Russia IYPT

Magnus glider

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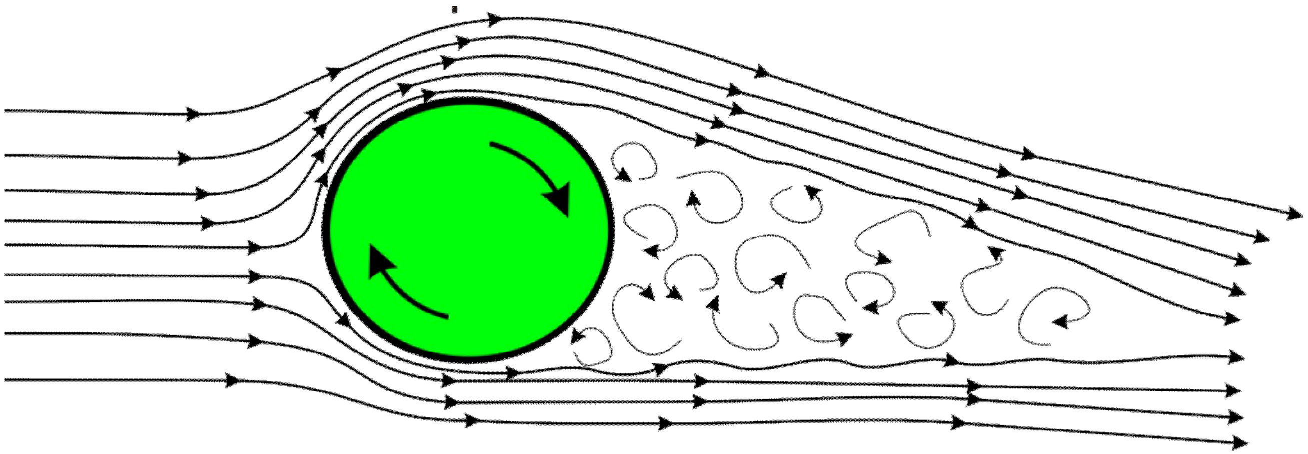
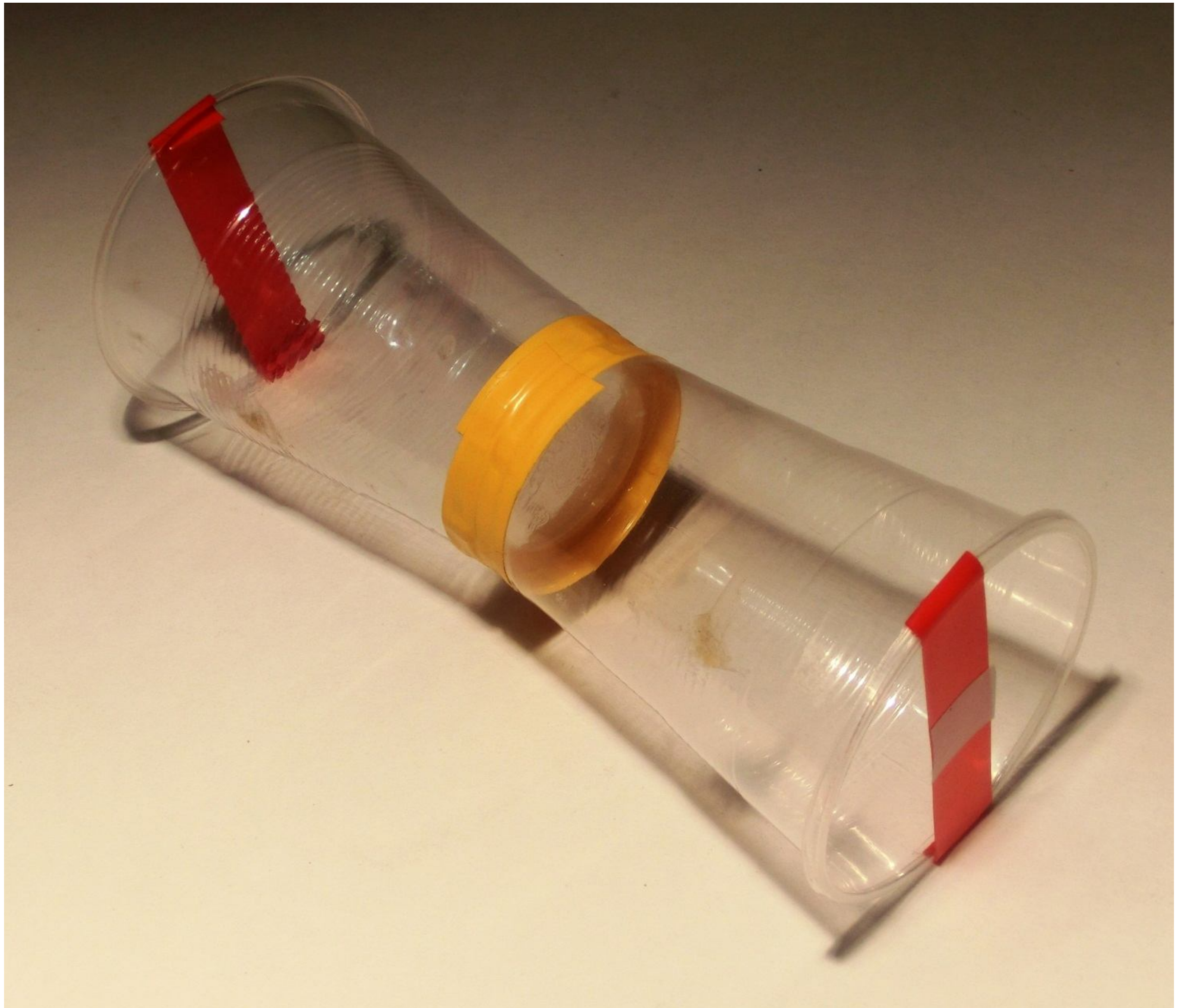
The problem

Glue the bottoms of two light cups together to make a glider. Wind an elastic band around the centre and hold the free end that remains. While holding the glider, stretch the free end of the elastic band and then release the glider. Investigate its motion.

