Fluid Mechanics

or

"Back by popular demand!"

Paul Pounds

23 April 2013

University of Queensland

But first…

Some house keeping

Calendar at a glance

Week	Dates	Lecture	Reviews	Demos	Assessment submissions
1	25/2 – 1/3	Introduction			
2	4/3 – 8/3	Principles of Mechatronic Systems design			
3	11/3 – 15/3	Principles of Sailing			Design brief
4	18/3 – 22/3	Sensor Fusion and Filtering	Progress review 1		
5	25/3 -29/3	Your Soldering is Terrible			
Break	1/4 – 5/4				
6	8/4 – 12/4	3D printing	Progress seminar		
7	15/4 – 19/4	Image Processing on Microcontrollers		25% demo	
8	22/4 – 26/4	Fluid mechanics			
9	29/4 – 3/5	Q&A	Progress review	50% demo	
10	6/5 – 10/5	Q&A			
11	13/5 – 17/5	Q&A		75% demo	Preliminary report
12	20/5 – 24/5	Q&A			
13	27/5 – 31/5	Closing lecture		Final testing	Final report and addendum

You are here →

Precipitous!

Progress reviews next week

- You all know the drill now
  - 4 minutes to show 3 weeks progress
- Tutors are instructed to be merciless
  - You must present **EVIDENCE** of your work
  - We will not take your word for it
  - Pass/fail caps will be enforced
- Session sign-ups open this evening and run until Sunday night
  - Get in early if you can’t make just any session!

End of lecture schedule

- Changing to Question and Answers sessions
  - This will be the last by-request lecture topic
  - If you have particular questions about a topic, come see me one on one and we'll go through it
- Meeting at the same time, same place
  - Start with usual announcements/house-keeping
  - If numbers are low, segue to Wordsmiths ~9:10

FAQ Roundup

- **How terrified should we be?**
  - Not too terrified. Enough time remains in the semester to do a good job.

- **How many fans will there be?**
  - Two to four fans, depending on need.

Onwards

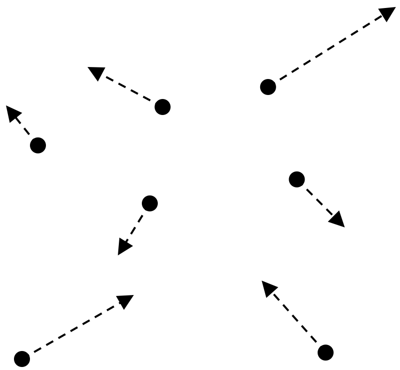
Fluid mechanics ho!

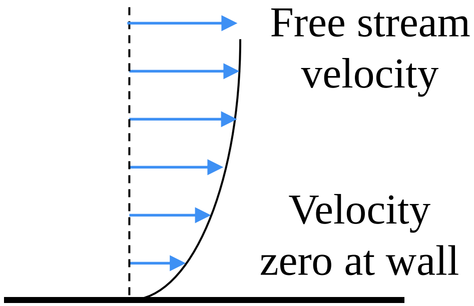
Some meta-commentary

- When you say “Paul, tell me about X!”, I realise what you are really saying is:“Paul, tell me how to use X to solve my problem!”
- As usual, I will tell you about fluids, and then give you specific pointers and tools for solving the particular problem.

Some thoughts about fluids

- Unsurprisingly, air and water are both fluids
  - Fluids are composed of many tiny particles
- Common false assumptions:
  - Fluids are incompressible
  - Fluids are inviscid
  - Fluids have negligible mass





Fundamental reality stuff

In a closed system:

- Mass, energy, and momentum: constant
- Shape, volume, temperature: not constant

Fluid flows are directed by forces acting upon the individual particles, and (by extension) the flow as a whole

Fluid statics

- At rest, all fluid forces balance
  - Gravity (hydrostatic) pressure, thermal expansion pressure:

$$(\quad)$$

P: pressure, g: accl. due to gravity, ρ: fluid density, h: height, M: molecular weight,

k: Boltzman constant, T: absolute temperature

Momentum

- Air has mass and velocity
  - Travels in constant direction until acted upon by a force
- Kinetic energy of flows can be non-trivial
  - Sails and turbines depend on this!

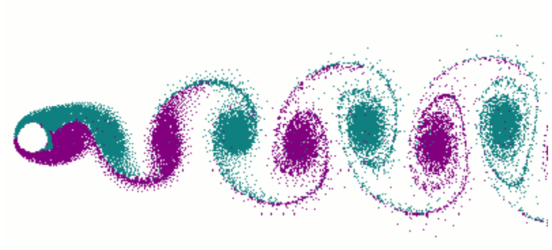
–

E: kinetic energy, ρ: density of air,

V: fluid volume, v: velocity

Vorticity

- Fluids can rotational energy
  - Each particle is moving quasi-linearly, but the overall body of particles acts like it is rotating
  - Rotation centres are called "vorticies"
  - Range from very small to very, very large!



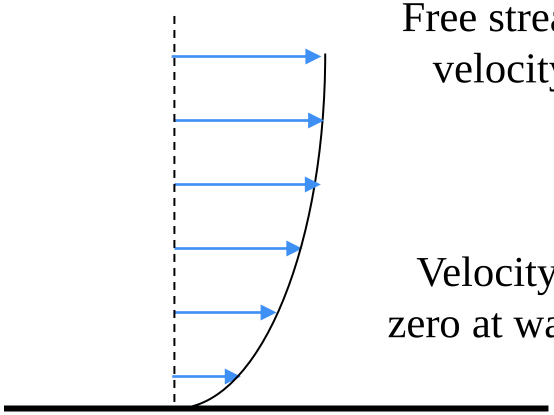
Vortices shed from a cylinder [Cesareo de La Rosa Siqueira]

Wingtip vortex [DLR]

