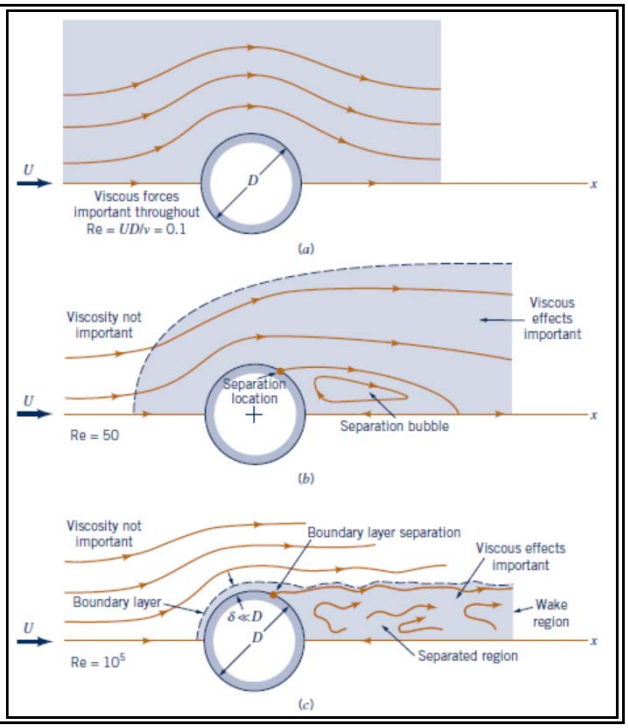
ESO204A, Fluid Mechanics and Rate Processes

Flow Separation and Related Topics

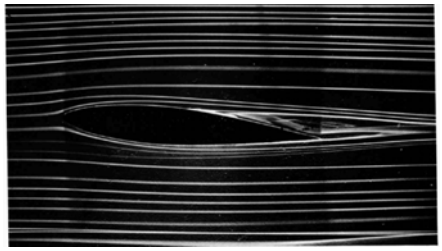
Chapter 7 of F M White
Chapter 9 of Fox McDonald

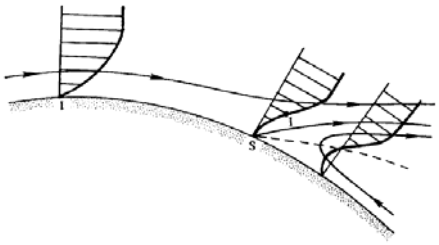
Flow Separation

Boundary layer separates from the solid surface



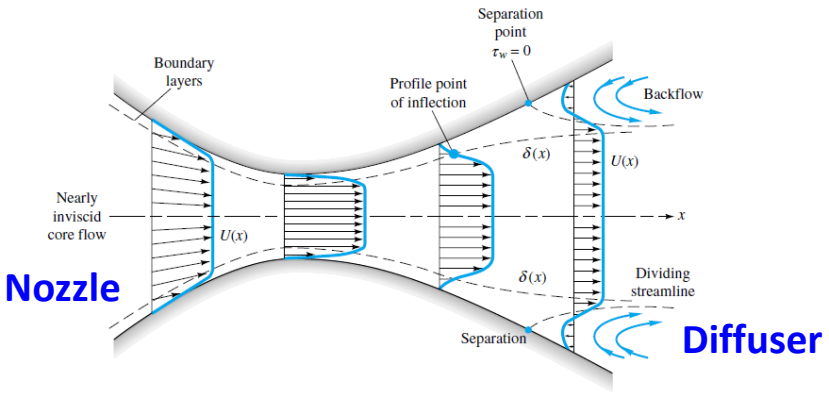
BL *separates* from the wall where it was generated
Concept of BL still exists, approximate Eqn. fails (full N-S solution necessary)
Pr. grad. plays a significant role; geometry is more important than Re





Pr. drag (form drag) increases; necessary condition: adverse pr. grad.

