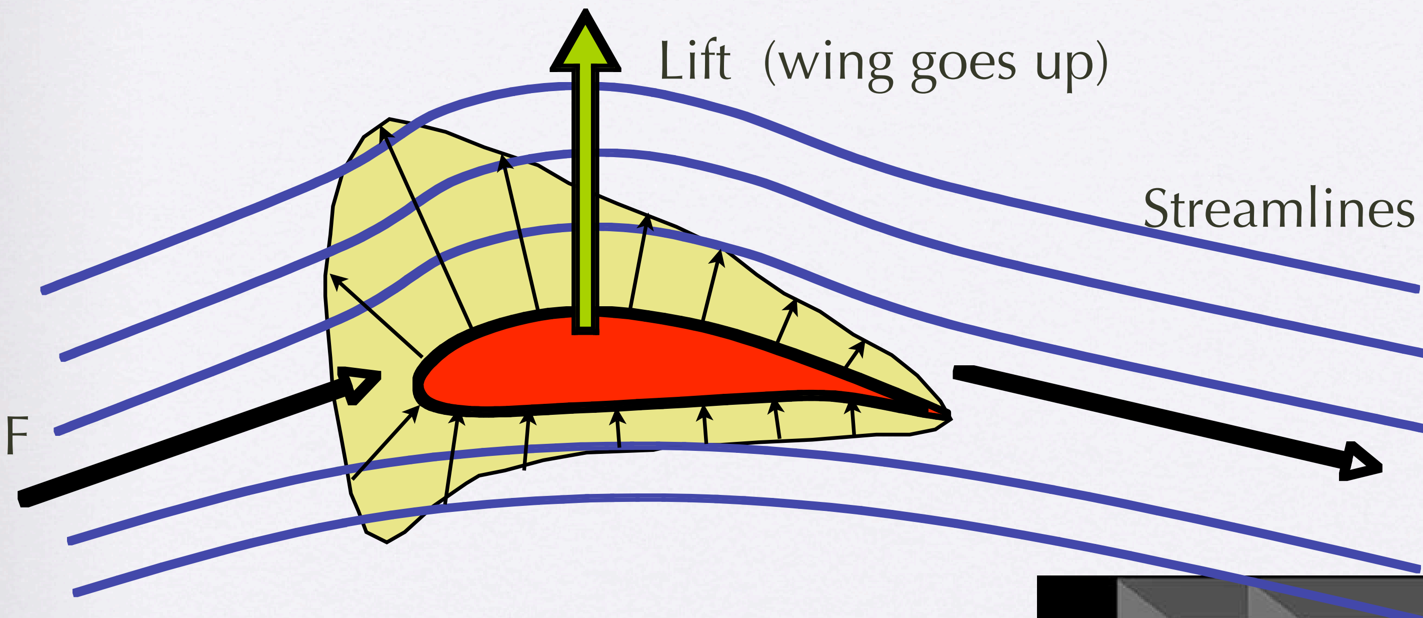
Force causes a change in velocity which in turn generates another force.

For every action , there is an equal reaction.

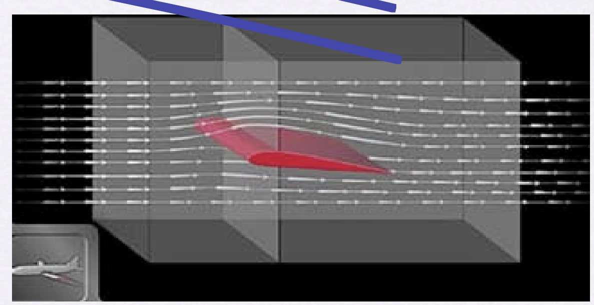
Conservation of momentum (m * v)

Motion effects on lift (2)

- Pressure difference

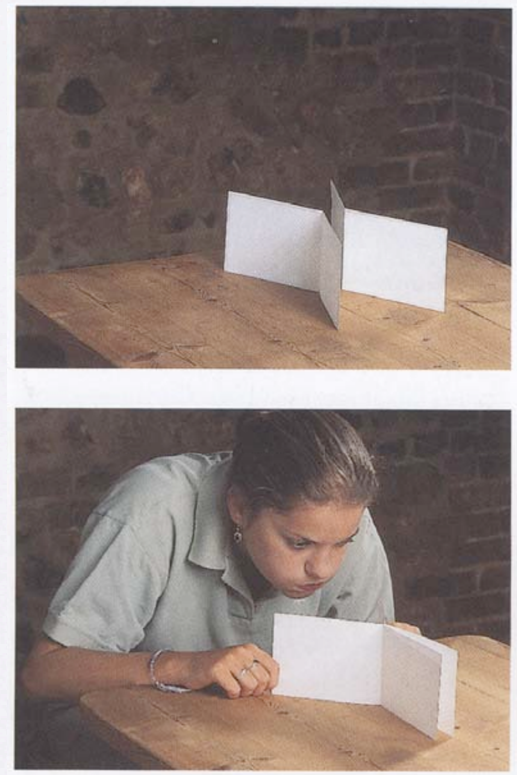



Issac Newton



Faster flow = lower relative pressure

- The speed of a fluid is directly related to pressure

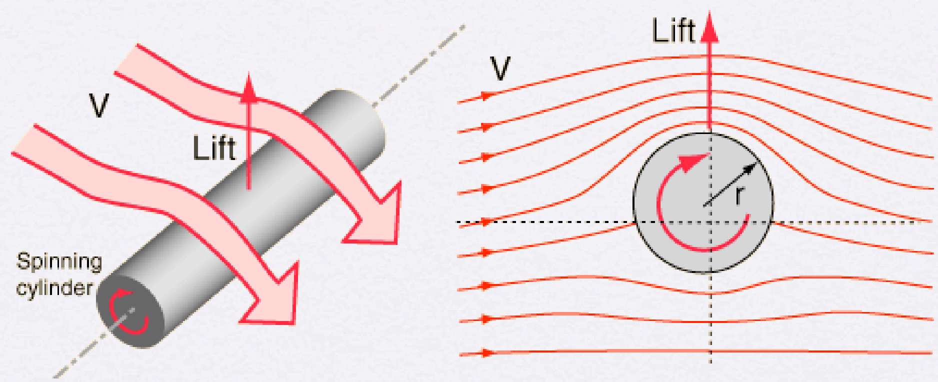


Bernoulli's principle is demonstrated by blowing between two sheets of paper.

Conservation of energy
(Energy: the capacity for doing work)

Motion effects on circulation (3)

- Circulation



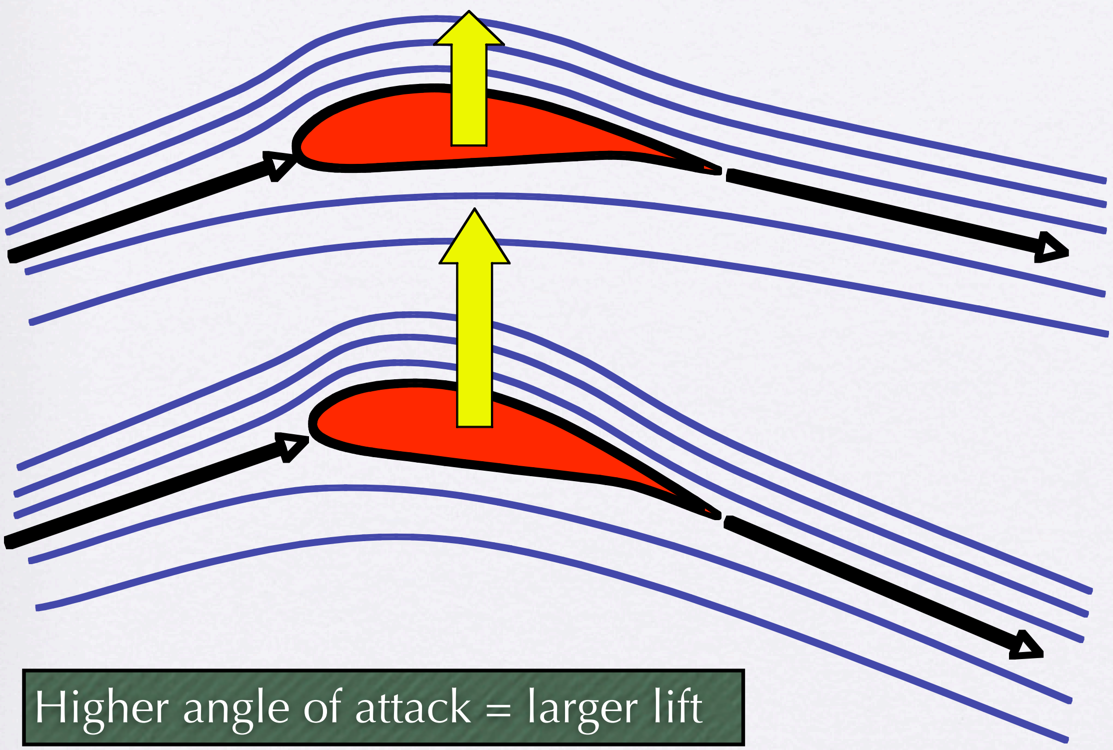
Conservation of angular momentum

Kutta-Joukowski lift theorem

http://hyperphysics.phy-astr.gsu.edu/

Shape causes lift (1)