Hurricane Sandy

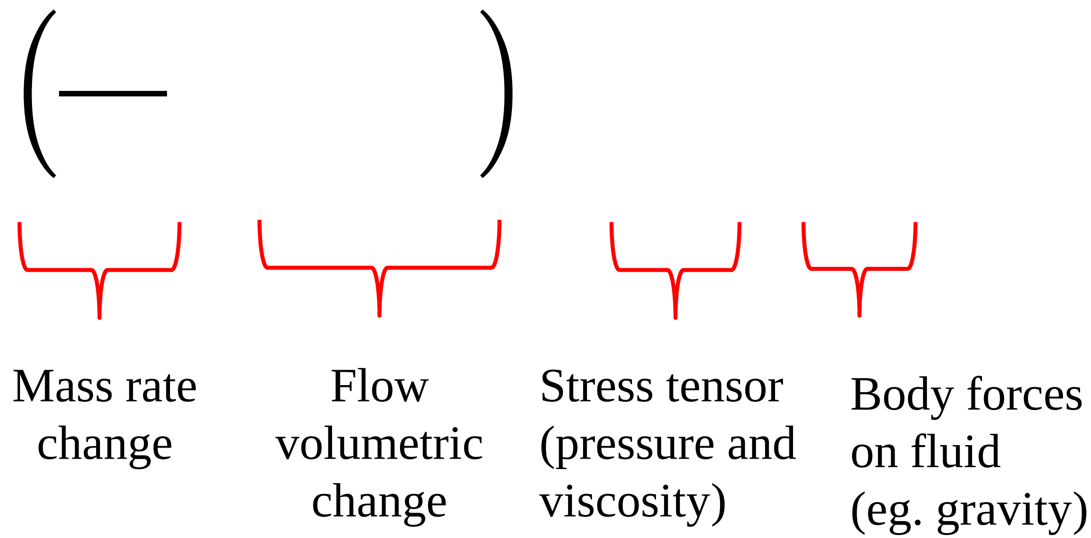
Viscosity

- Frictional forces between particles moving with different velocities
  - Dissipative effect: turns kinetic energy into heat
  - Dependent on fluid type and temperature
- Strongly influences fluid dynamics at small flow scales
  - Gives rise to vorticity



Navier-Stokes equation

- Put all these different effects together in an energy conservation equation:



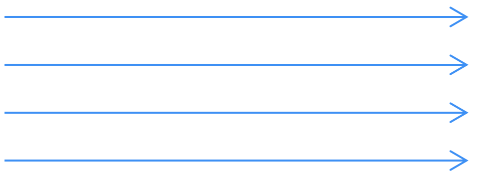
This is an expression of Newton’s second law

(Bernoulli’s principle is a special case of N-S)

Laminar vs turbulent flow

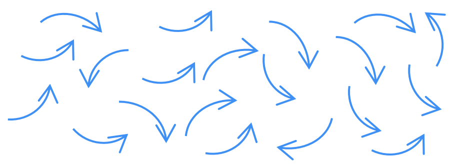
Fluid systems give rise to chaotic behaviour

- Laminar flow
  - Parallel streamlines
  - Smooth pressure gradients



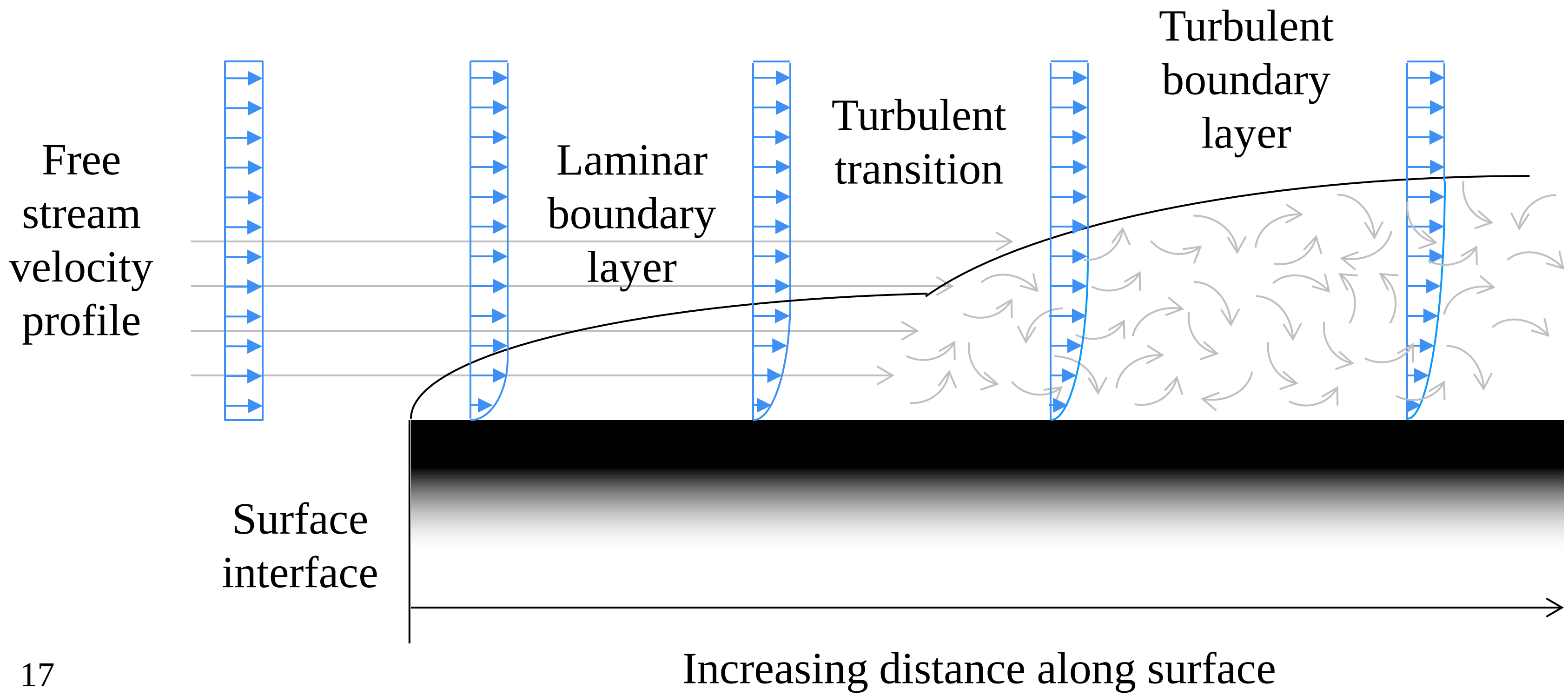
becomes

- Turbulent flow
  - Erratic movement of particles
  - Chaotic mixing of fluid layers



Flow development

- Laminar flow ‘develops’ into turbulent flow when interacting with surfaces



Reynold’s Number

- Measure of the development of the flow

v: flow velocity, ρ: fluid density, μ: fluid viscosity,
L: “characteristic length”

- Characterises dynamic scaling of flow
  - Fluid-body interactions differ at different Res*:
    - RE <10,000 is highly viscous
    - RE > ~200,000 is dominated by flow inertia
    - RE > ~1,000,000 is turbulent

*For airfoils – different scenarios have different transition numbers

Characteristic length

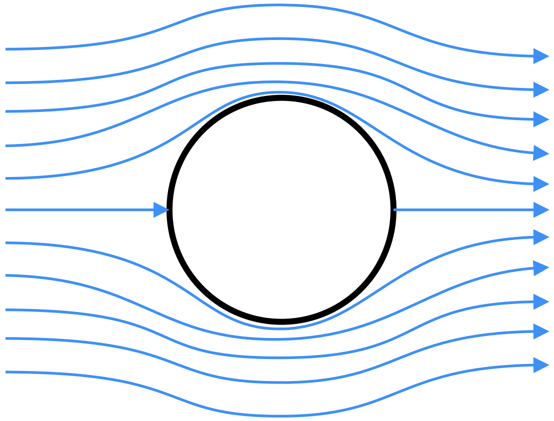
- L is a parameter of the interacting surface geometry – application specific:
  - Airfoils: wing chord length
  - Flat surface: length along surface
  - Channels: channel width
  - Pipes: pipe diameter
  - Cylindars/spheres: cross-section diameter

