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Intermediate Fluid Dynamics

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Lecture 19

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- Classical Aerodynamics

Aerodynamics

Given its geometry and the velocity, what is the force on an object moving in a fluid?

a reasonable question, but surprisingly difficult to answer.

Governing Equations

Navier-Stokes equations for incompressible flows:

$$\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} = -\nabla p + \frac{1}{\mathrm{Re}} \nabla^2 \mathbf{u}$$

$$\nabla \bullet \mathbf{u} = 0$$

Boundary condition (no-slip) (wing kinematics):

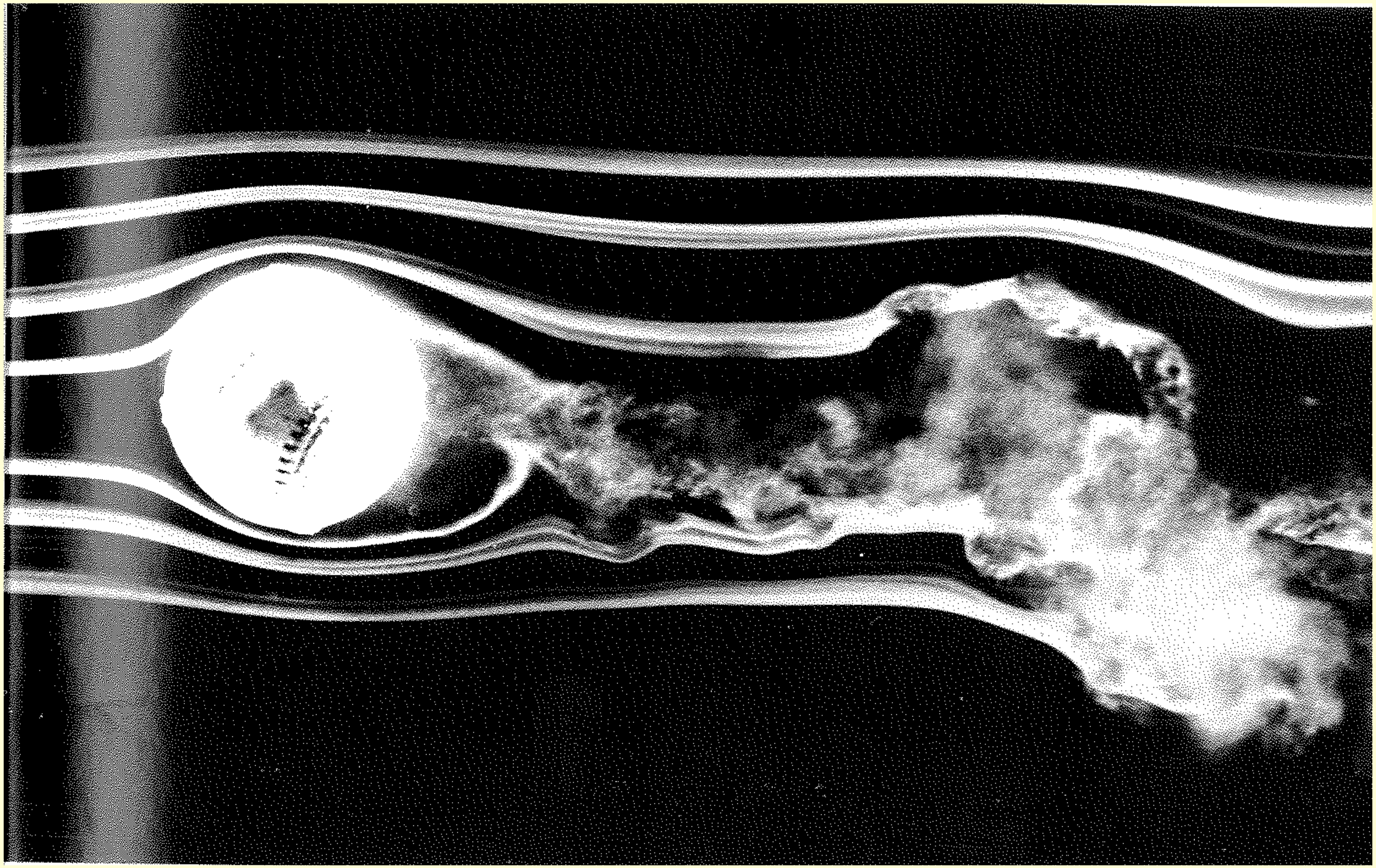
$$\mathbf{u}_b = \mathbf{v}_b$$

Dynamics of the solid object coupled to the fluid:

$$m \frac{d\mathbf{v}_b}{dt} = \mathbf{F}_{fluid} + F_{ext}$$

Direction of the force, without solving equations

What is force on the ball, and which direction does it spin?