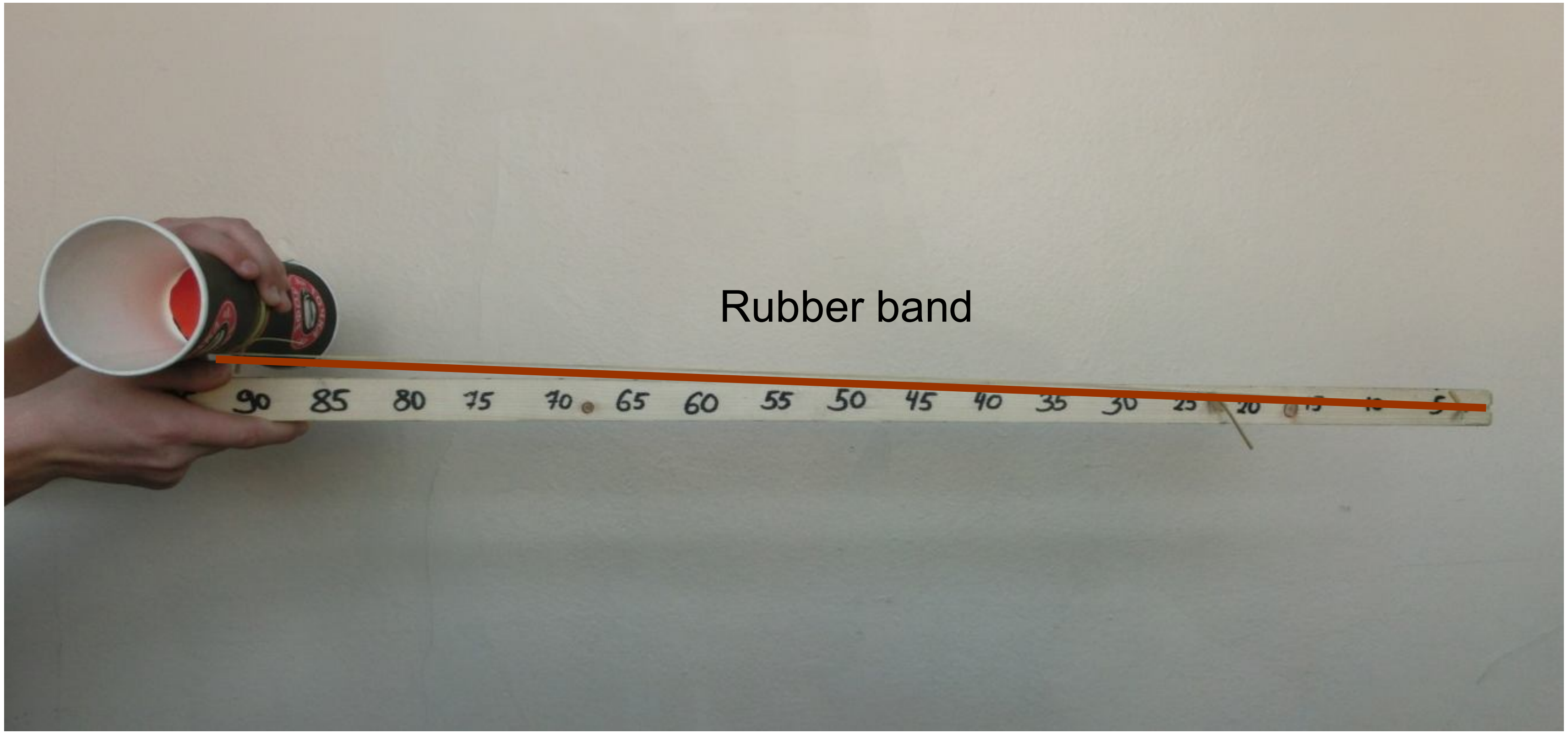


First observations

Glider

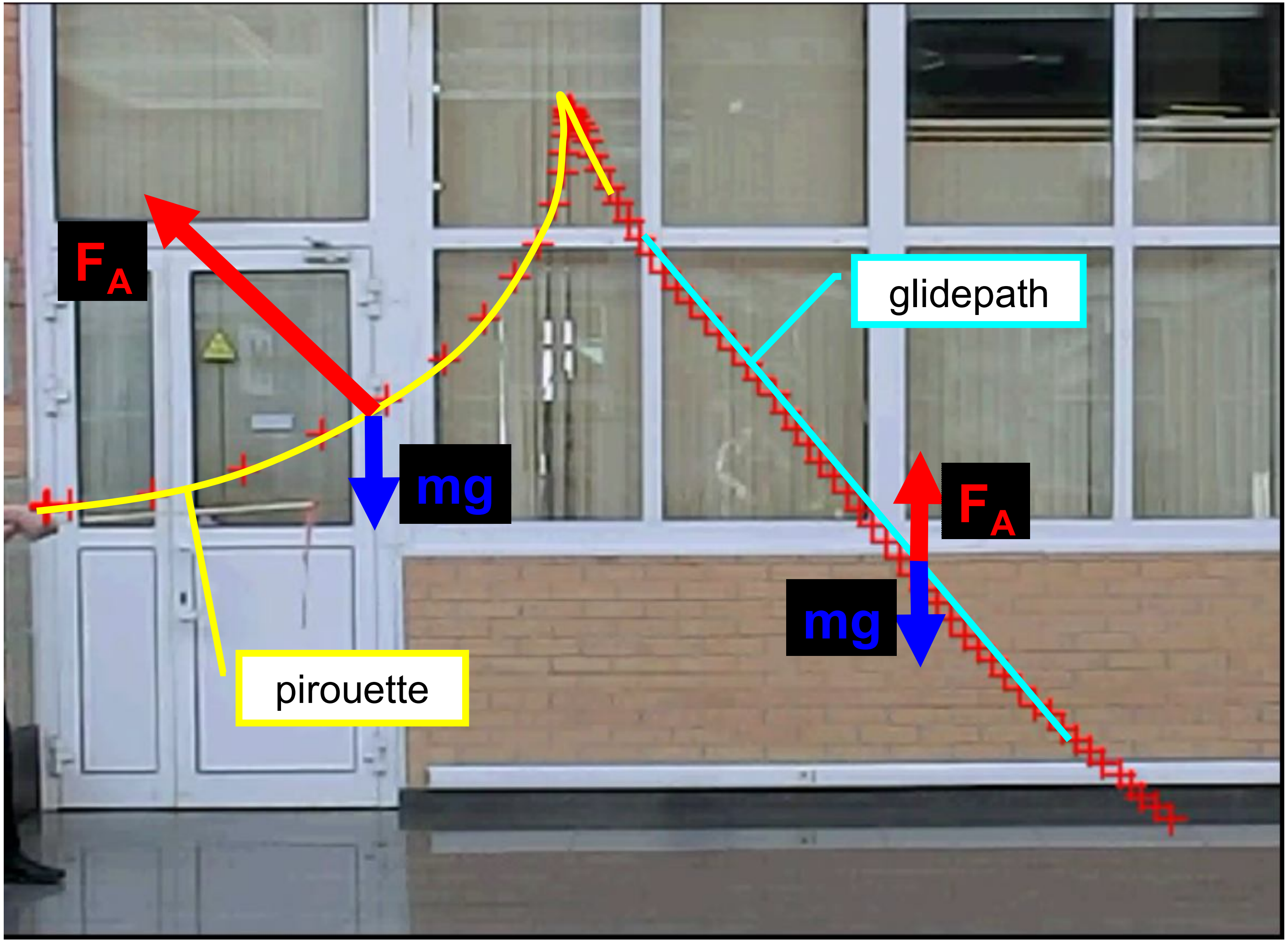


Launcher



Flight path of a glider (120 fps)

Parts of the flight path



Outline of the report

Air flow around the rotating cylinder

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Typical flight paths

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Aerodynamic characteristics of the glider

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Computer simulation of glider's motion

