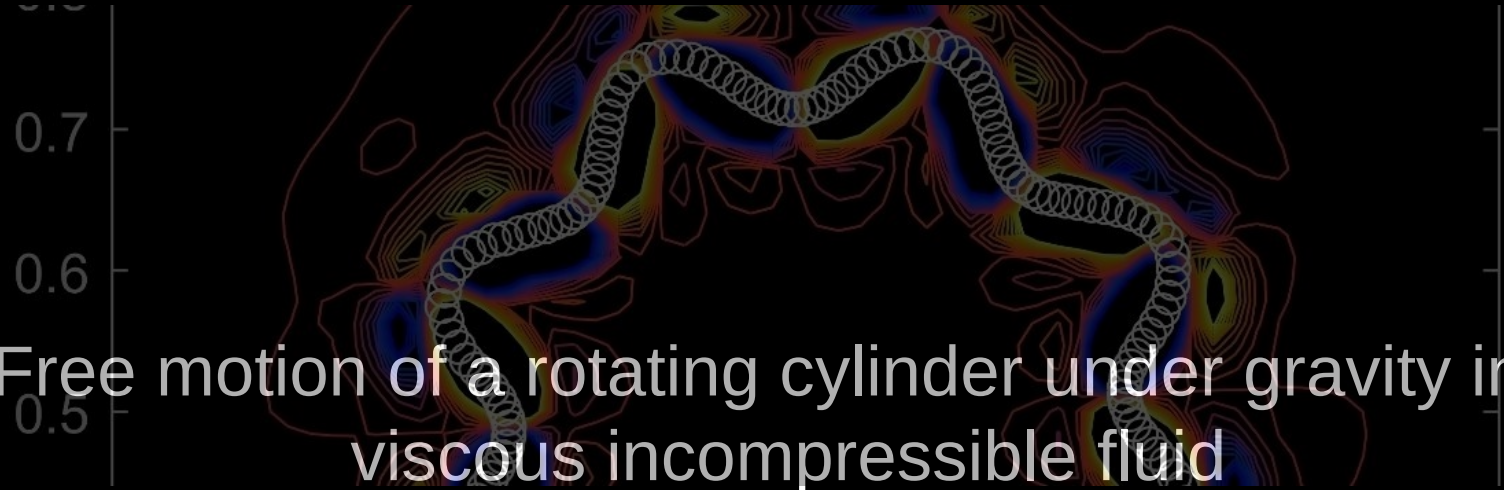


Free motion of a rotating cylinder under gravity in a viscous incompressible fluid

Eleven Chen
with Charles S. Peskin, Elaine Li, Leif Ristroph

AMSURE 2022

Motivation

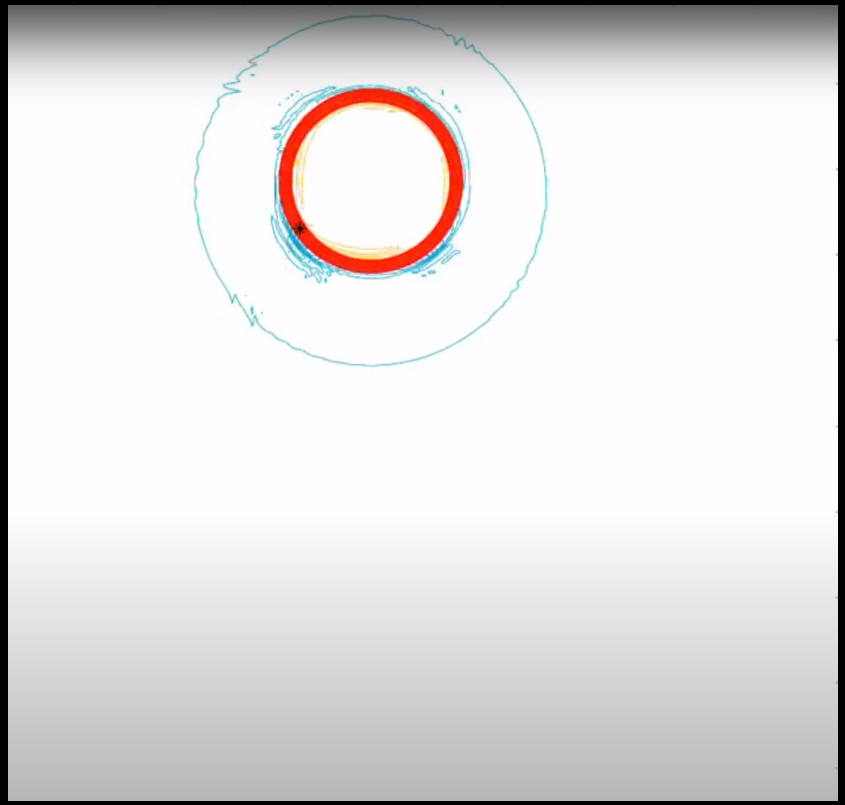
- No spinning: Fall straightly to the ground
- Backspin: Gliding for a long distance