Why? Because that's just how it is!*

*More specifically because *meaning* derived from Re is application specific

Boundary conditions

- Consider a shape in an on-coming flow:
  - The flow adheres to the surface of the shape



Blue lines are streamlines; locally tangent to velocity field

Boundary conditions

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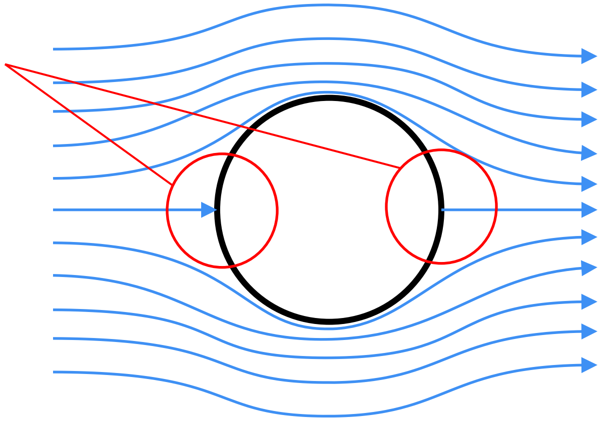
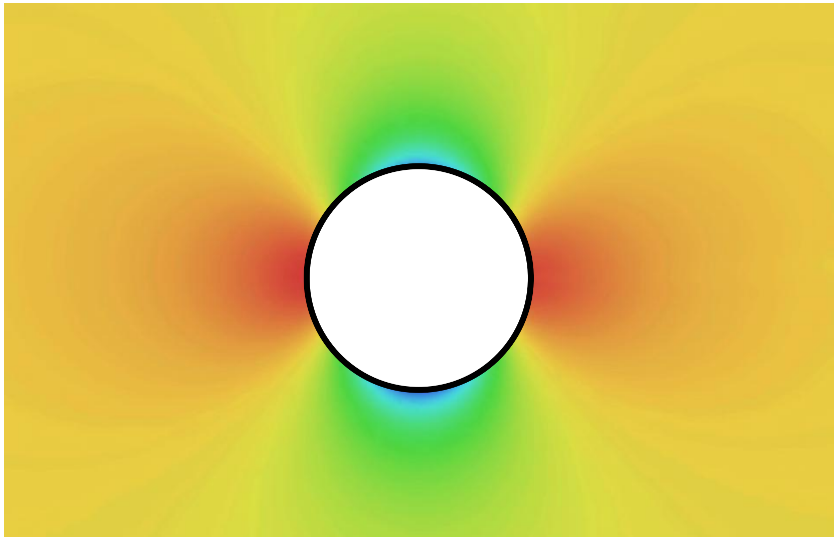
Stagnation points



Blue lines are streamlines; locally tangent to velocity field

Boundary conditions

- Pressure increases where flow ‘bunches up’, Decreases where flow ‘spreads out’