Viscous-region thickens
Basic assumption of BL approximation becomes questionable

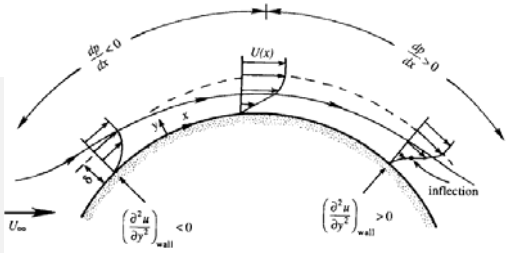


Nozzle:	*Throat*:	*Diffuser*:
Decreasing pressure and area	Constant pressure and area	Increasing pressure and area
Increasing velocity	Velocity constant	Decreasing velocity
Favorable gradient	Zero gradient	Adverse gradient (boundary layer thickens)

Flow past a cylinder

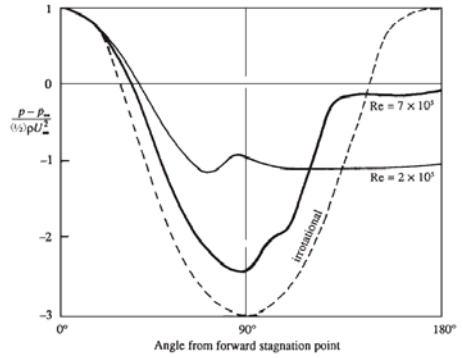
Favorable Pr. Grad.

Adverse Pr. Grad.

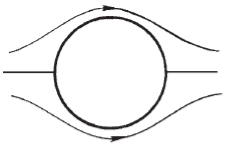


For flow past a cylinder, flow accelerates and then decelerates leading to favorable and adverse pressure gradients

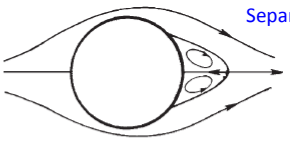
For viscous flow, adverse pr. grad. 'overcomes' momentum near the wall, generates inflection point in the velocity profile, may lead to separation



Flow past a cylinder

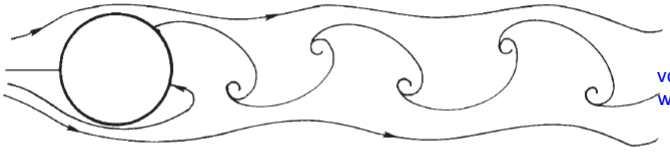


Re < 4



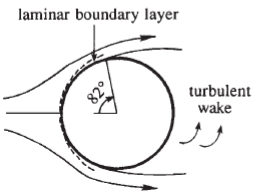
4 < Re < 40

Separation starts, wake forms

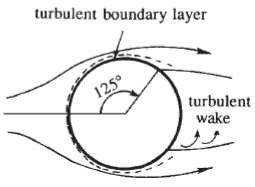


80 < Re < 200

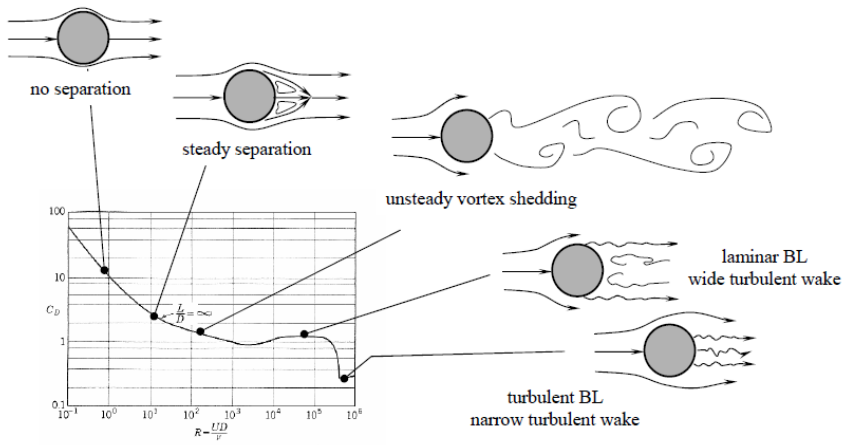
Unsteady phenomena: vortex shedding; wake-separation interaction