Credit: Veritasium

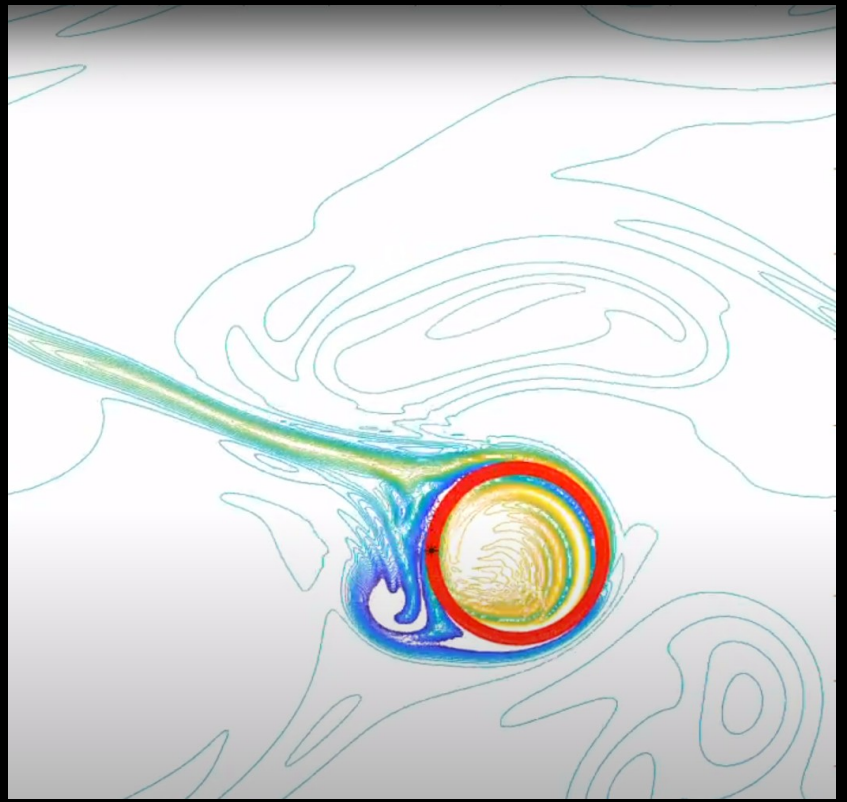
Can we simulate a simplified basketball?

- A hollow cylinder slightly heavier than water(~%3), in a periodic domain
- Fix rotation rate but leave the center of mass free
- We found:
  * Frequency(f) is high, steady horizontal motion
  * Frequency is low, unsteady gliding motion
  * The transition is sharp, there exists critical f
- Key result: quantitative relation between U and f during steady state