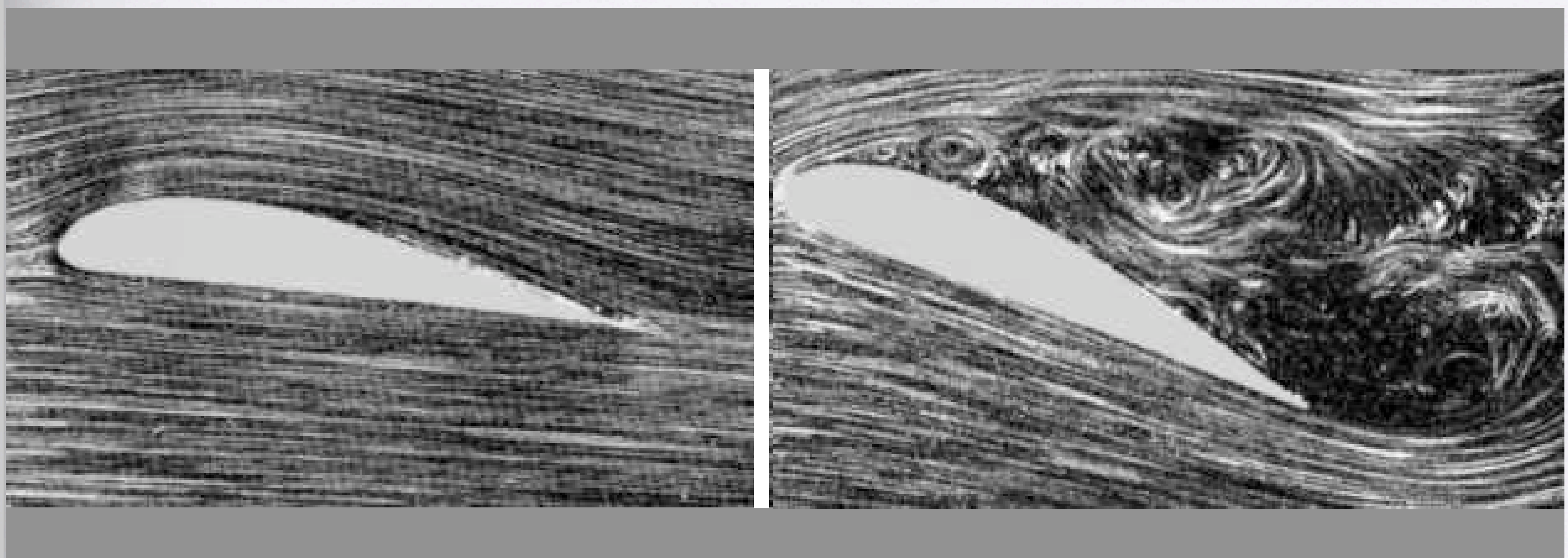
- Angle of attack



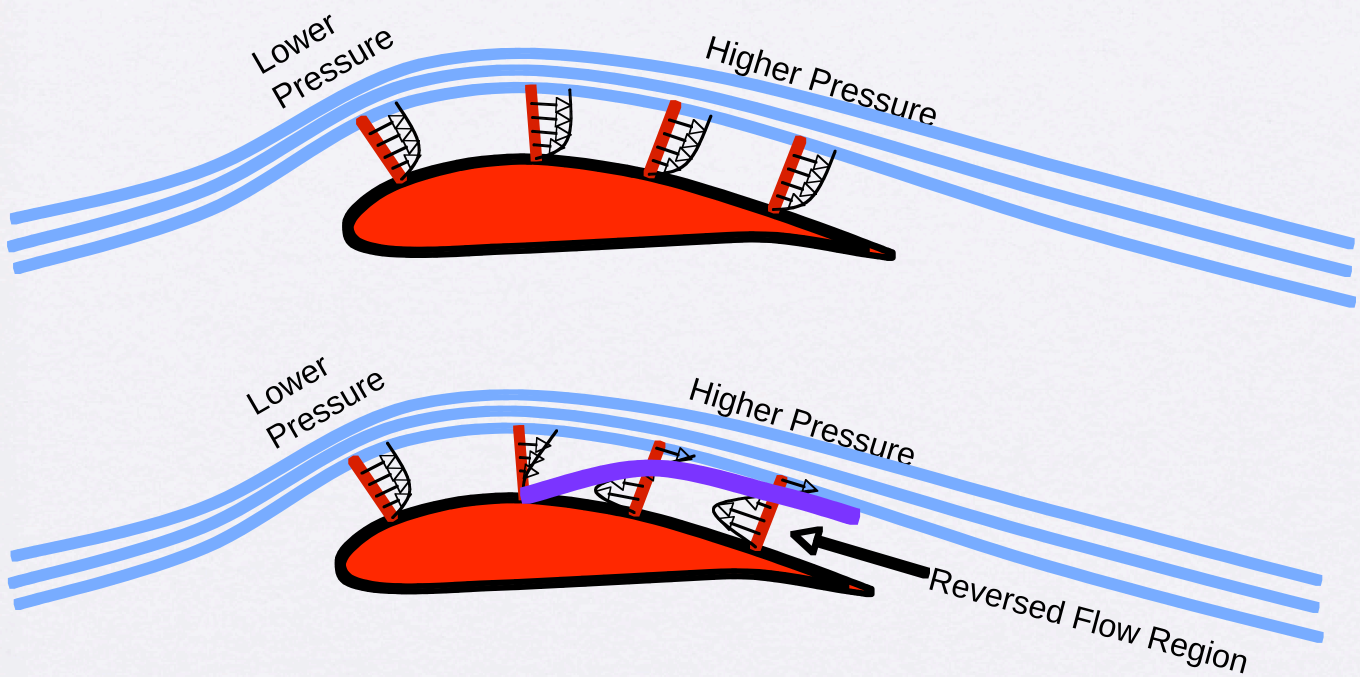
Higher angle of attack = larger lift

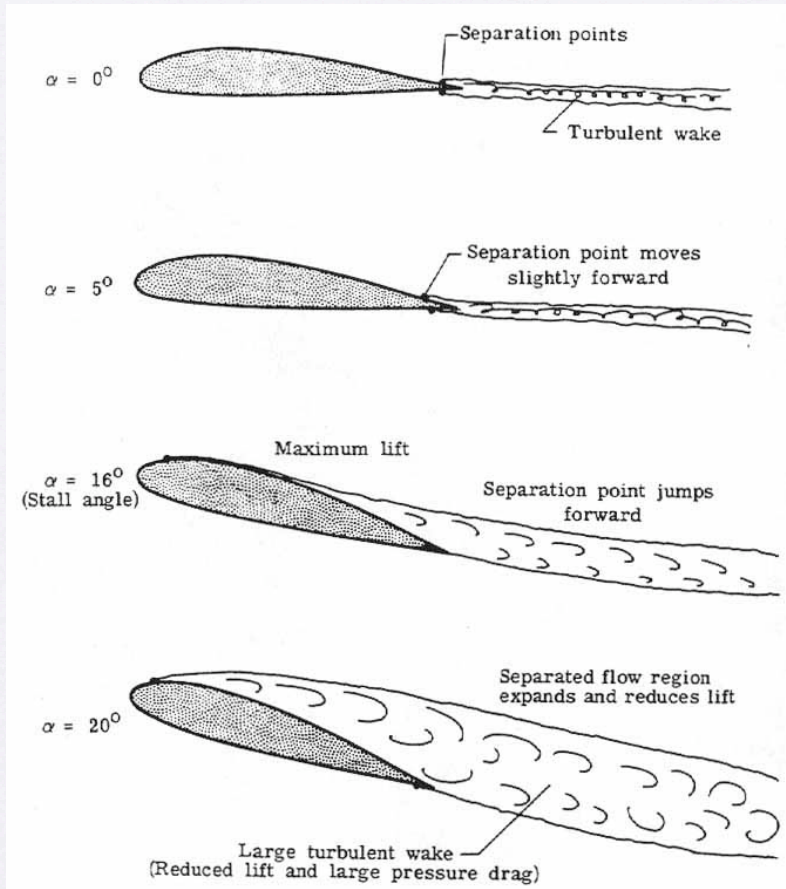
But ...