↓

Explanation of uniqueness of the loop

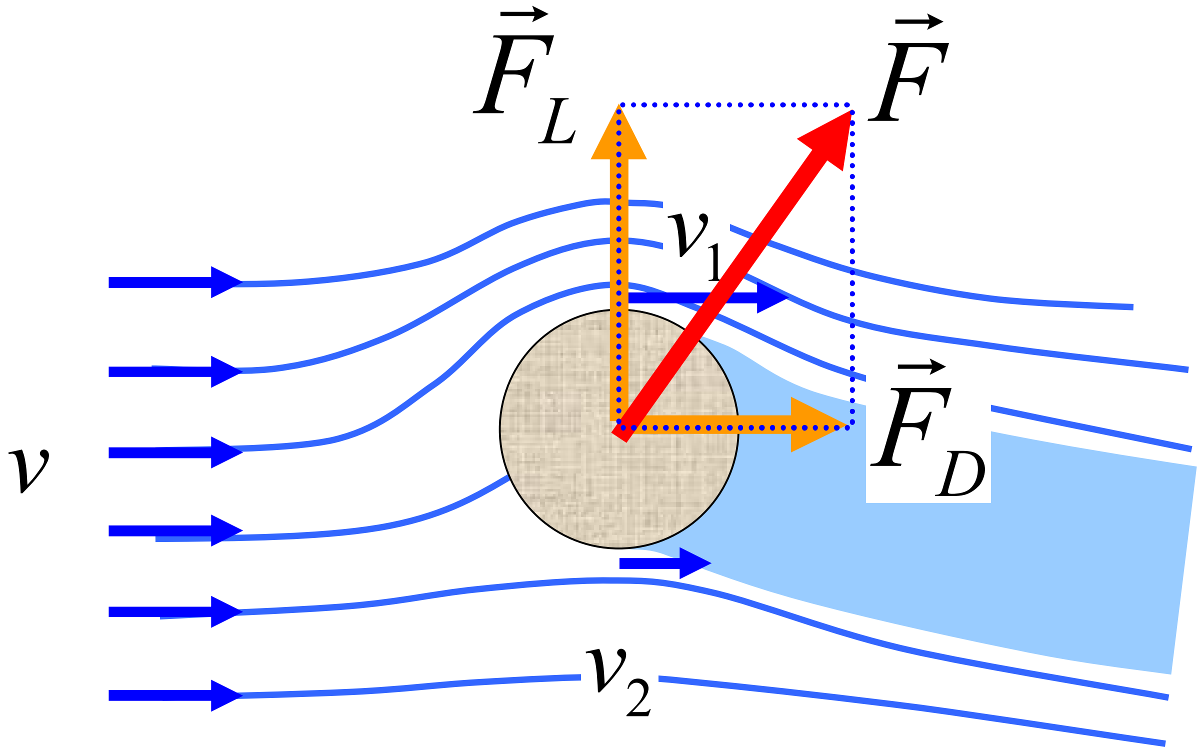
Air flow around a rotating cylinder

Flow type behind the glider