Re < 3 × 10⁵

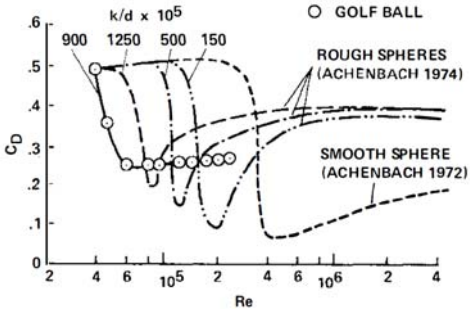


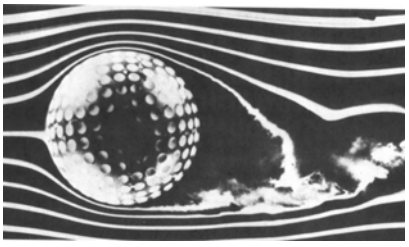
Re > 3 × 10⁵

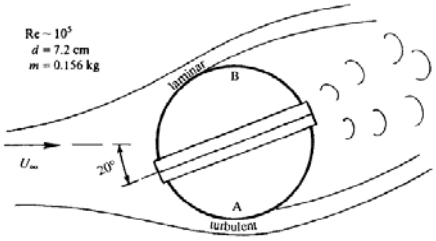


Experimentally determined drag coefficient for flow past a circular cylinder; relate flow structure with the drag coefficient

Sports ball aerodynamics

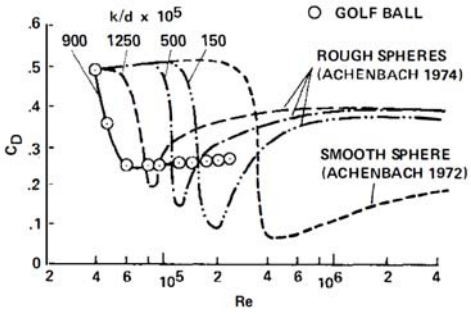




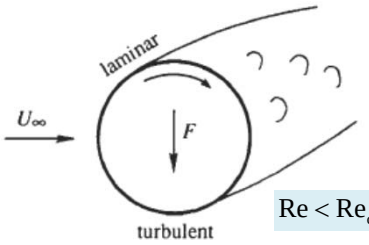


Flight and swing of golf and cricket balls

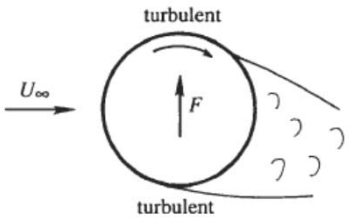
Sports ball aerodynamics: Tennis and Soccer



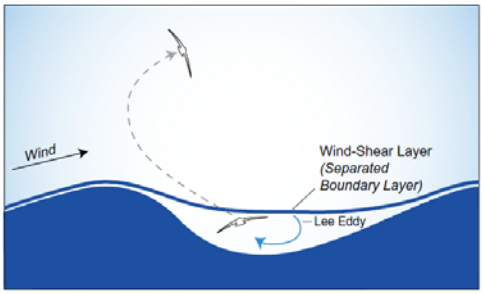
Swings of tennis/soccer ball are induced by the spin

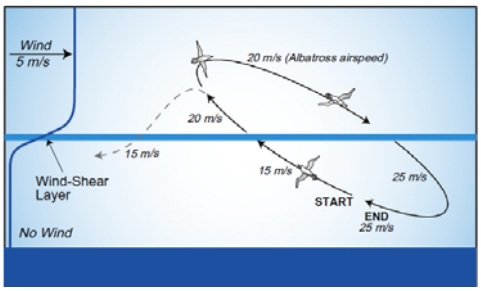


$Re < Re_{critical}$



$Re > Re_{critical}$





- BL separation, in most cases, is not desirable (leads to higher form drag). Some birds (Albatross, for instance) make use of BL separation for long distance gliding
- Albatross can fly very long distance (~1000km) with near-zero energy expenditure; a phenomenon still under investigation (first reported by Lord Rayleigh, 1883)

Richardson, Progress in Oceanography, 88 (2011), 48-56