Animations



Steady, 5.5 rotations/second



Unsteady, 2 rotations/second

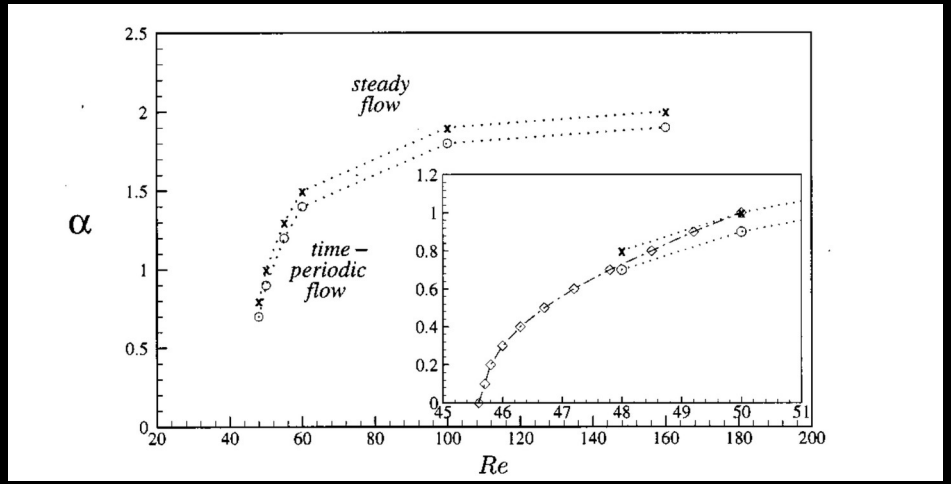
Literatures

- Flow past a rotating cylinder which was hold in place (experiments/simulations)
- Novelties:

  * Effect of gravity

    * Degree of freedom, cylinder itself finds its U

- Re-α phase diagram. Line shows separation between steady and unsteady state.



Kang et al. 1999

A model

- Analyze: superposition of two steady flows in an infinite domain
  (Ask me if you want more details)
- Good at predicting U(f) when f large enough
- Not good at predicting the critical transition frequency

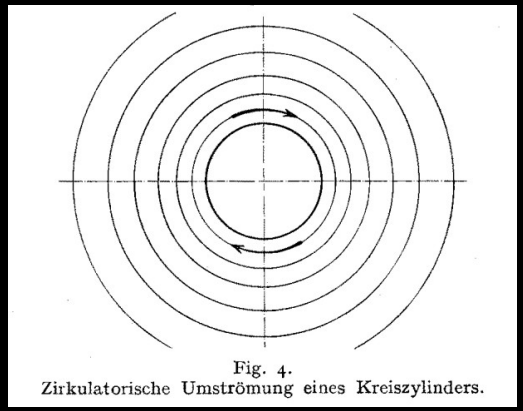


Fig. 4.
Zirkulatorische Umströmung eines Kreiszylinders.

+

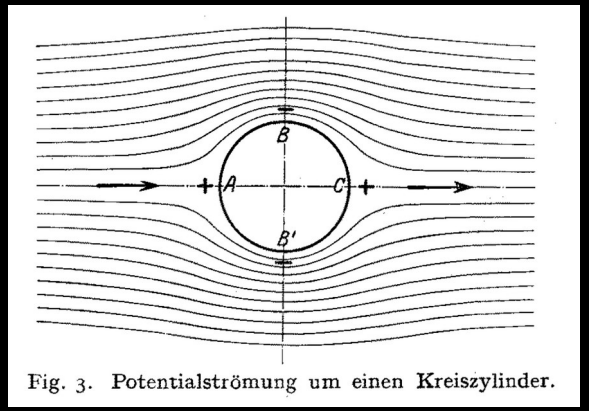


Fig. 3. Potentialströmung um einen Kreiszylinder.