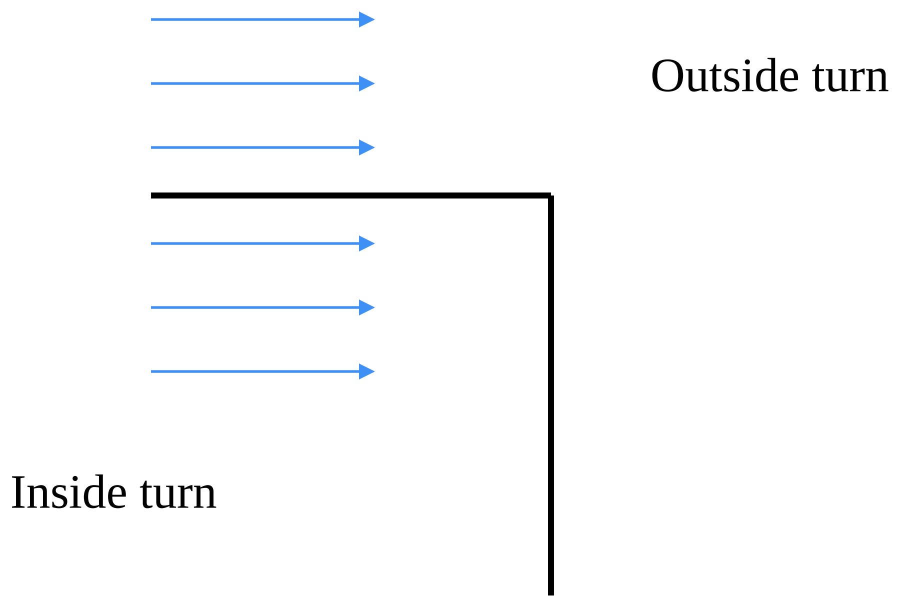


Colours represent pressure field

Red = high pressure, green = low pressure

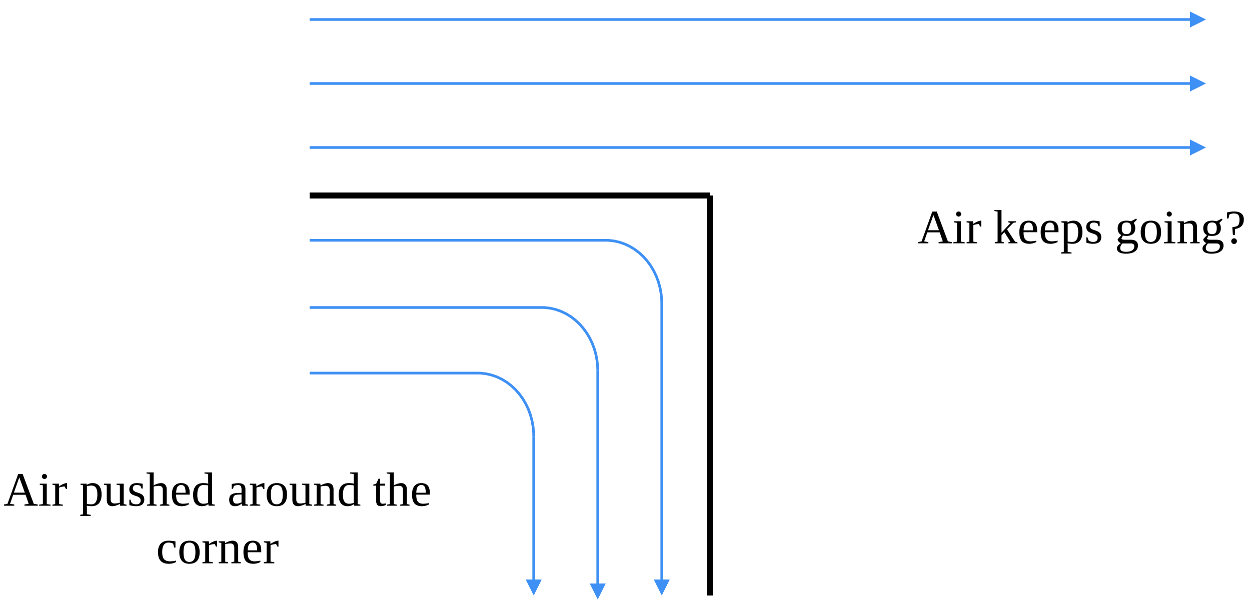
Some intuition

- Consider fluid encountering a corner



Some intuition

- The fluid must follow the surface contour, to satisfy the boundary condition



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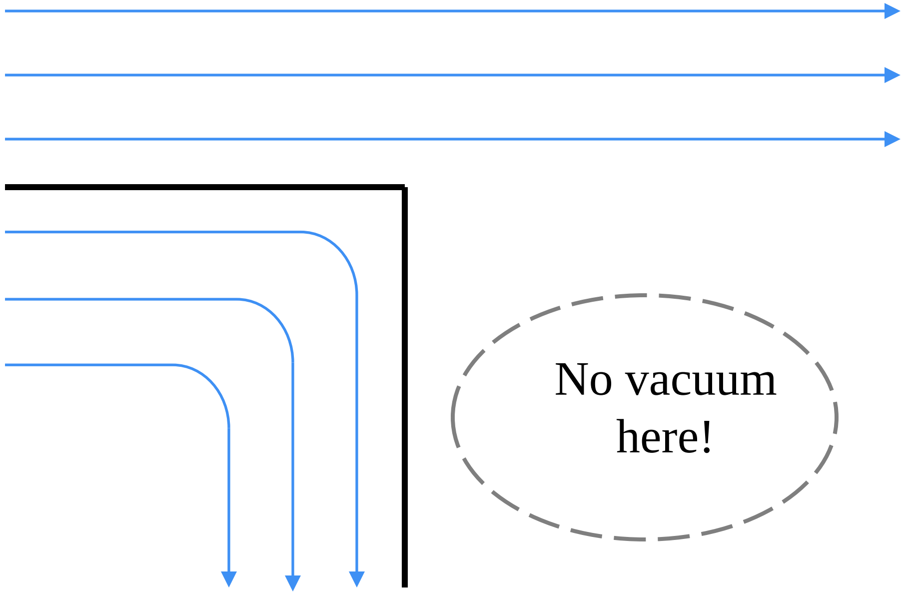

An intuitive idea

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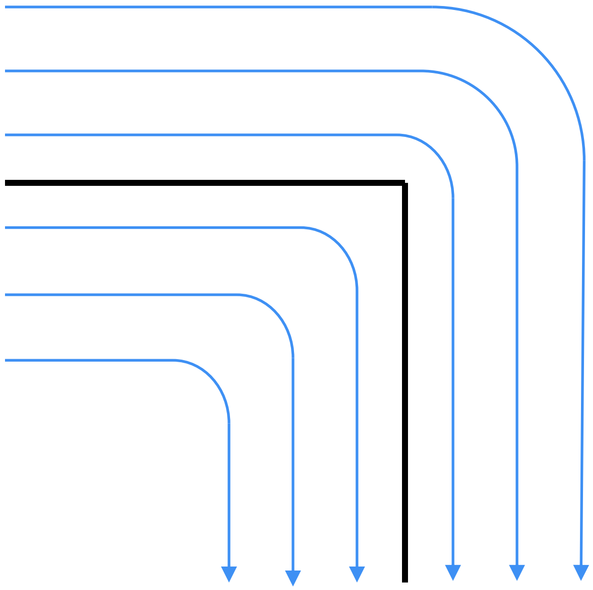
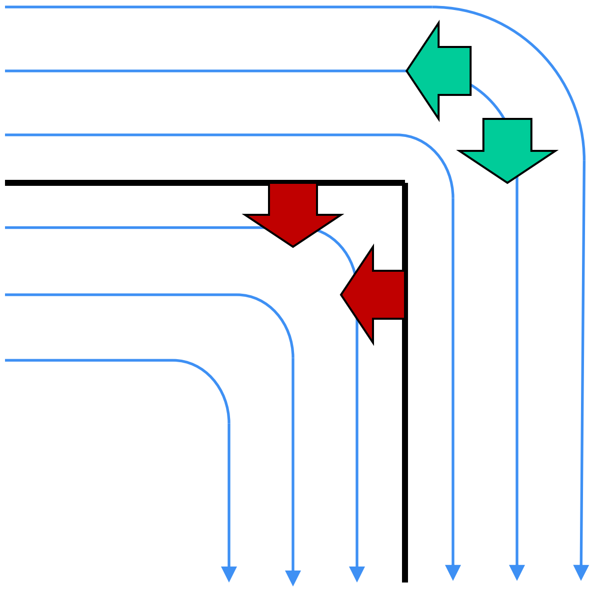