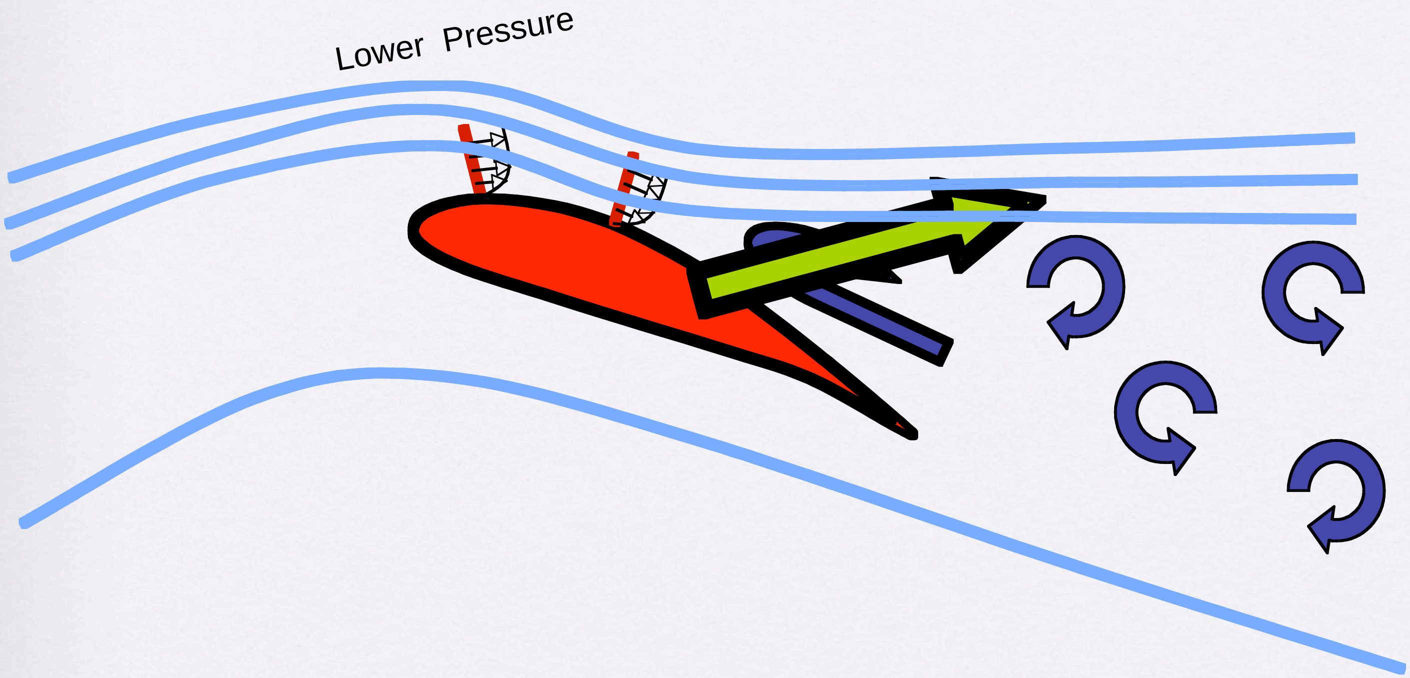
Stall and Separation!



What causes Separation?

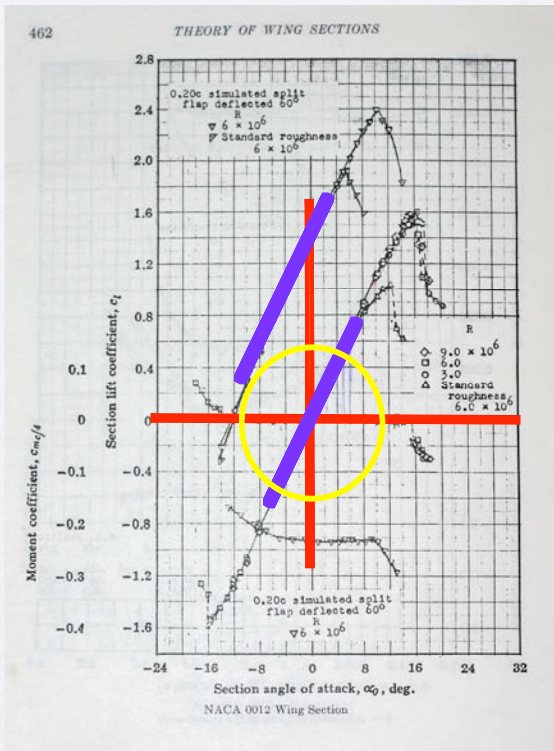


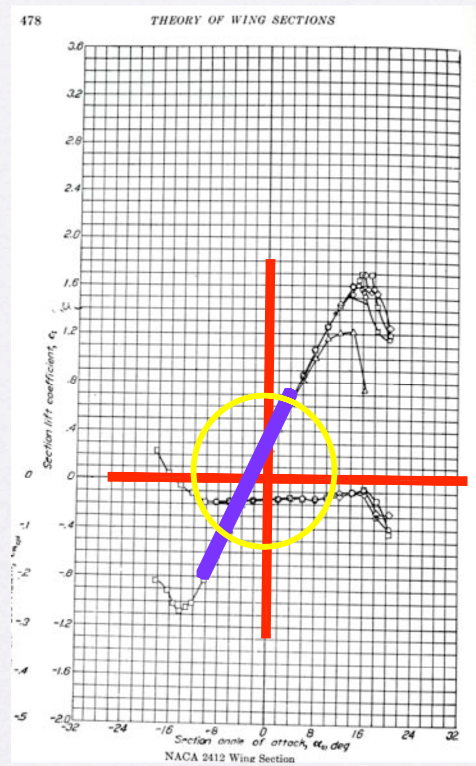

Separation points
α = 0°
Turbulent wake
Separation point moves
slightly forward
α = 5°
Maximum lift
α = 16°
(Stall angle)
Separation point jumps
forward
Separated flow region
expands and reduces lift
α = 20°
Large turbulent wake
(Reduced lift and large pressure drag)



Lower Pressure

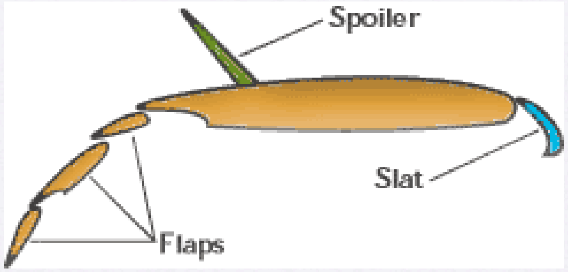
Camber in Actual Airfoils





Design of an airplane is an Art
(alternative ways to increase lift)

- Camber augmentation (Splat, flap, spoiler)



Factors that affect Lift

- Air
    - Mass, viscosity, compressibility
- Motion
    - velocity and inclination to flow
- Object
    - Shape and size

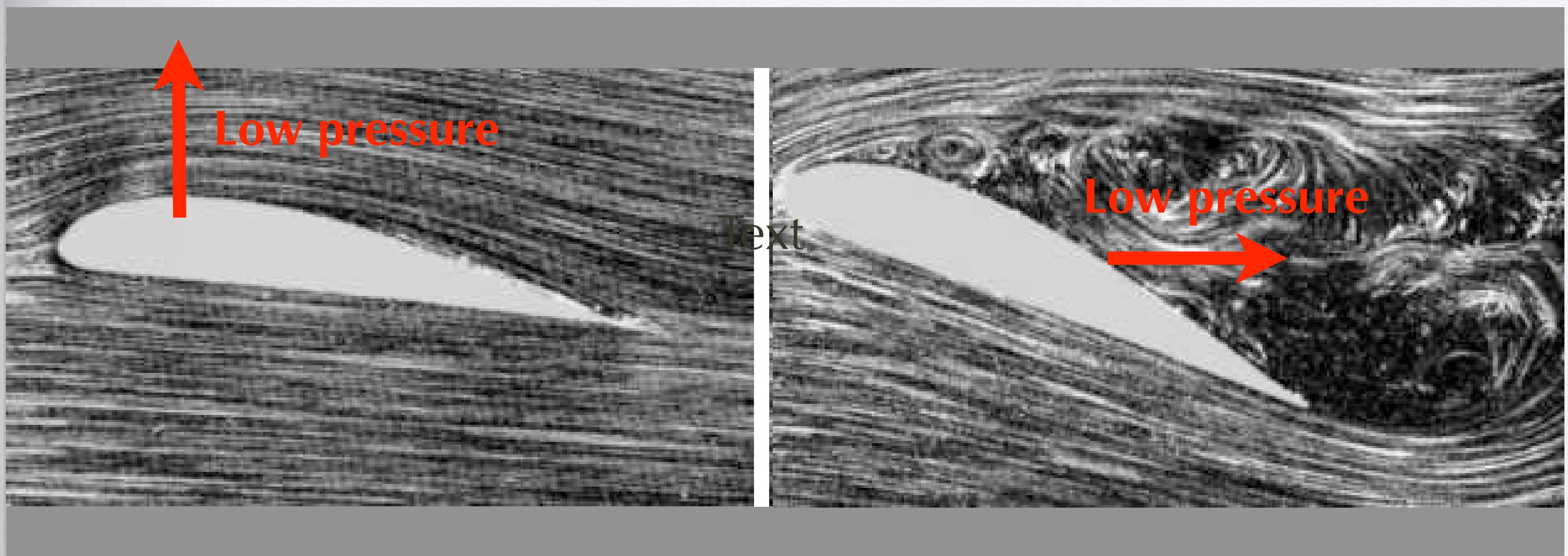
Governed by Newton's laws and Bernouli's equation