$$\mathrm{Re} = \frac{\rho v r}{\eta} \approx 10^4$$

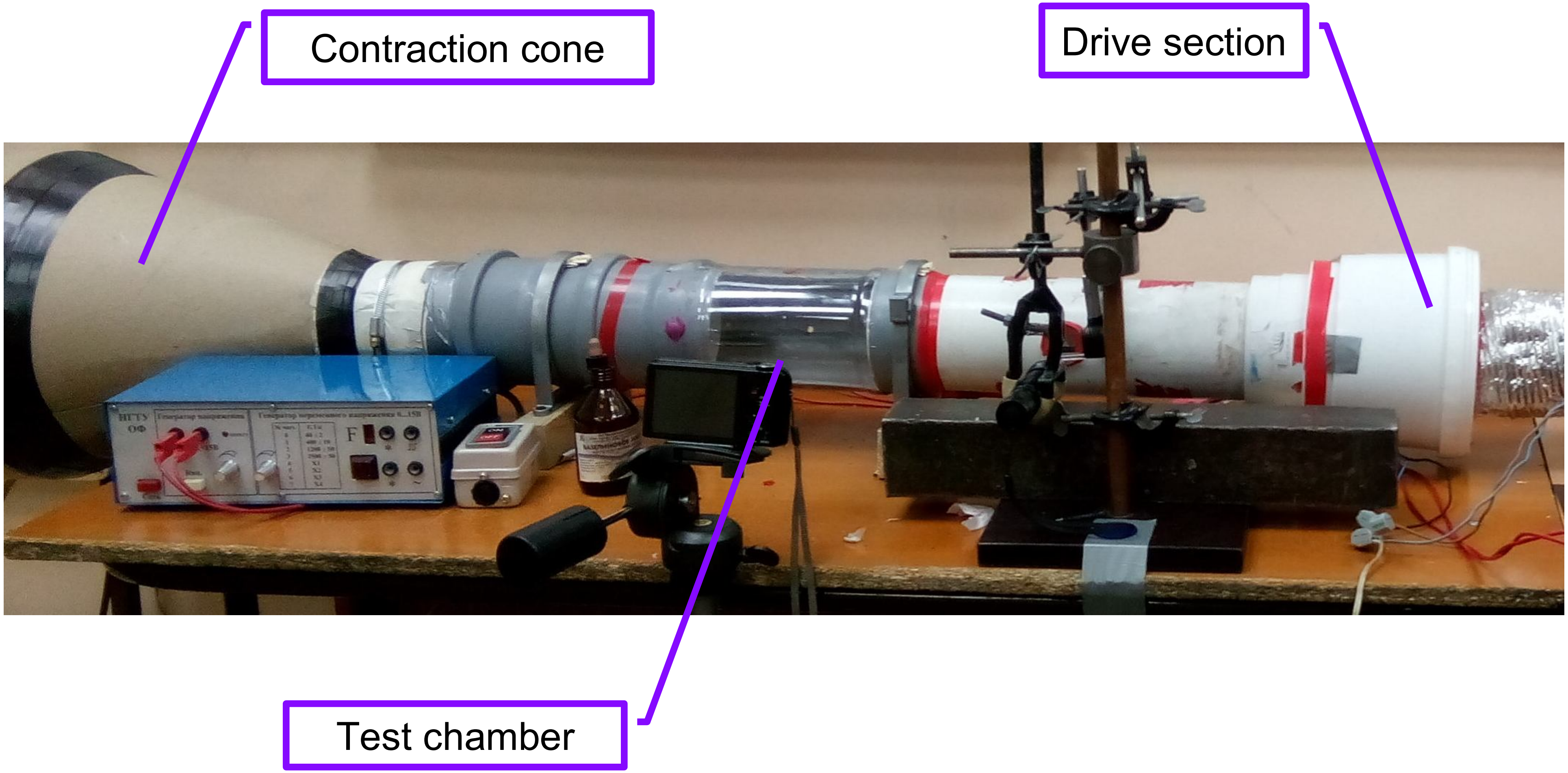
Flow behind the glider is turbulent