∴ at least some fluid must turn the corner

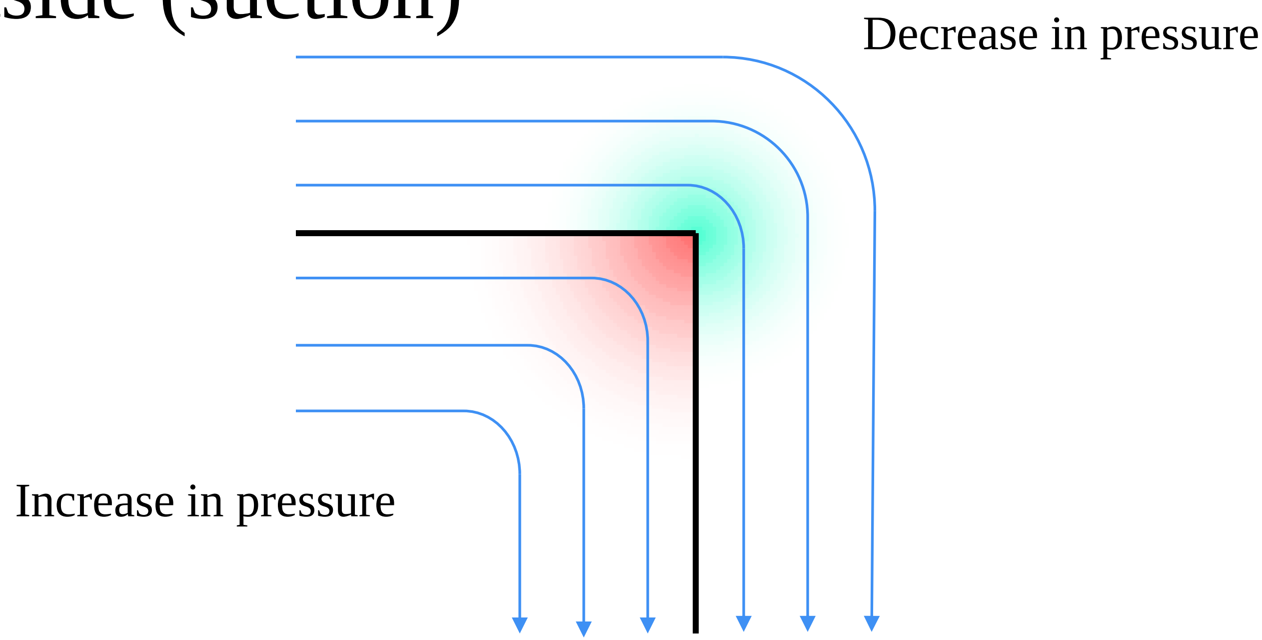
Some intuition

- Some force must act to decelerate the fluid horizontally and accelerate it vertically



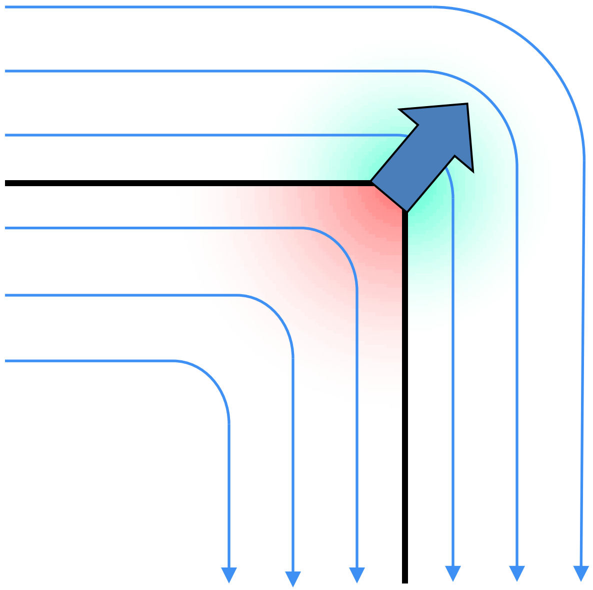
An intuitive idea

- This takes the form of increased pressure inside the corner and decreased pressure outside (suction)



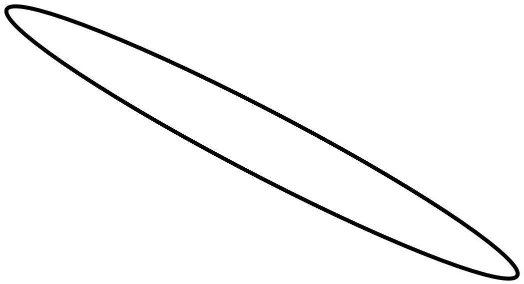
An intuitive idea

- A corresponding force acts on the corner
  - Ie. Newton's third law



Slightly more complicated

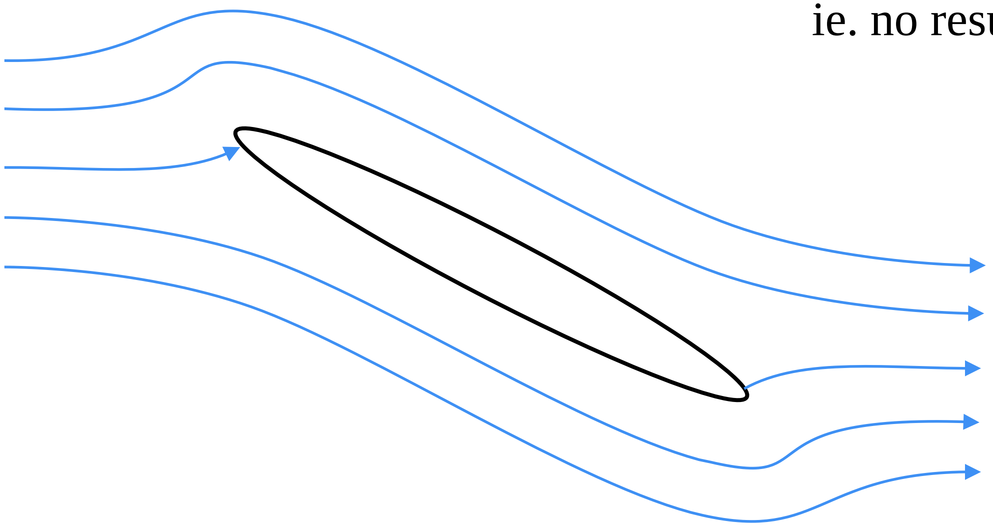
- Now consider a symmetric body in a flow