Drag

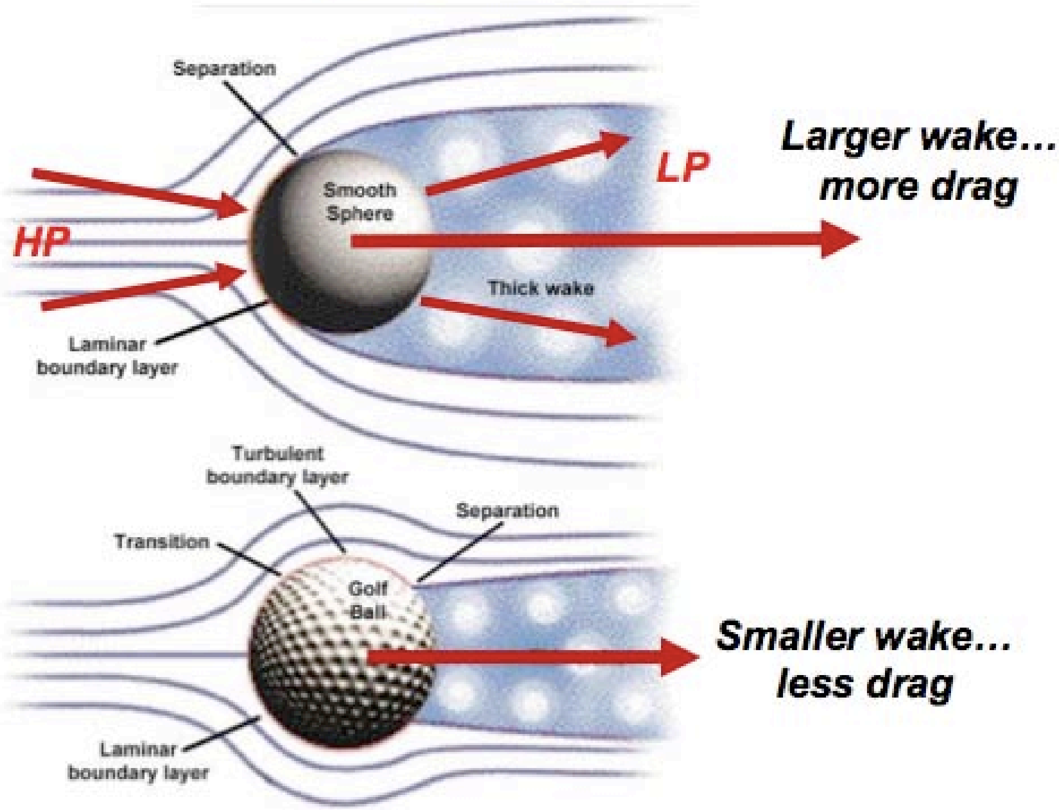
- A force of resistance when an aircraft moves through the air.
- We want to minimize it.

Separation!

- Pressure

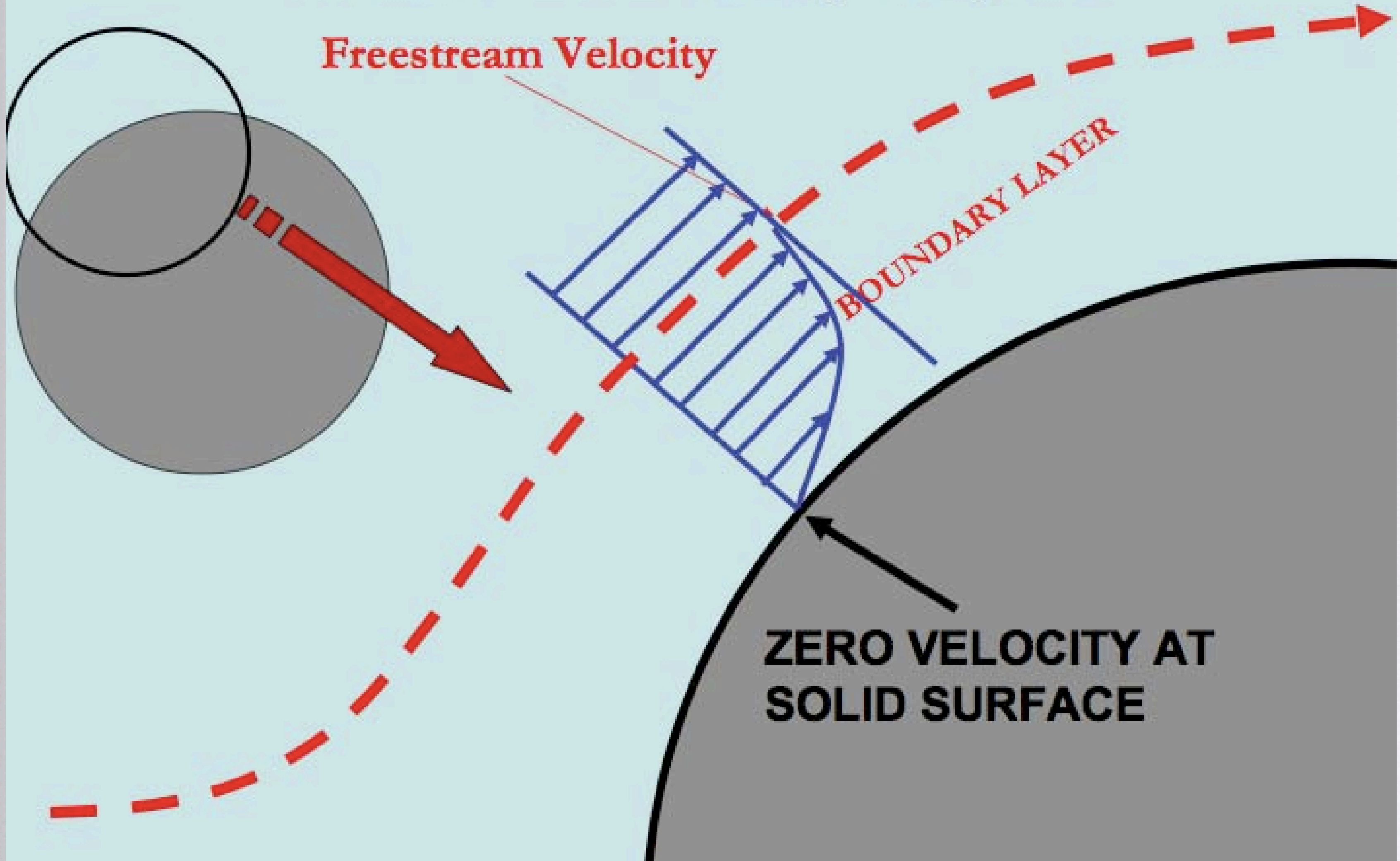


Separation and Boundary Layer Type



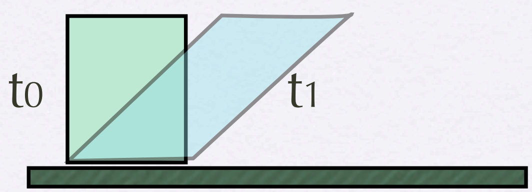
http://www.aerospaceweb.org/question/aerodynamics/sports/sphere-flow-comparison.jpg

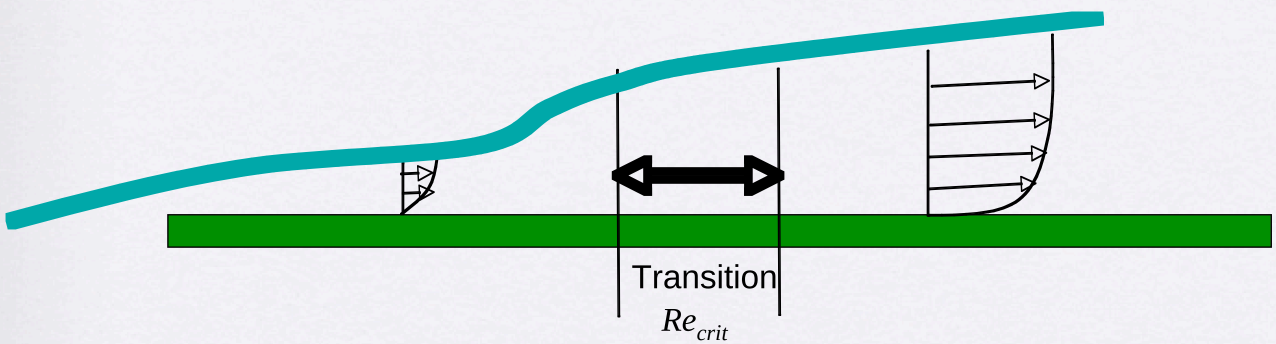
Aside: Boundary Layers



Friction Drag

- Turbulence vs. Laminar Boundary Layers





Viscosity

Drag

- Pressure / Form Drag
    - Delayed separation in Turbulent flow (less drag)
    - Early separation in laminar flow (more drag)
- Friction Drag
    - Low for Laminar flows
    - High for turbulent flows