Aerodynamic force

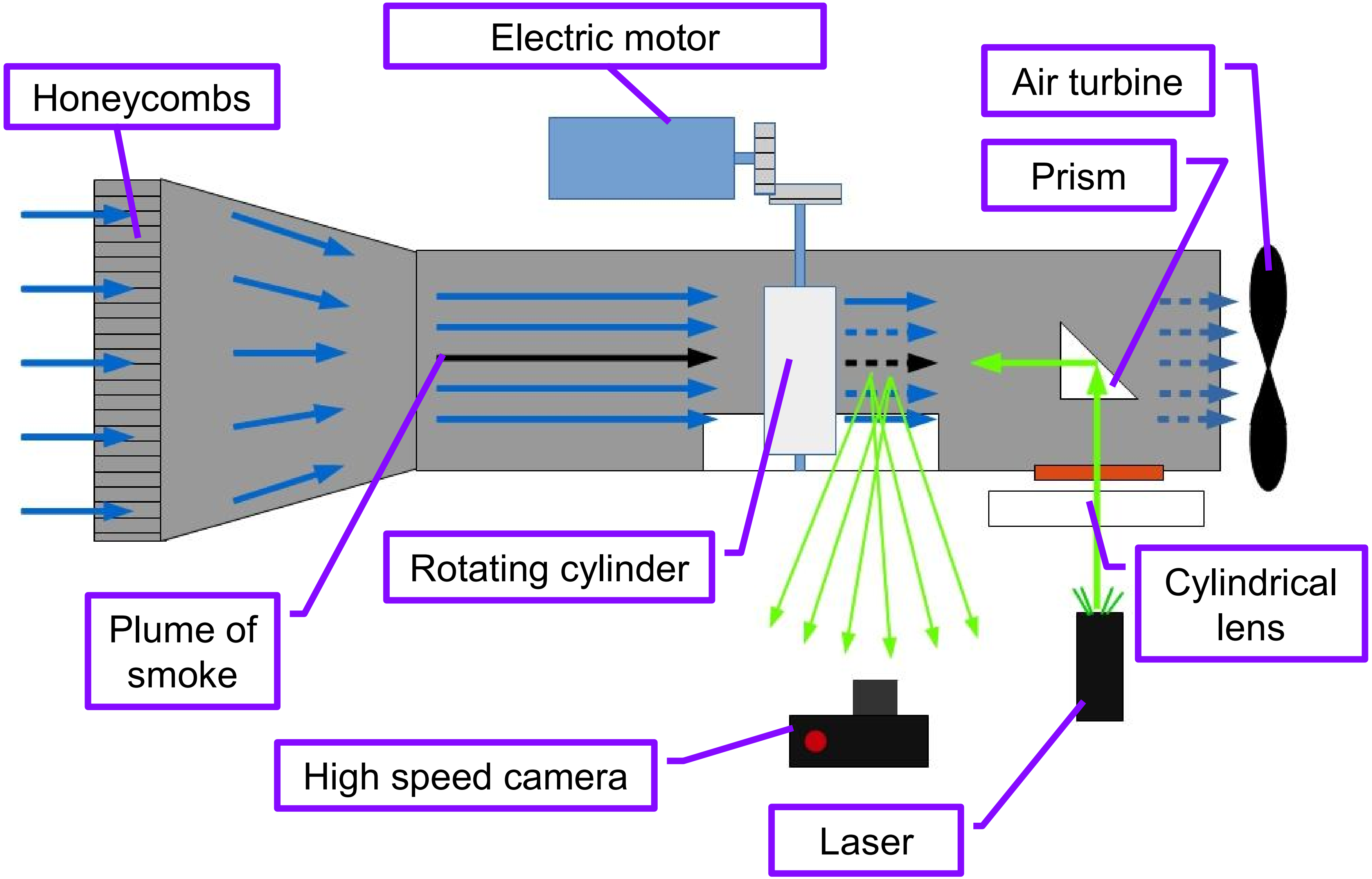


Bernoulli's principle: $v_1 > v_2 \quad \Rightarrow \quad p_1 < p_2$