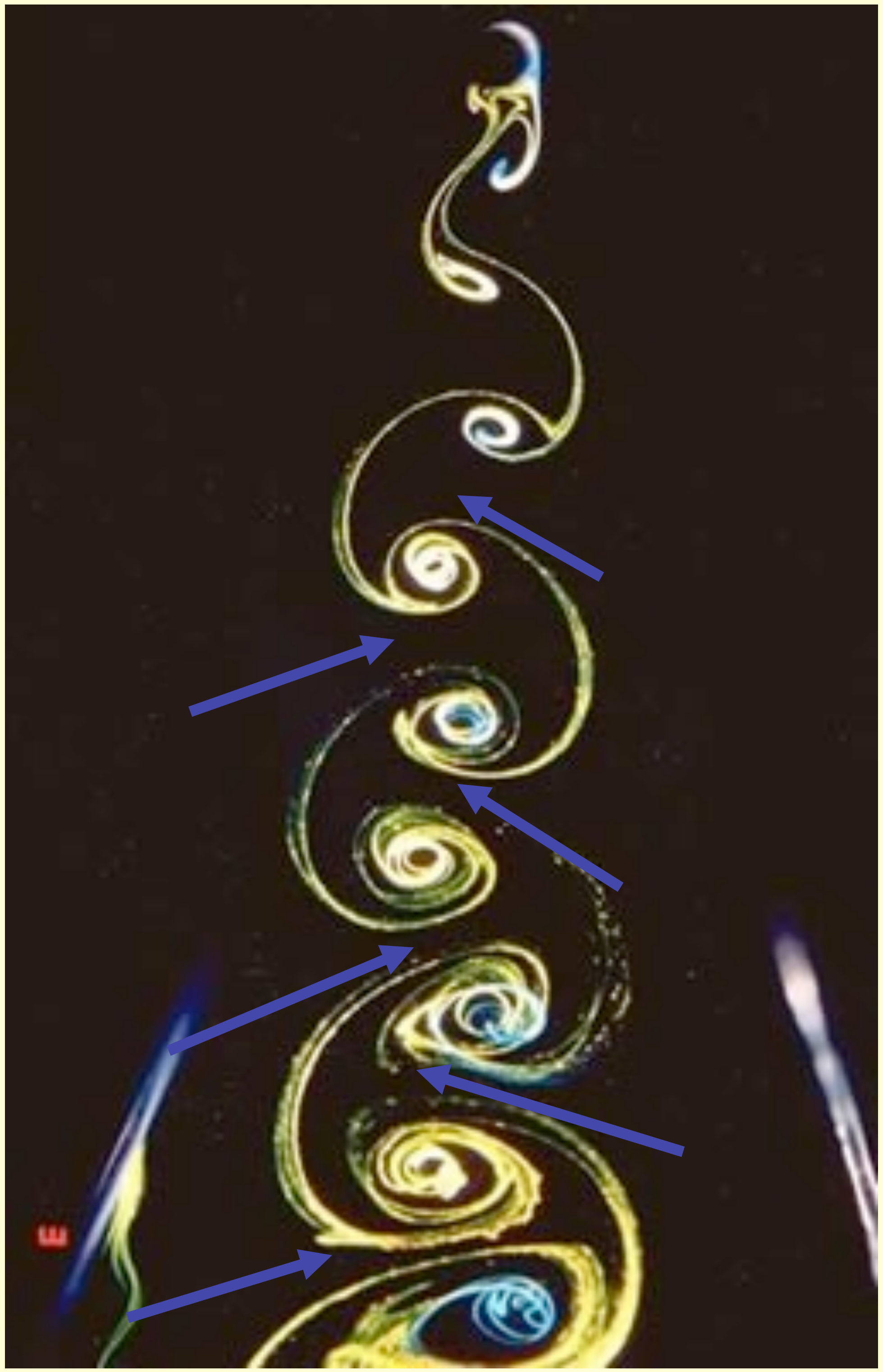


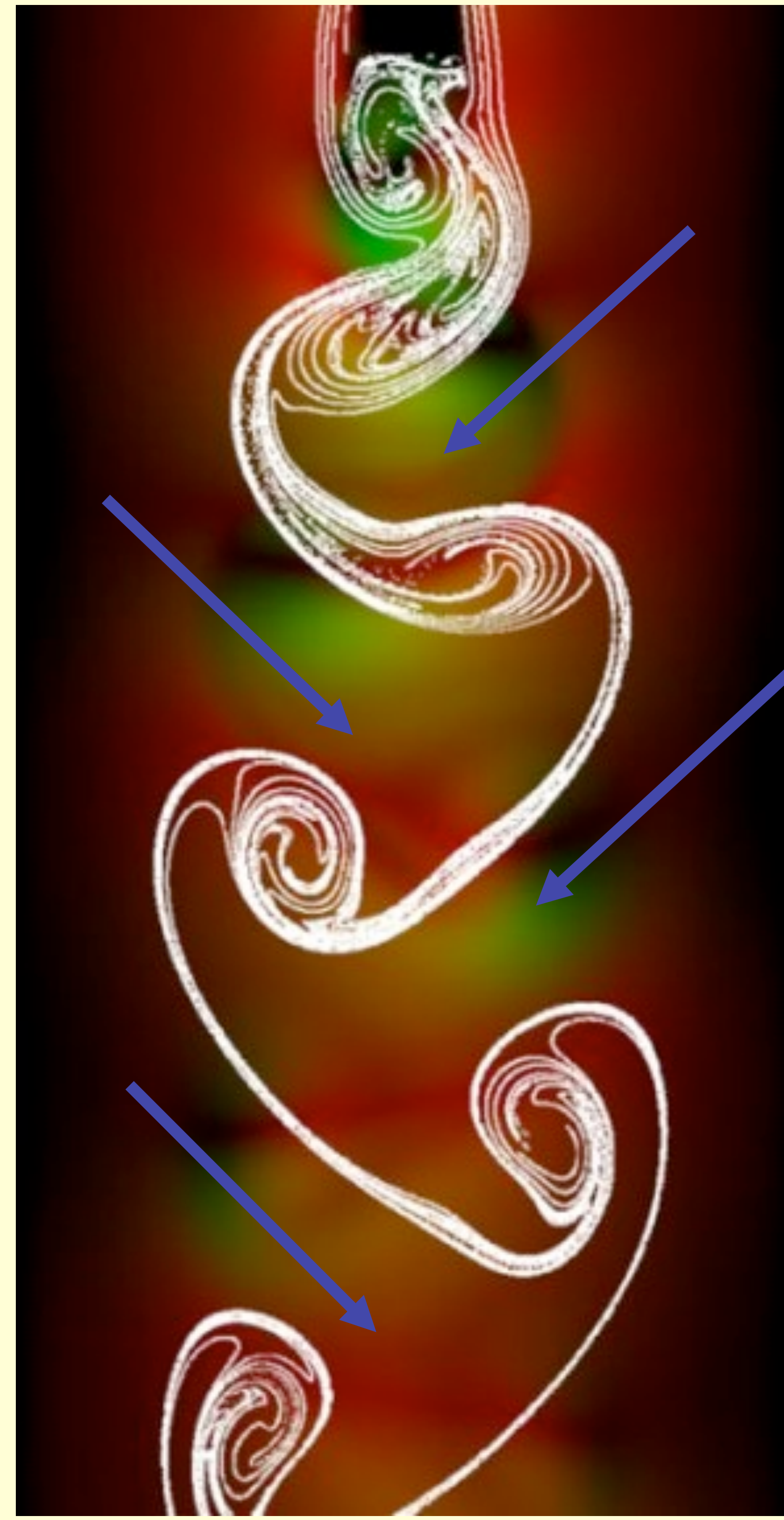
Wake Signature of Thrust and Drag

- most agree that the there is a lift on the ball, but there is confusion about which direction does the ball turn.

Wake Signature of Thrust

Von Karman and reversed Von Karman Wake





Definition of Lift and Drag

Lift

force component orthogonal

to the wing velocity relative to flow at infinity

drag

force component anti-parallel

to the wing velocity relative to flow at infinity

Remarks

- steady motion does not imply steady force
- at high Re, there is LIFT in addition to drag
- when the angle of attack α is small, the rate of change of lift with respect to α is much greater than that with drag, thus, as the angle of attack is increased, the lift-to-drag ratio can be significantly higher than one.

Stokes drag

Slender body theory

Attached flow

Classical Airfoil theory

Kutta Joukowski Theory for LIFT

Re

Separated flow

Kirchhoff-Rayleigh theory for DRAG

How to estimate lift to drag ratio

- define the lift to drag ratio during a steady gliding

- the best paper airplane we saw in the class had about a lift-to-drag ratio of 6

Typical Lift to Drag Ratio

- airfoil: 10 -100

- the lift to drag ratio of high performance sailplane wing ~ 200
- the lift to drag ratio of sailplane ~50

The Theoretical Estimate of Aerodynamic Lift

$$F_L = C_L(\rho U^2 L)$$

$$C_L = 2\pi \sin\alpha$$