Slightly more complicated

- It would be reasonable to expect the flow pattern to be symmetric

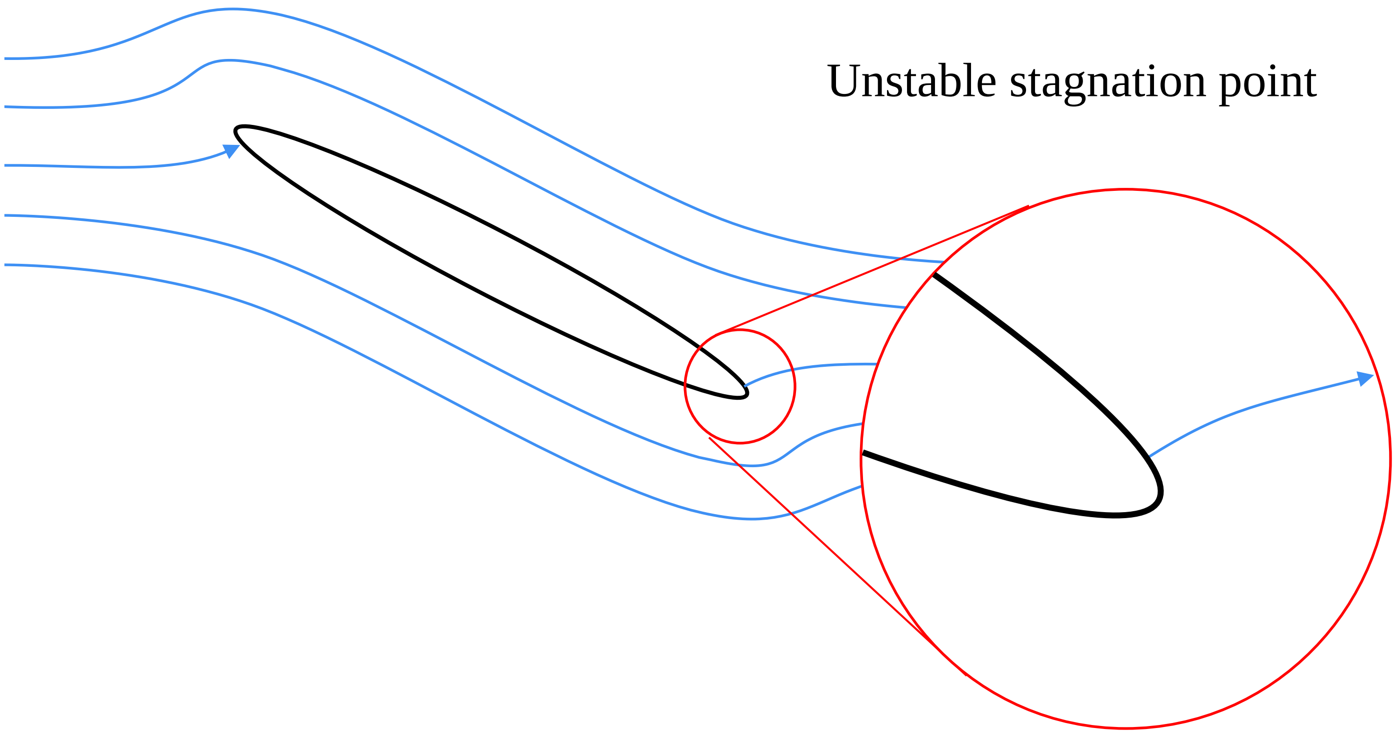
ie. no resultant force



This is true only in the (aphysical) inviscid flow case

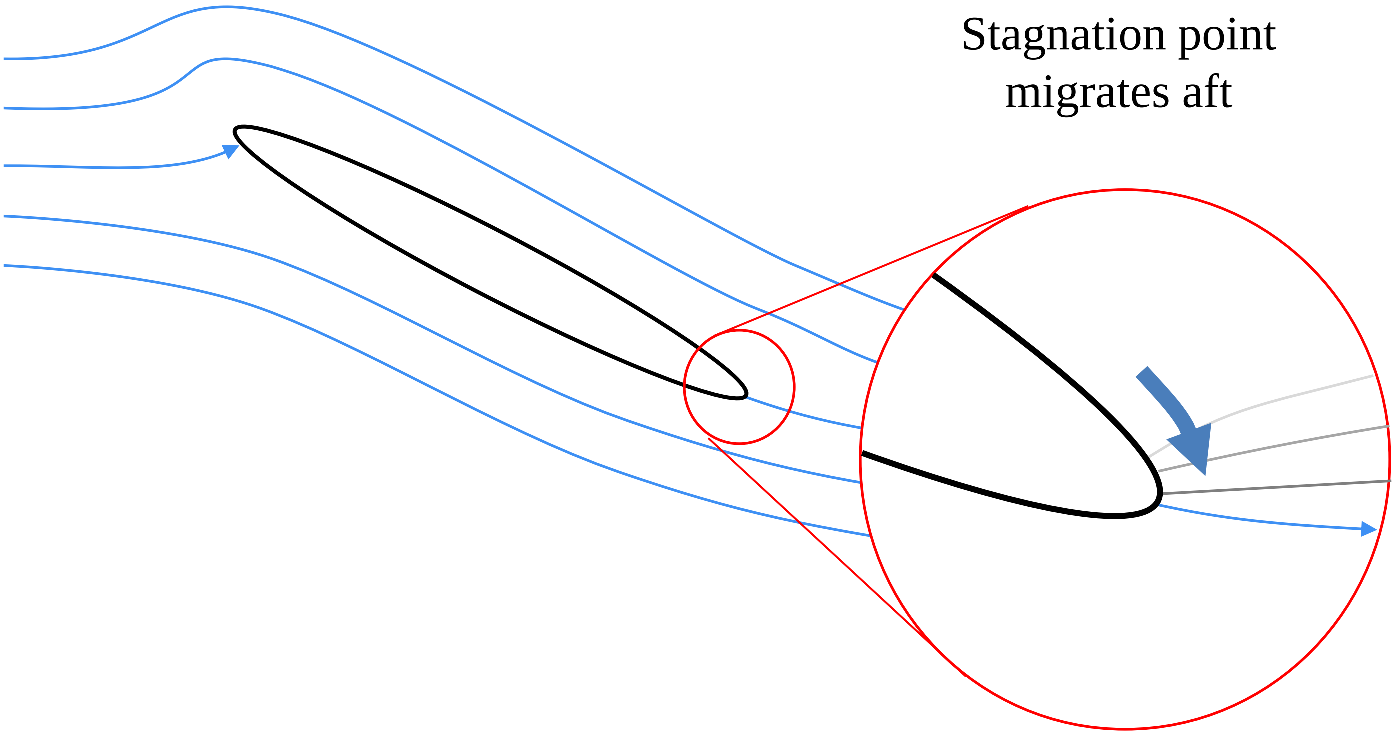
Slightly more complicated

- In reality, viscosity in the flow removes energy along the boundary layer



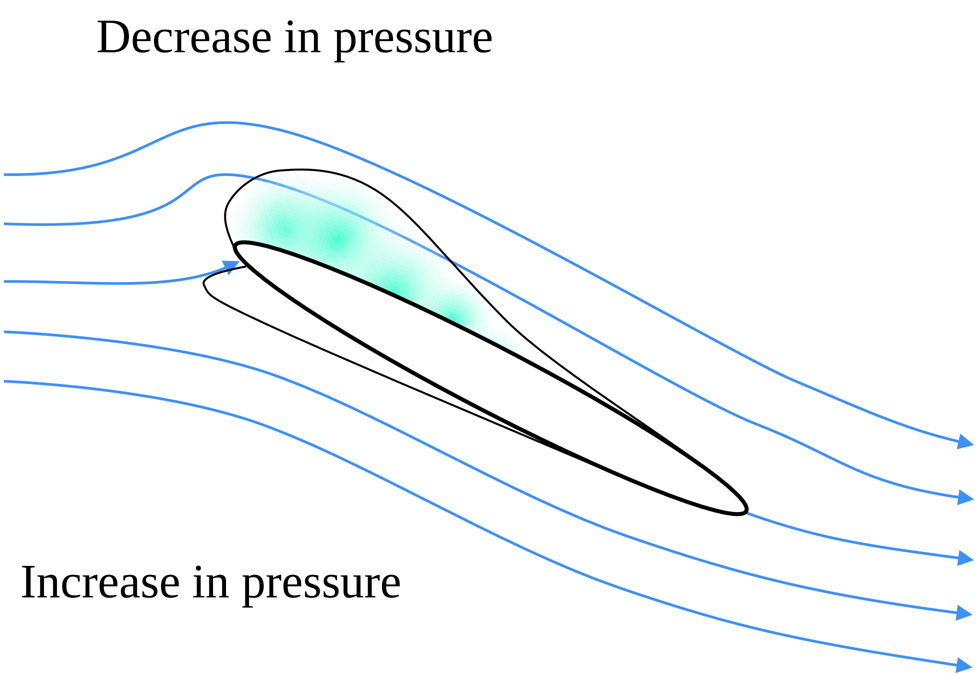
Slightly more complicated

- The rear stagnation point shifts to the trailing edge (the Kutta condition)