Reynolds Number

$$Re = \frac{\text{Inertia force}}{\text{Viscous force}} = \frac{\text{Fluid Velocity *Length}}{\text{Viscosity}}$$

- Predication of laminar vs. turbulent flow
- Defines dynamic similarity

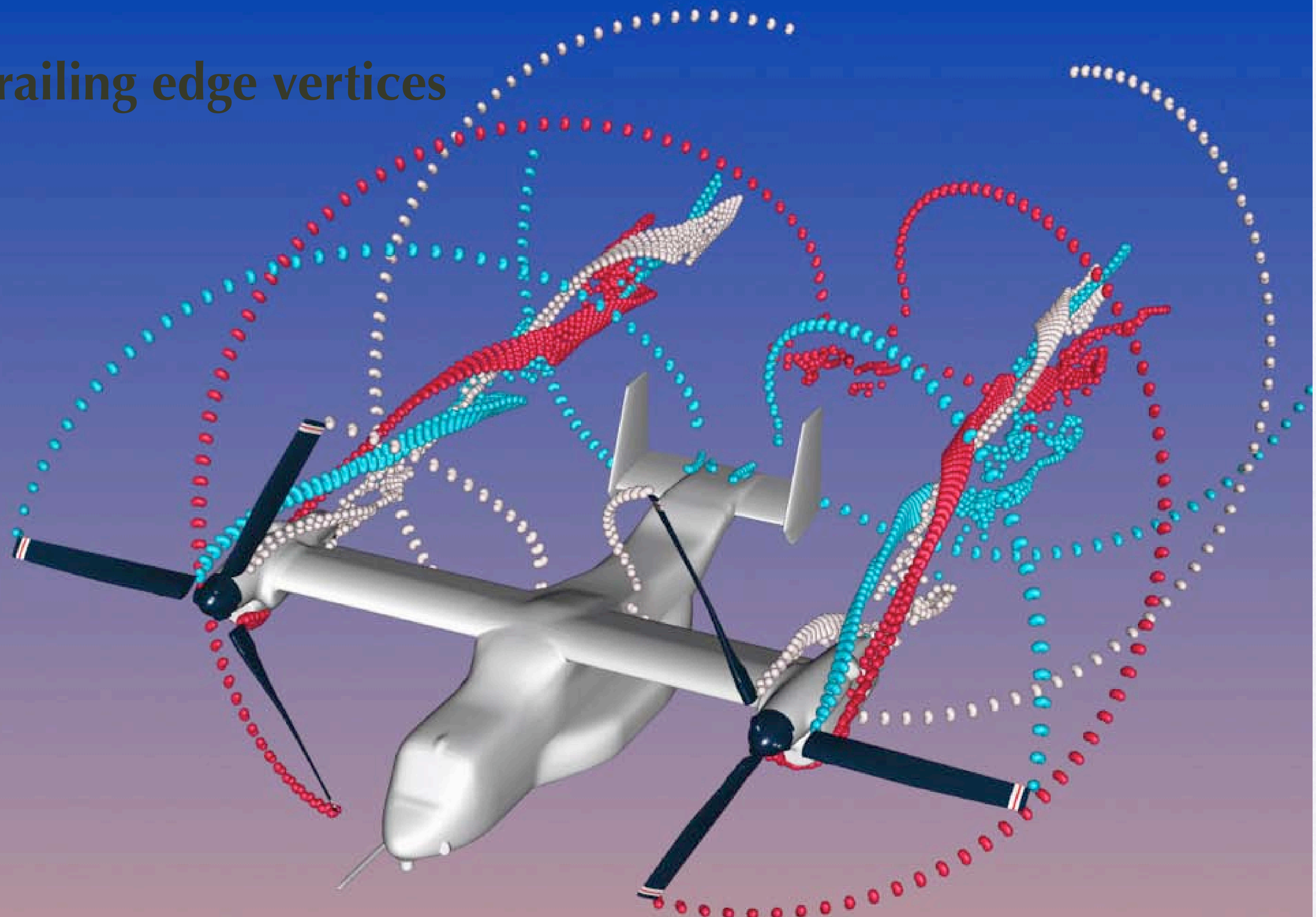
Blood flow in brain: ~100
Blood flow in aorta: ~1000

Typical pitch in Major League Baseball: 200,000
Person swimming: 4000,000
Blue Whale: 300,000,000
A large ship: 5000,000,000

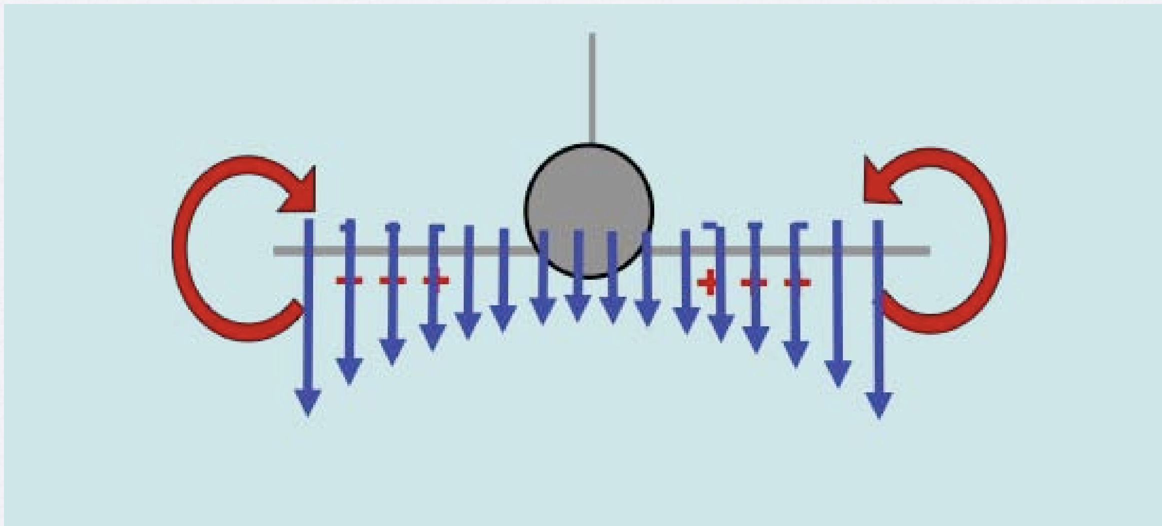
From 2D to 3D

What is missing from our discussion? What assumption did we make about the geometry of the wing?

Trailing edge vertices



Downwash Introduces Drag

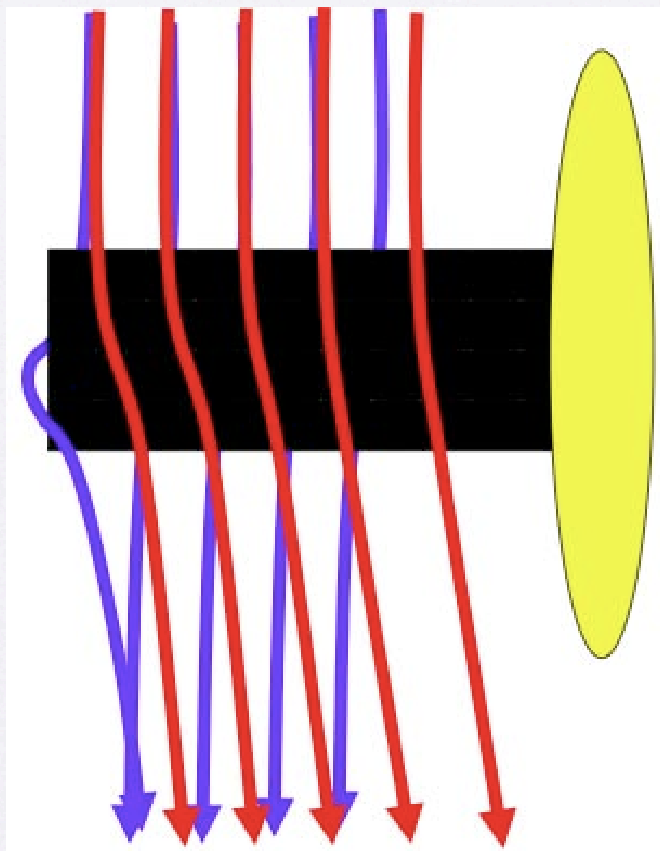


Flow from the lower side (higher pressure) wants to 'leak' to the low pressure side of the wing.