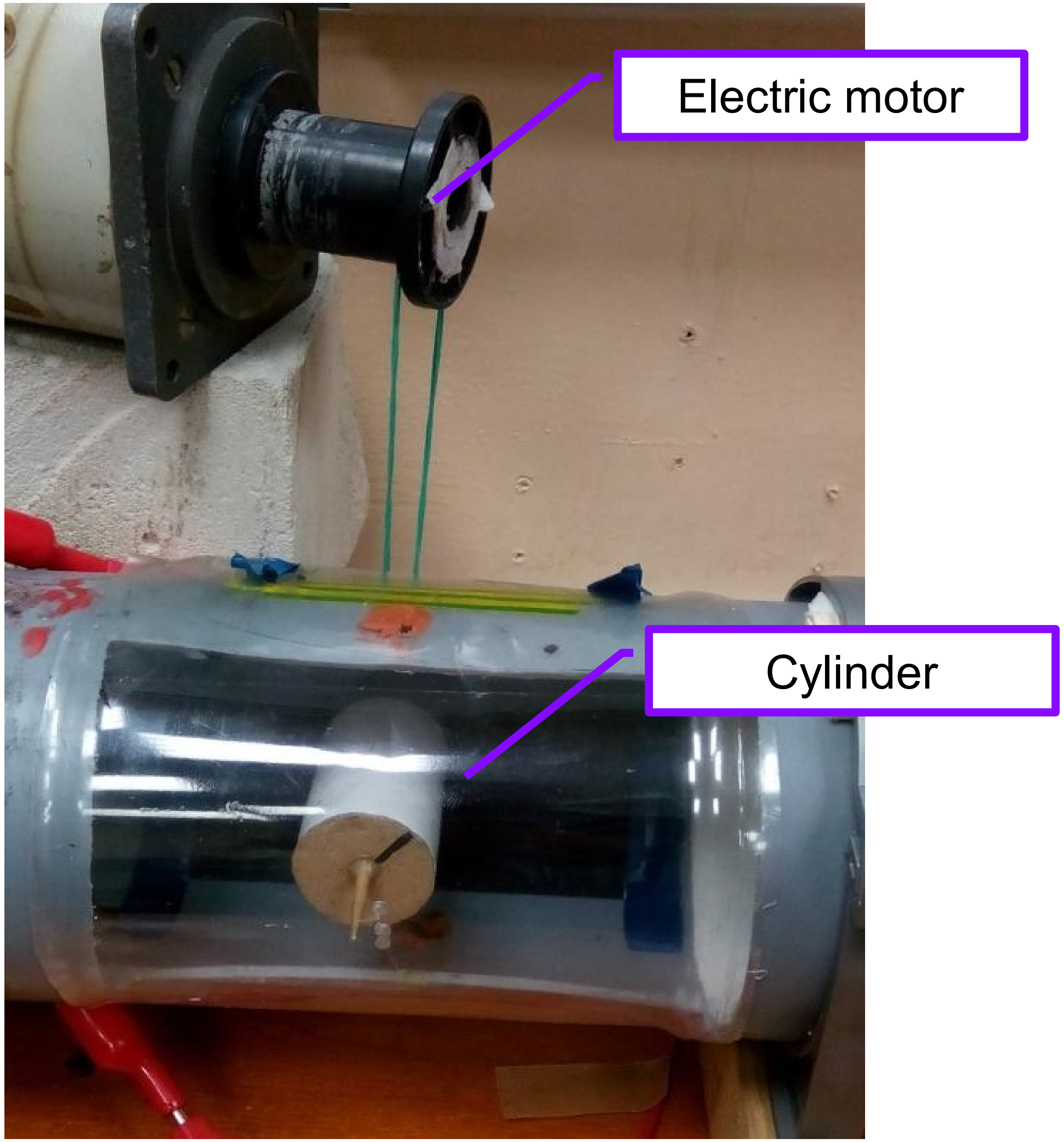
Setup #1: wind tunnel



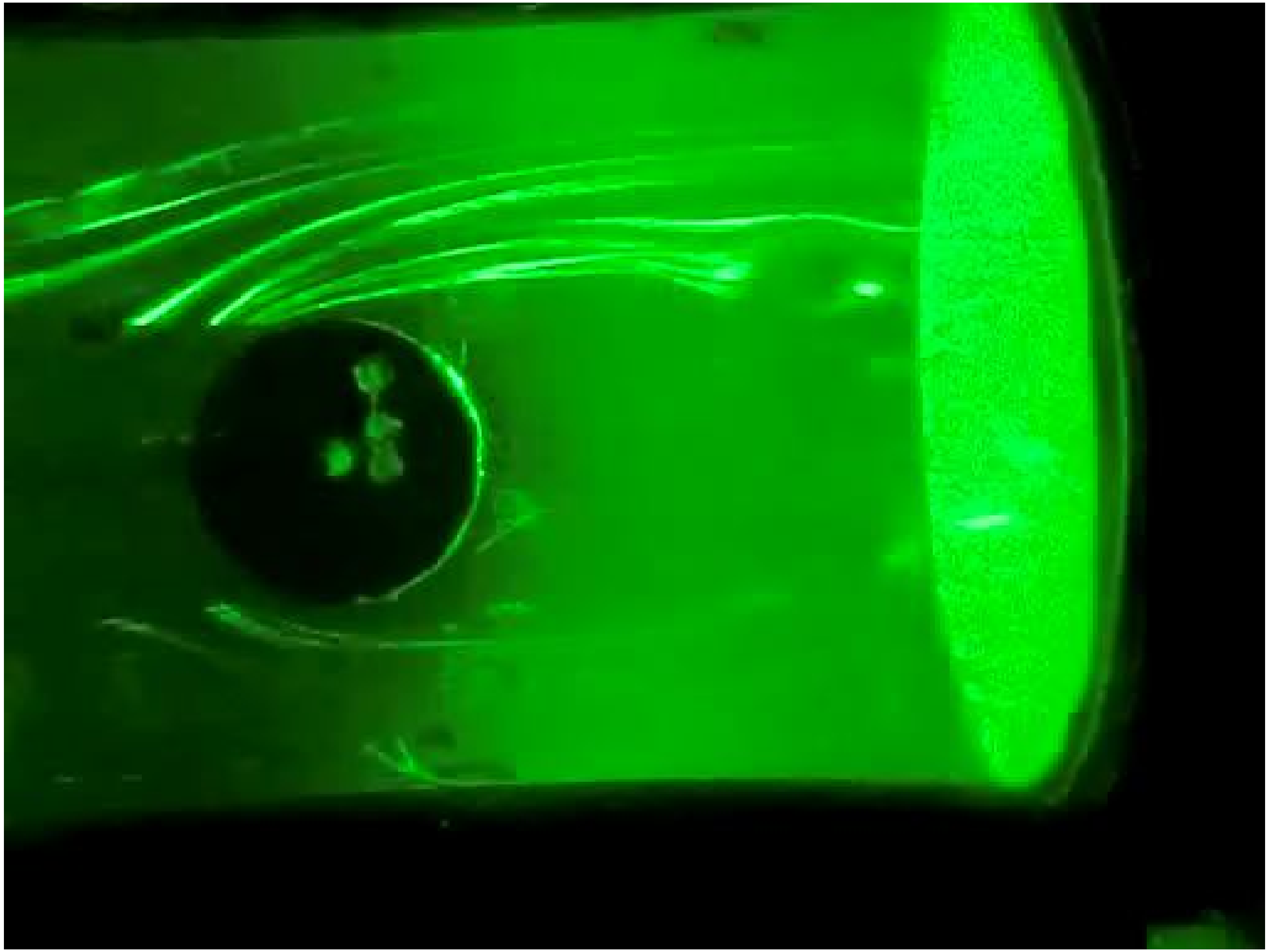
Wind tunnel scheme