$$Lift = 2\rho U \pi \omega R^2$$

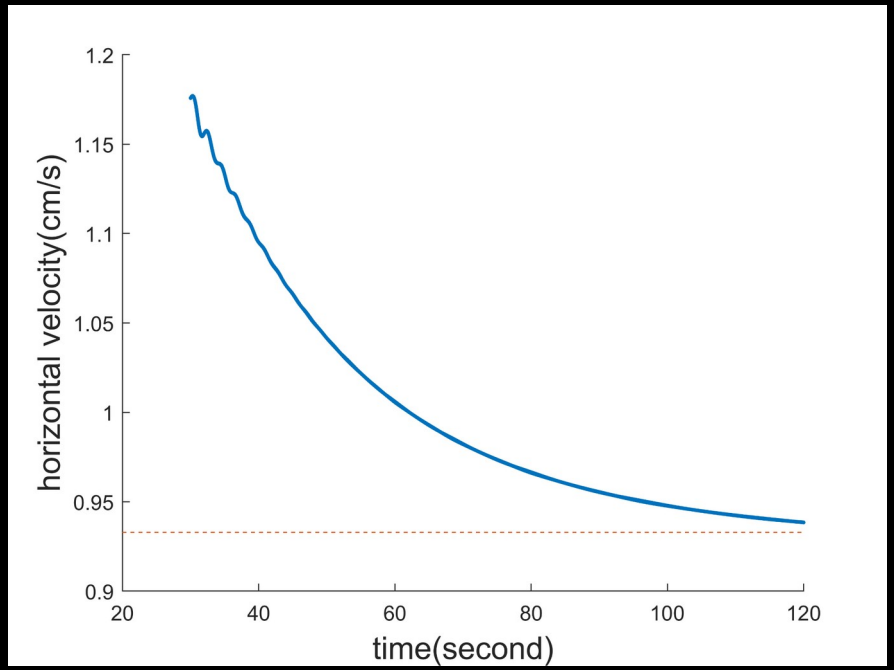
$$2\rho U \pi \omega R^2 = mg$$

$$U(f) = \frac{mg}{4\pi^2 \rho R^2 f}$$

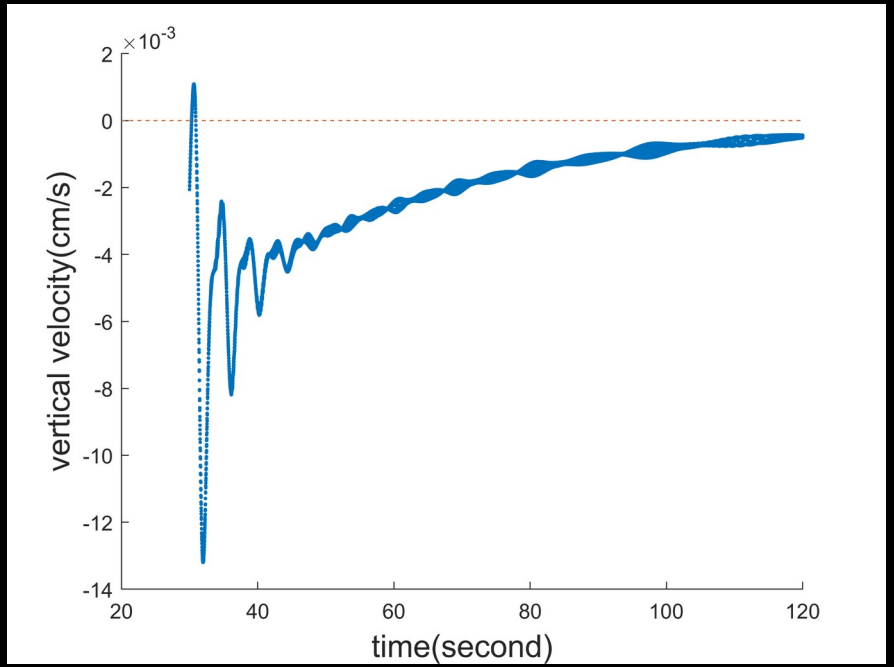
Von L. Prandtl, 1925

Velocity components of the cylinder