Starts from wing tip

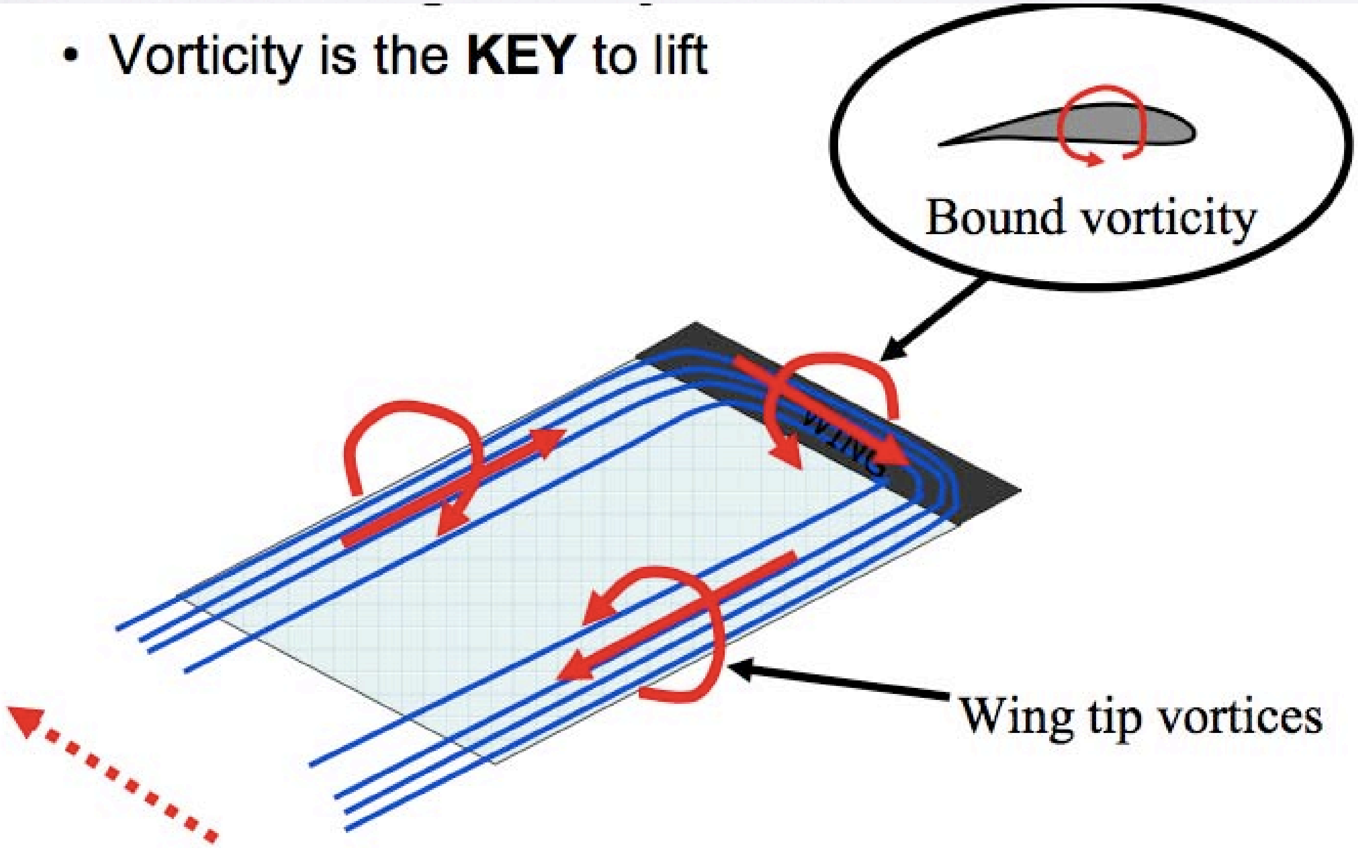
Vorticity from trailing edge

Vorticity

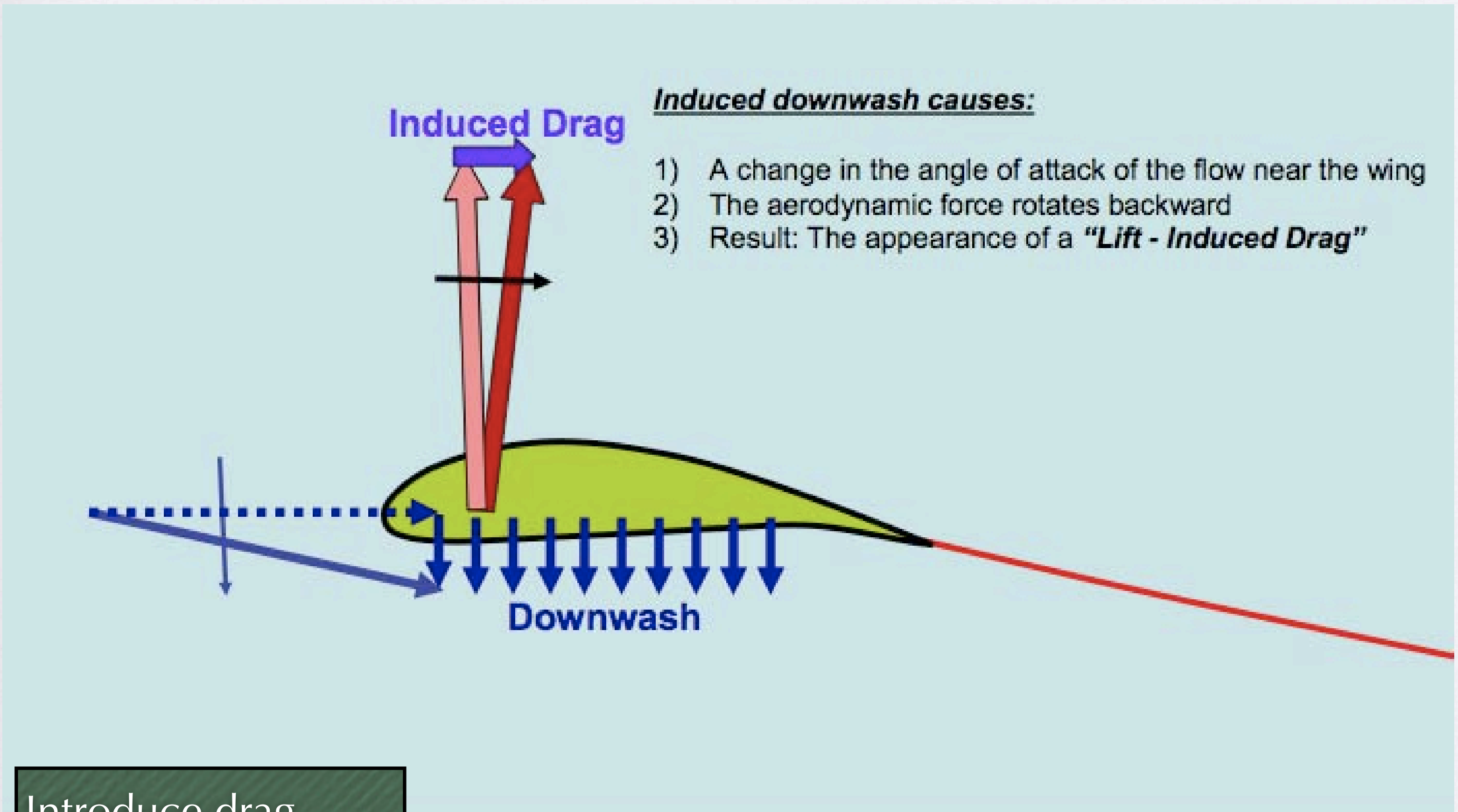


Lifting Body Problems

- Vorticity is the **KEY** to lift

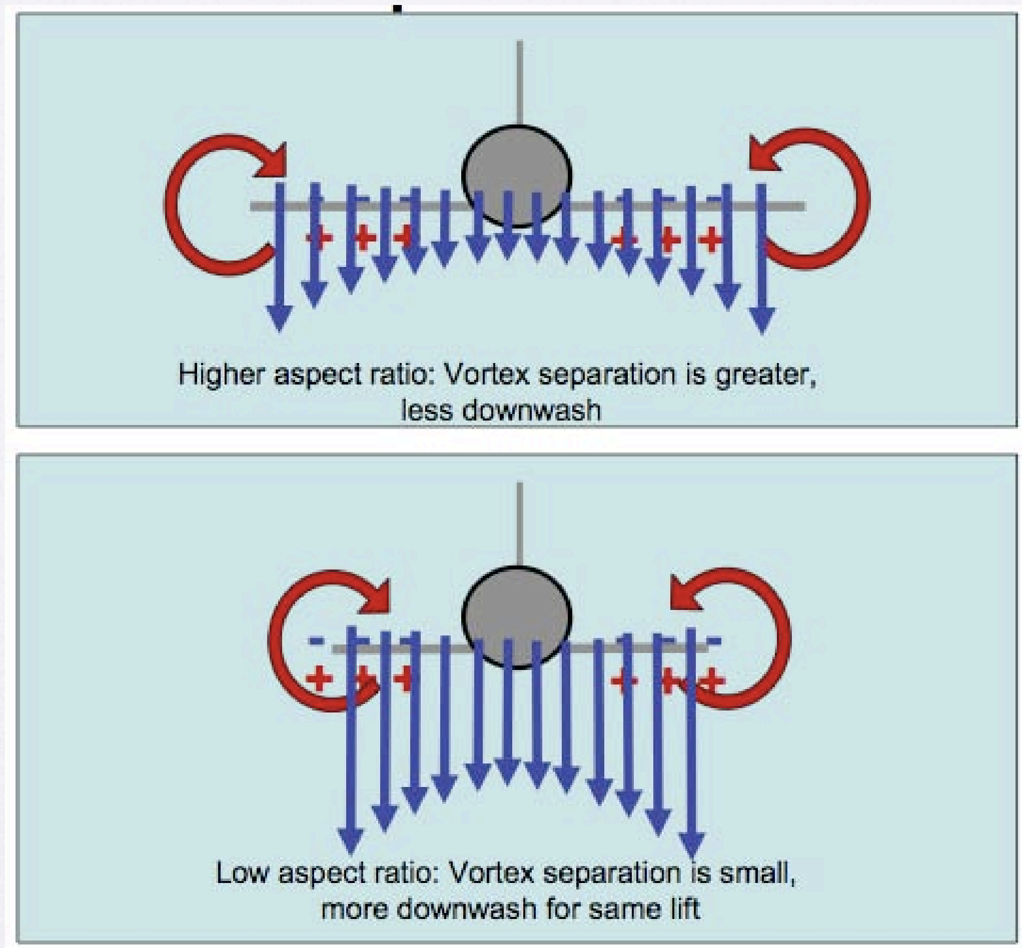


Ramifications of Downwash

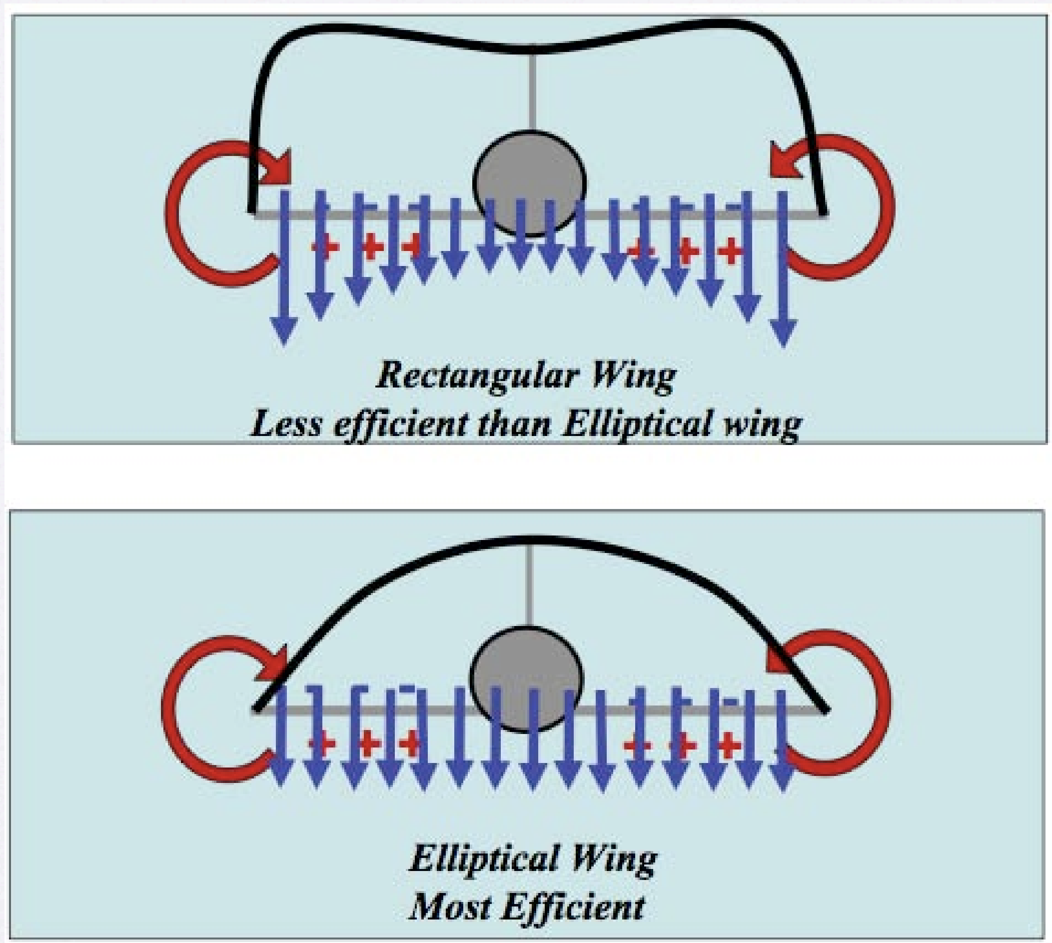


Introduce drag
Reduce lift

Aspect Ratio