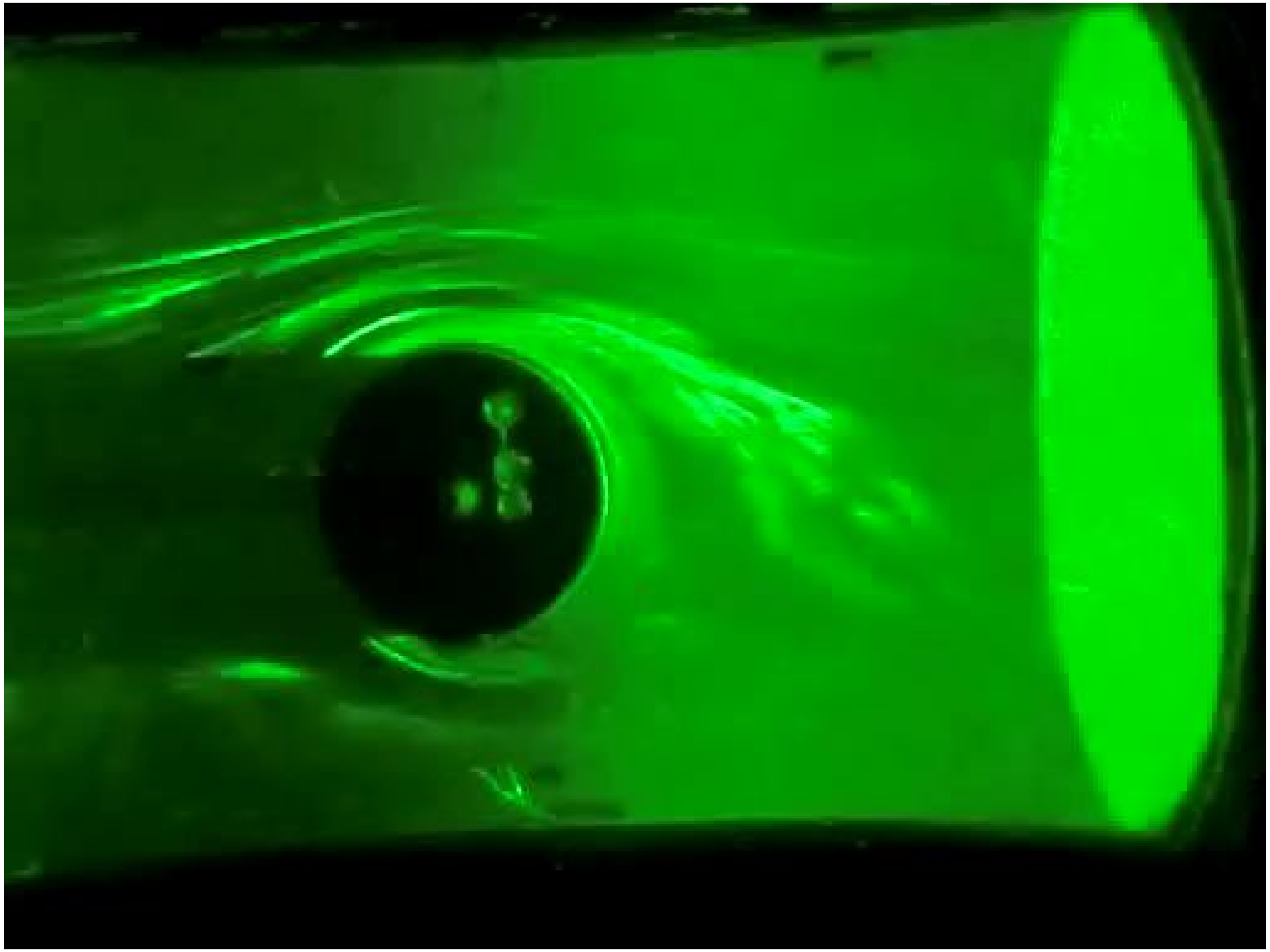
Cylinder rotates in the test chamber



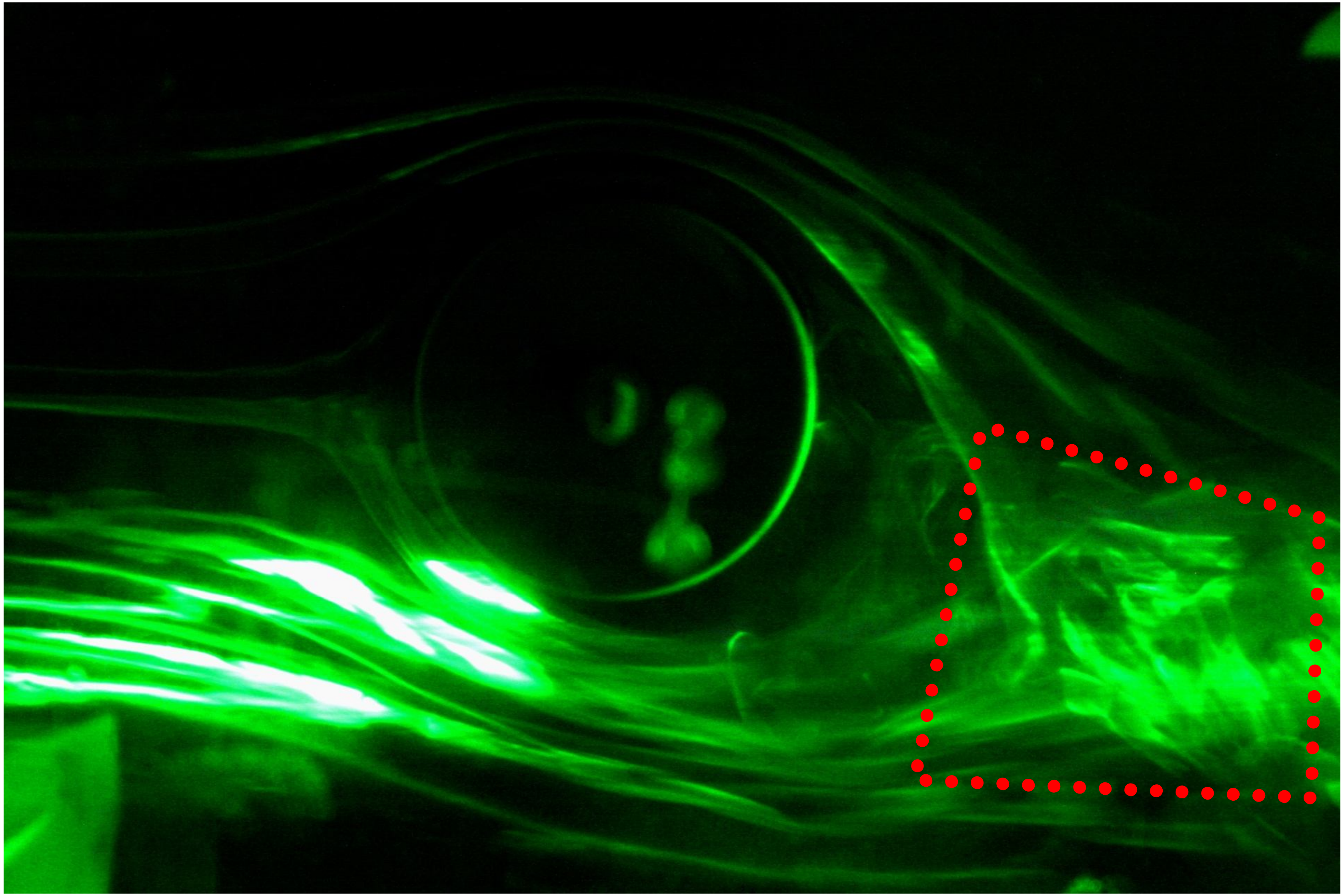
Flow without rotation (video)