Slightly more complicated

- This is the basic idea behind wing lift



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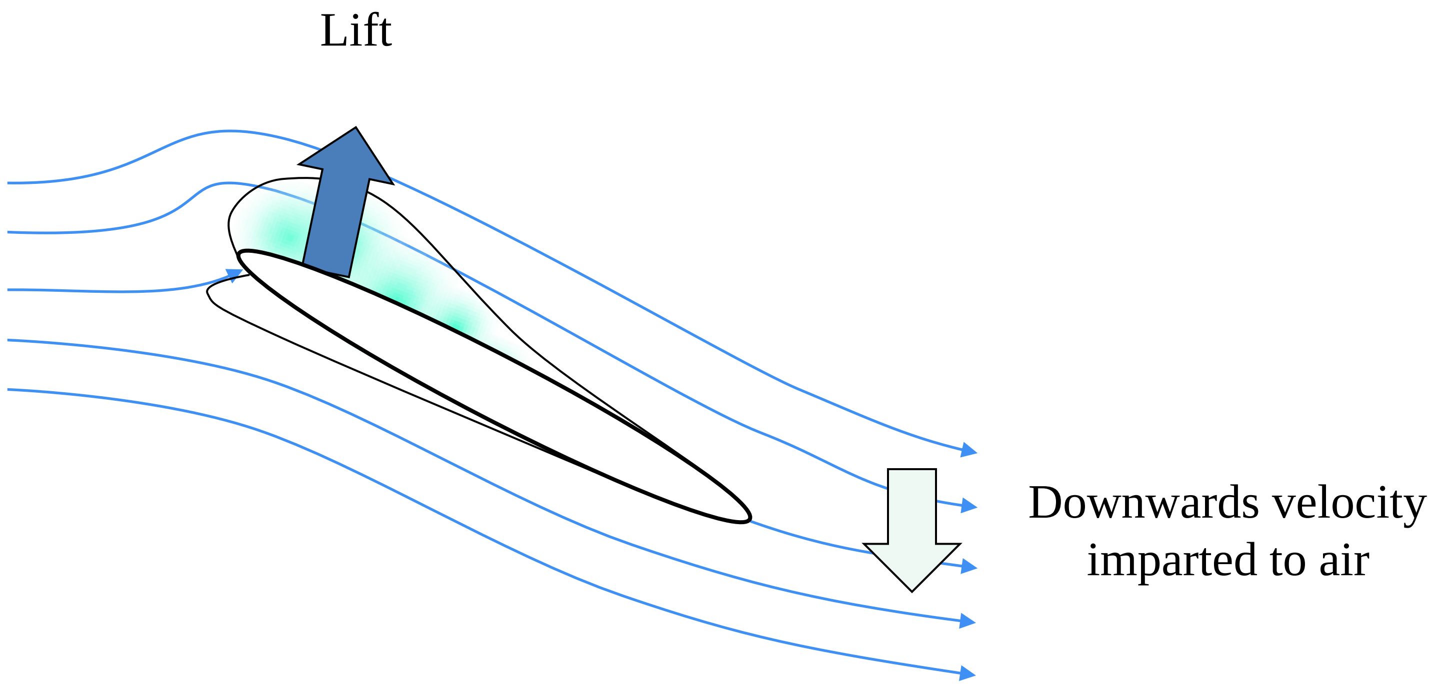
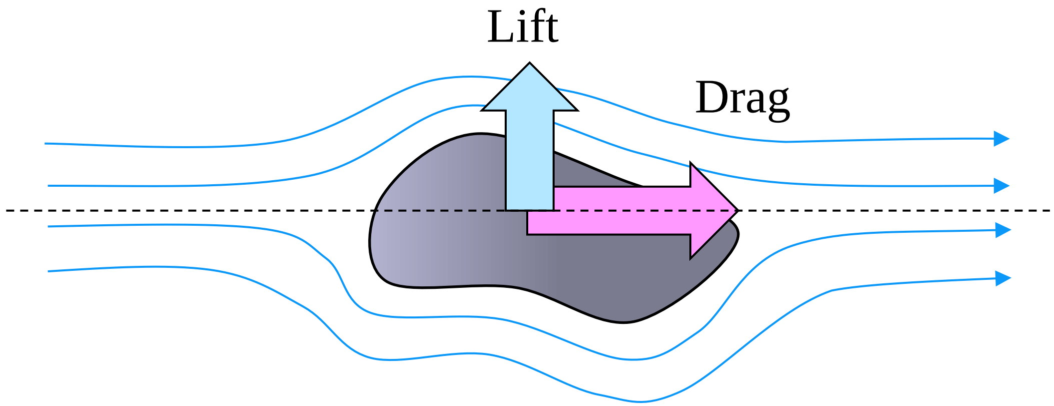


Note: You may also hear reference to "airfoil circulation", "vortex theory," "potential flows", and element or momentum methods. All are valid ways of describing the mechanics of wings

Bodies in a flow

- The forces acting on a body in a flow can be calculated from geometric parameters
- Forces are decomposed into ‘lift’ and ‘drag’
  - Drag acts parallel to the flow (usually retarding)
  - Lift acts perpendicular to the flow



Dynamic pressure

- Lift and drag forces are proportional to dynamic pressure:

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- This is also equal to:
  - The kinetic energy per unit volume of fluid
  - Pressure at the stagnation point minus the ambient hydrostatic pressure

Lift and drag equations

- The lift and drag of a convex body in laminar flow is given by:

–

–

where and are non-dimensionalised lift, drag and moment coefficients dependent on body geometry*, and is the density of air, is the body area, and is wind velocity

*Data for airfoils can be found published online or found by experiment or CFD

Pitching moment

- If the centre of pressure of a lifting surface is not coincident with its mechanical centre, the body may exhibit a ‘pitching moment’:

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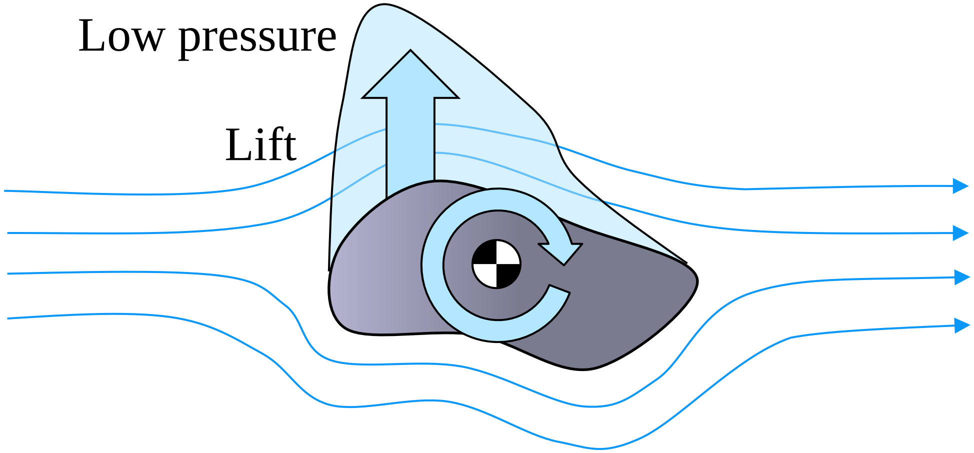
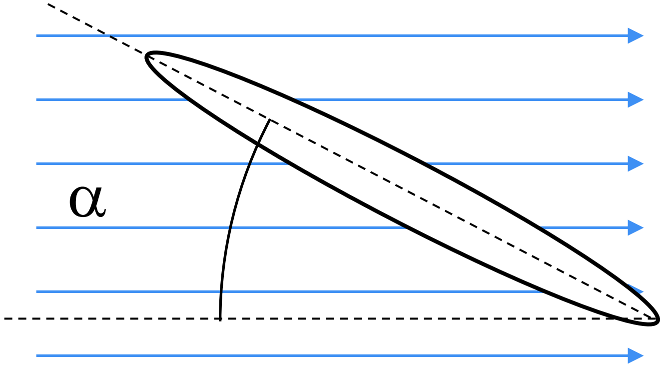


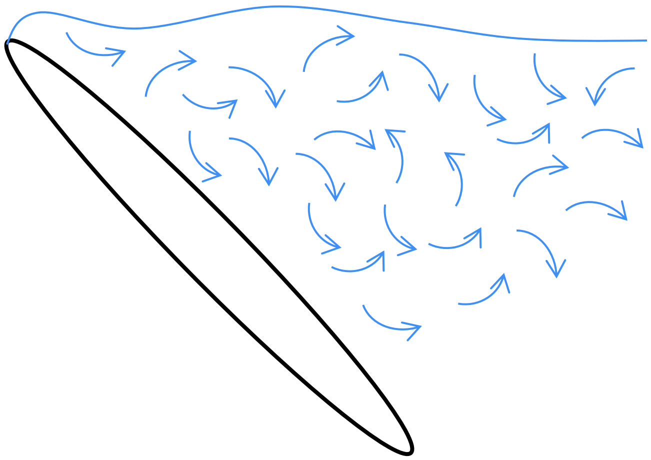
Polar plots

- c_l and c_d also depend on 'angle of attack' α
  - AoA is measured from the 'zero lifting line', the orientation which produces no lift



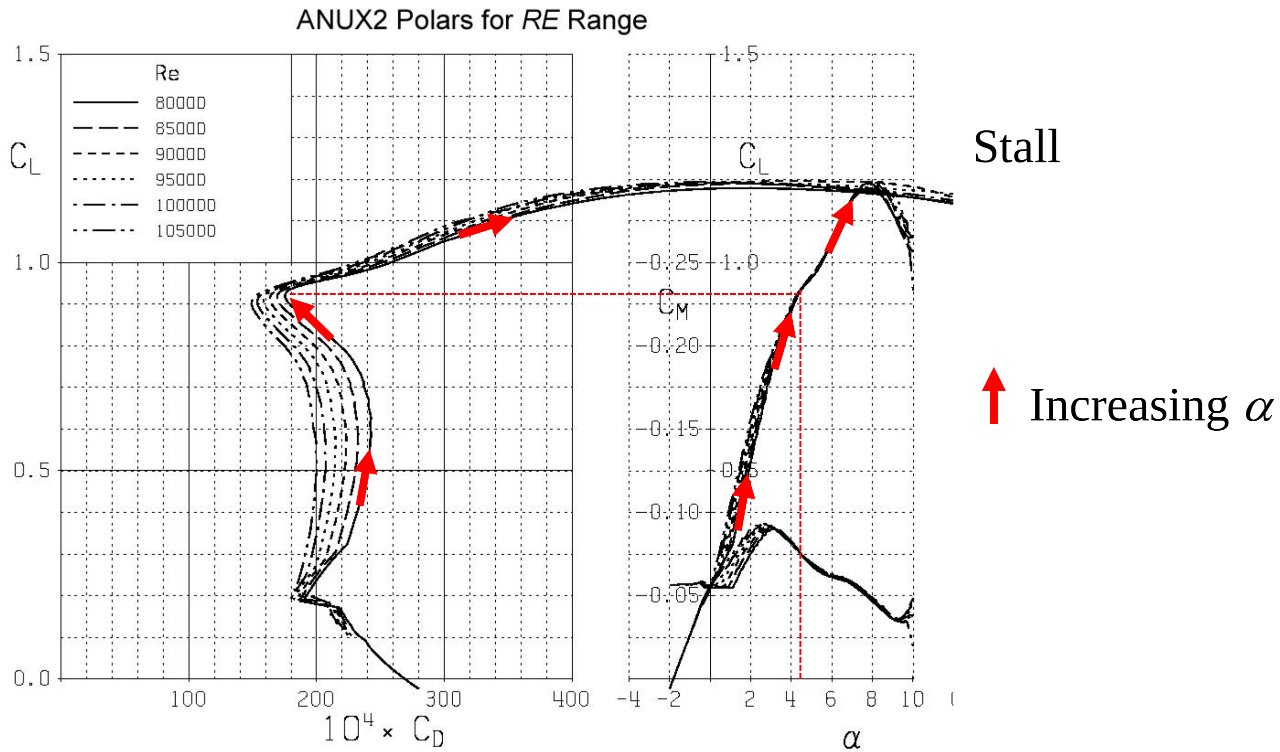
Flow separation

- At extreme angles of attack, an airfoil's flow may separate
  - That is, the boundary layer detaches and becomes turbulent
  - This produces high drag and little lift



Polar plots

- $c_l(\alpha)$ and $c_d(\alpha)$ vs α is nearly linear for some airfoils, but very non-linear for others
  - Plotted against each other on a 'polar plot'



Questions?

Tune-in next time for…

Questions and Answers Vol. 1

or

"Why didn't you ask me that sooner!?"

Fun fact: Two people accounted for 80 per cent of lecture requests.