Oswarld's efficiency

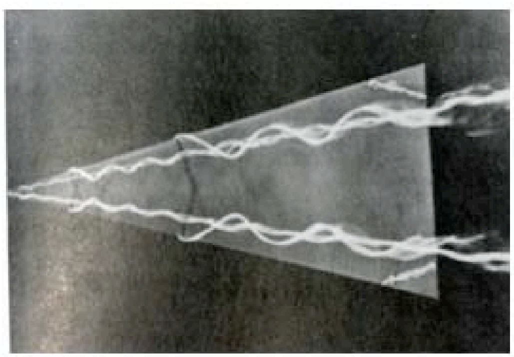


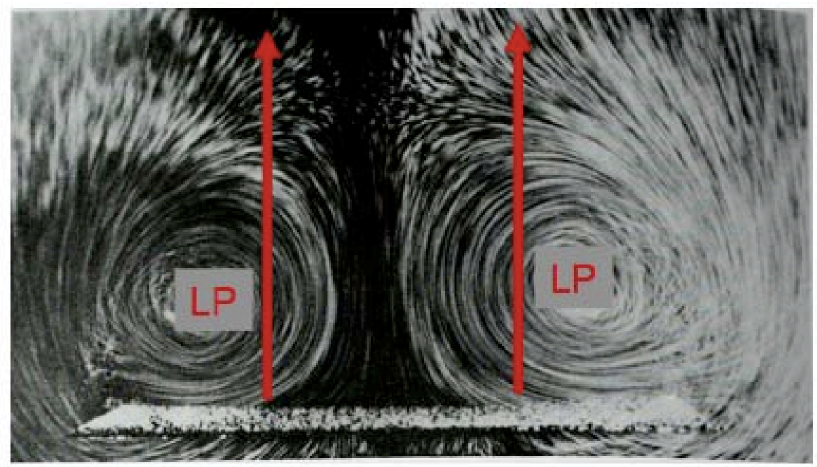
Lift Distribution

- For level flight, minimum induced drag occur when the lift distribution is elliptical
  - Either the wing shape is elliptical, or
  - The incidence angle produces an elliptical lift

Other 3D Effects

- LEV's. Vortex induced lift.