- Mass/length = 0.5 gram/cm, 10 rotations/second, radius = 0.5 cm



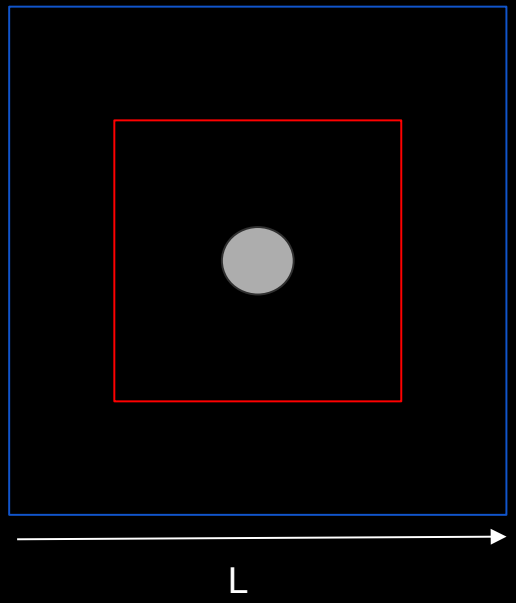
Horizontal velocity(cm/second) vs. time(second)



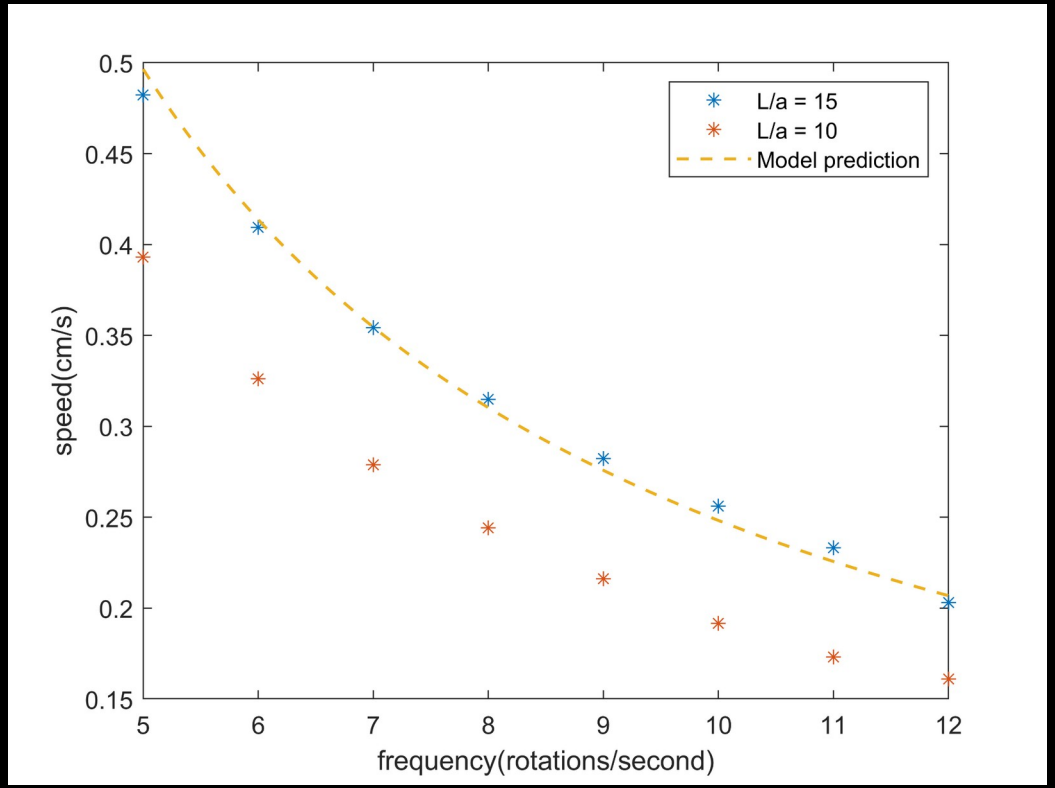
Vertical velocity(cm/second) vs. time(second)

Key result !