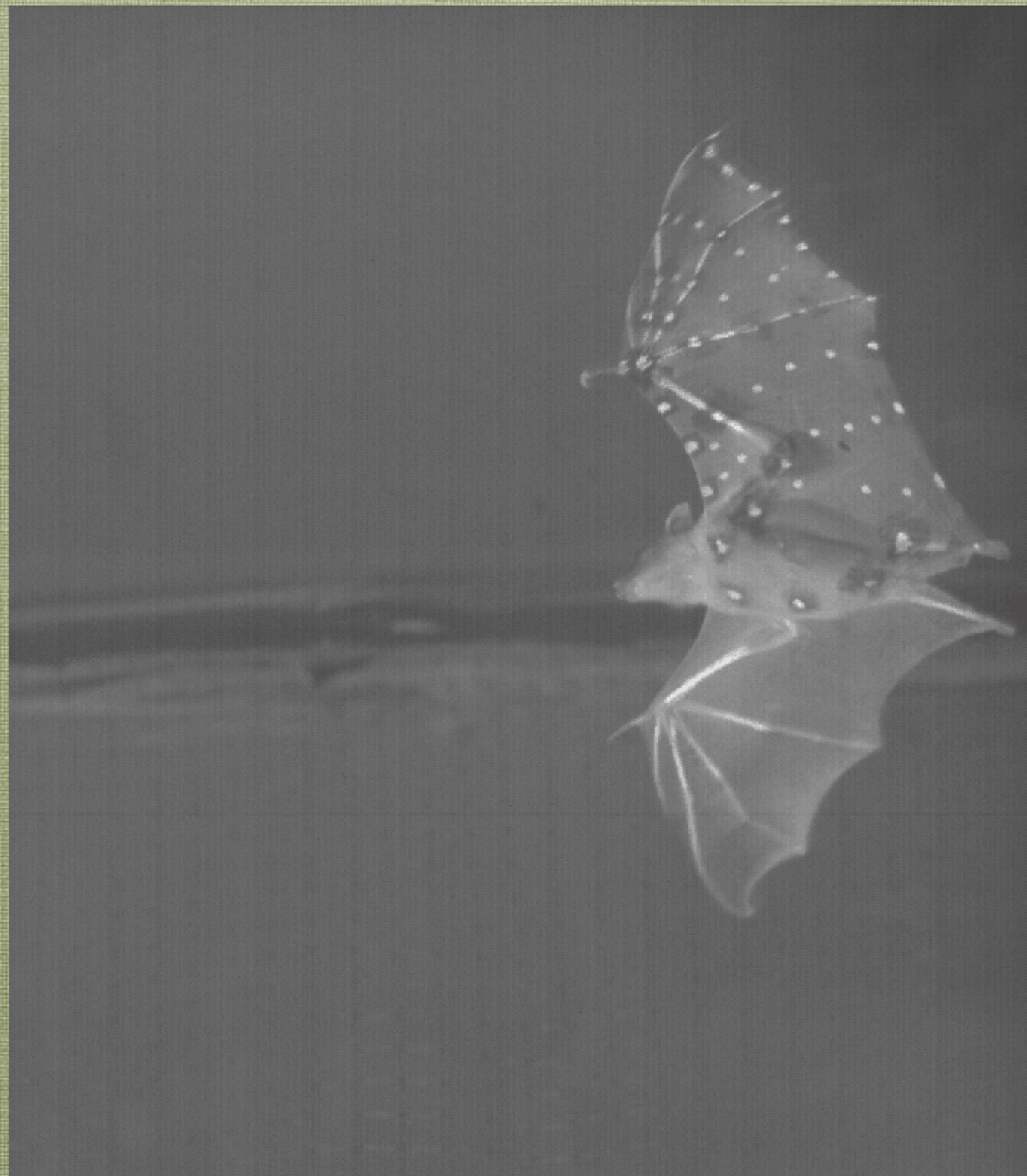
Summary

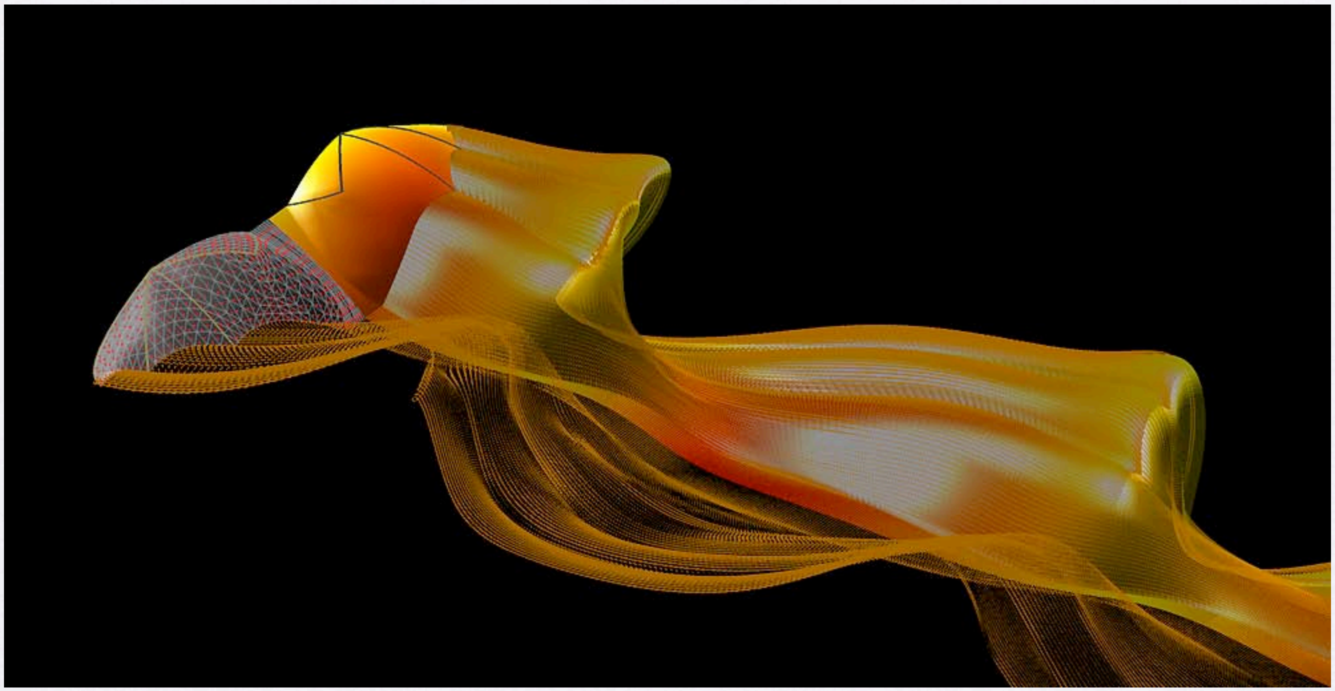
- Four forces
- Momentum
- Reynolds number (steady, un-steady flow)
- 2D vs. 3D

- Dave Willis: “so what?! we got all this lift / drag etc. Garbage!”

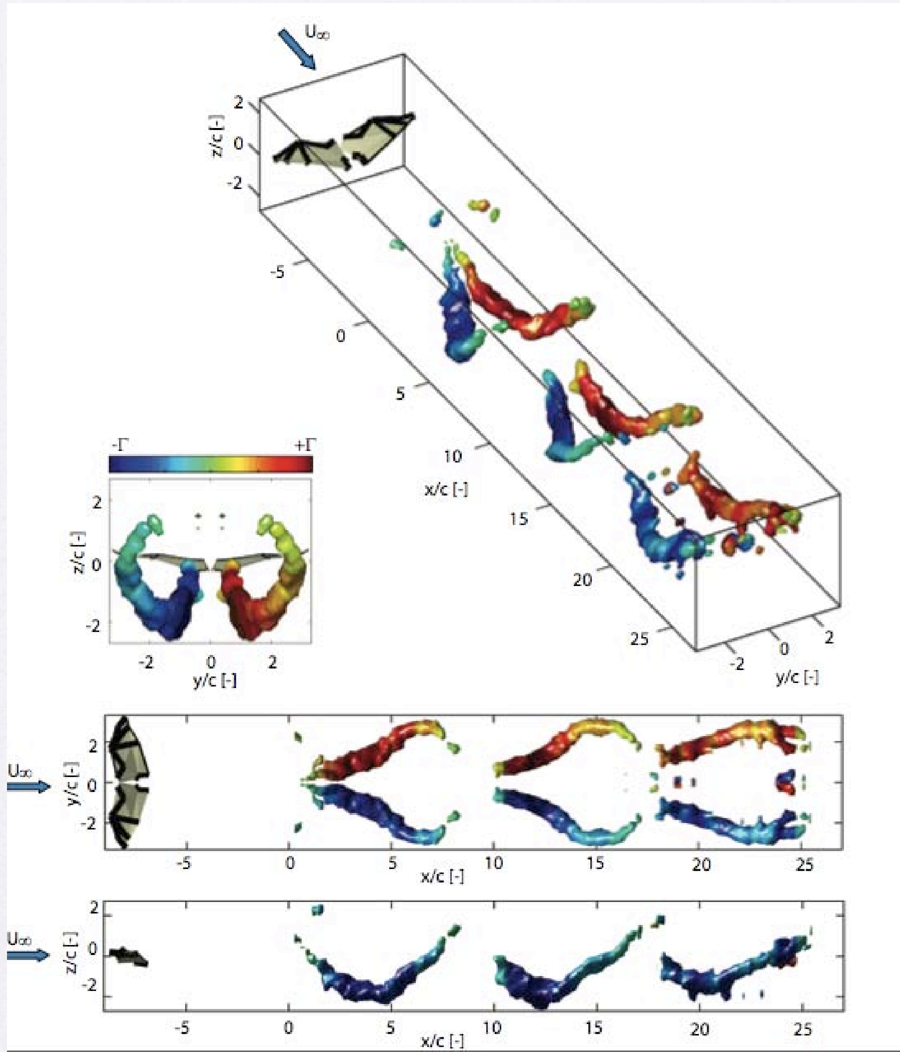
How to use the knowledge to:

- Design an airplane
- Study bats flight kinematics and flow wakes
- Conduct visual design





FastAero Bat flight simulation, Dave Willis et al.



Tatjana Hubel et al.

Conclusion

- Physical conservation principles to gain insights into fluid flow
- Trailing edge vortices play important role
  - Reduces lift and increases drag
- Unsteady effects are complicated due to vorticity distributions and added mass acceleration effects.

Acknowledgment

- David Willis (U Ma. Lowell)
  - for his slides from last year and many pretty pictures
- Tatjana Hubel (Brown)
  - for her suggestions on this presentation

Love in Looking and Comprehension is the Nature's Most Beautiful Gift.

- Albert Einstein