- Relationship between steady horizontal speed and rotational frequency

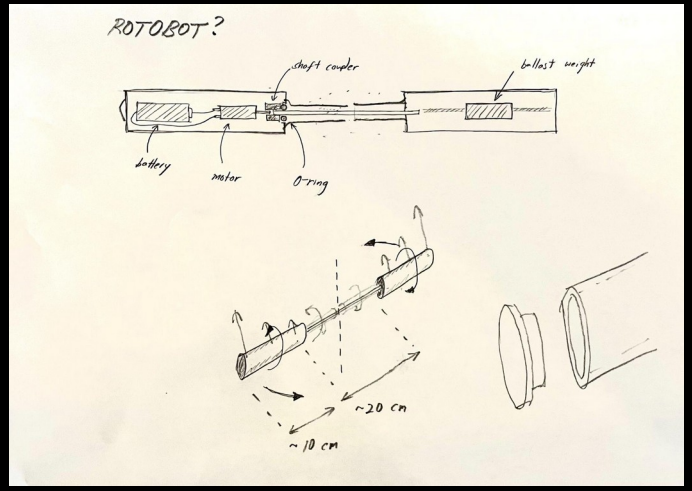


a: radius of the cylinder

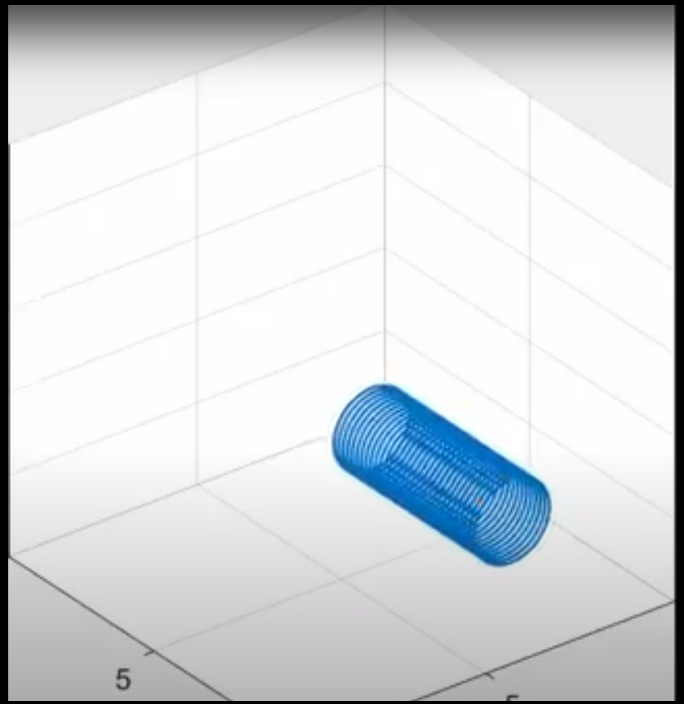


Current and future work

- Transition(boundary layer theory)
- Experiment
- 3D simulation(rigid body motion in 3d)



Credit: Leif Ristroph



A simple 3d simulation

Questions?

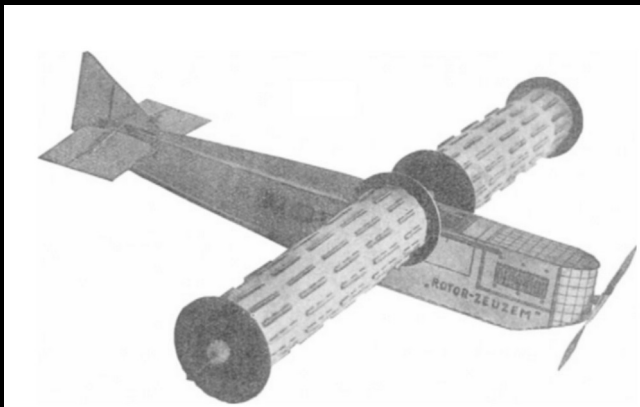


Fig. 10. Model *Rotor-Zeuzem*. Courtesy of Deutsches Museum Archiv.

Jost Seifert, 2012

Numerical method

- A penalty immersed boundary method for a rigid body in fluid, Kim & Peskin 2016
- Red dots stick and move with rigid body
- Green dots move with the velocity of the fluid
- The center of rigid body moves according to

  F = m a

  where F is calculated from gravity and the

  spring forces