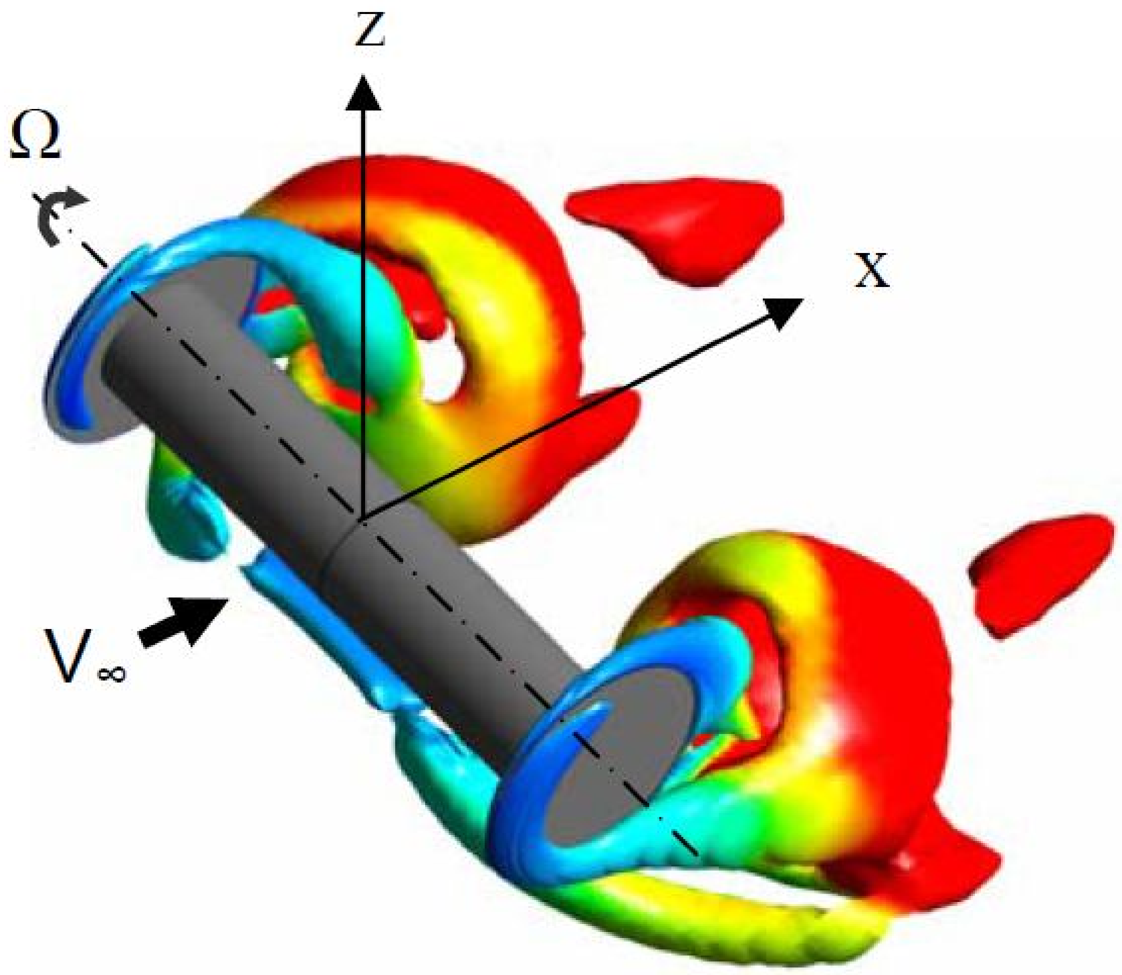
Flow with rotation (video)



Induced tip vortices



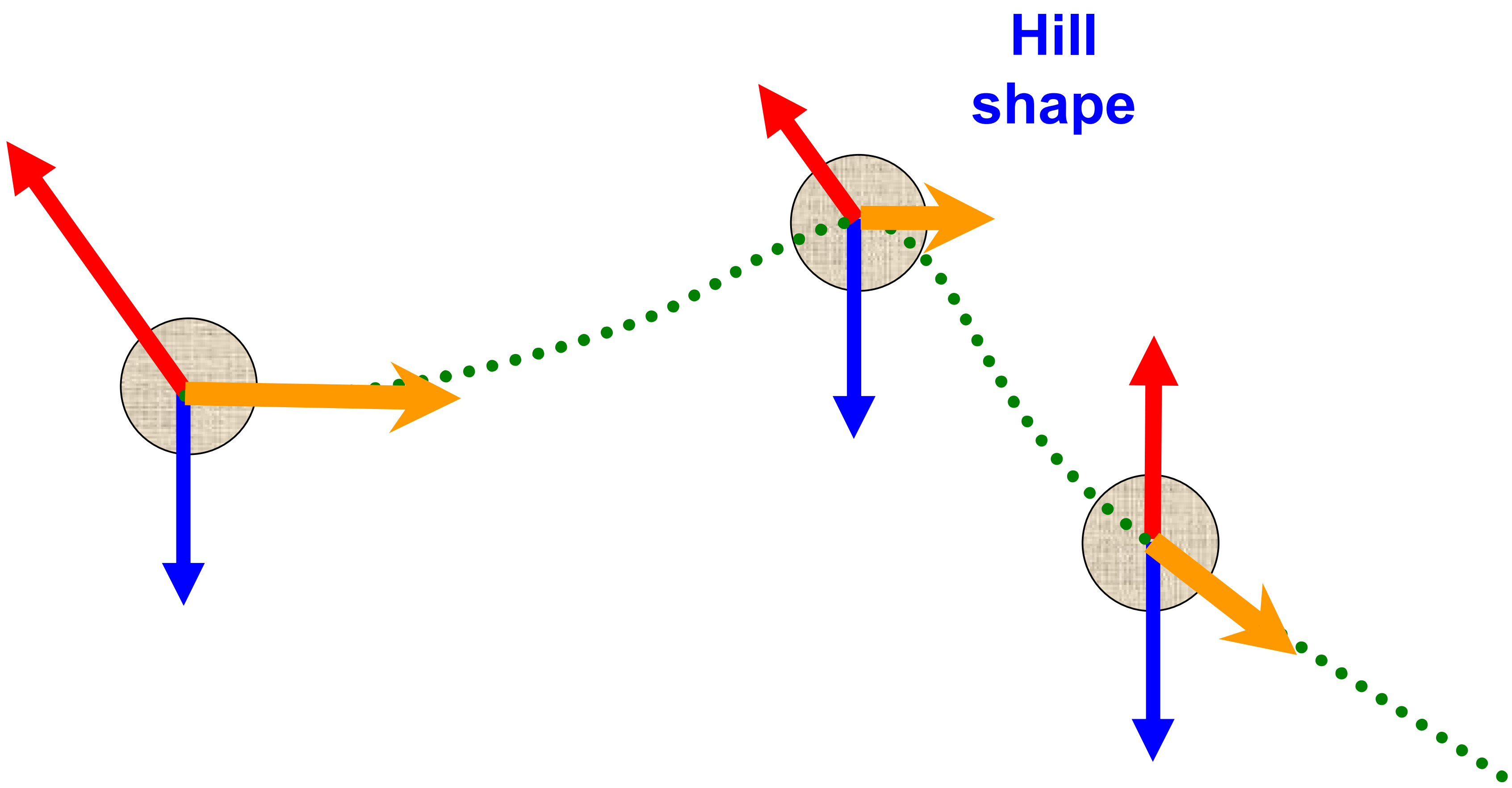
Induced tip vortices



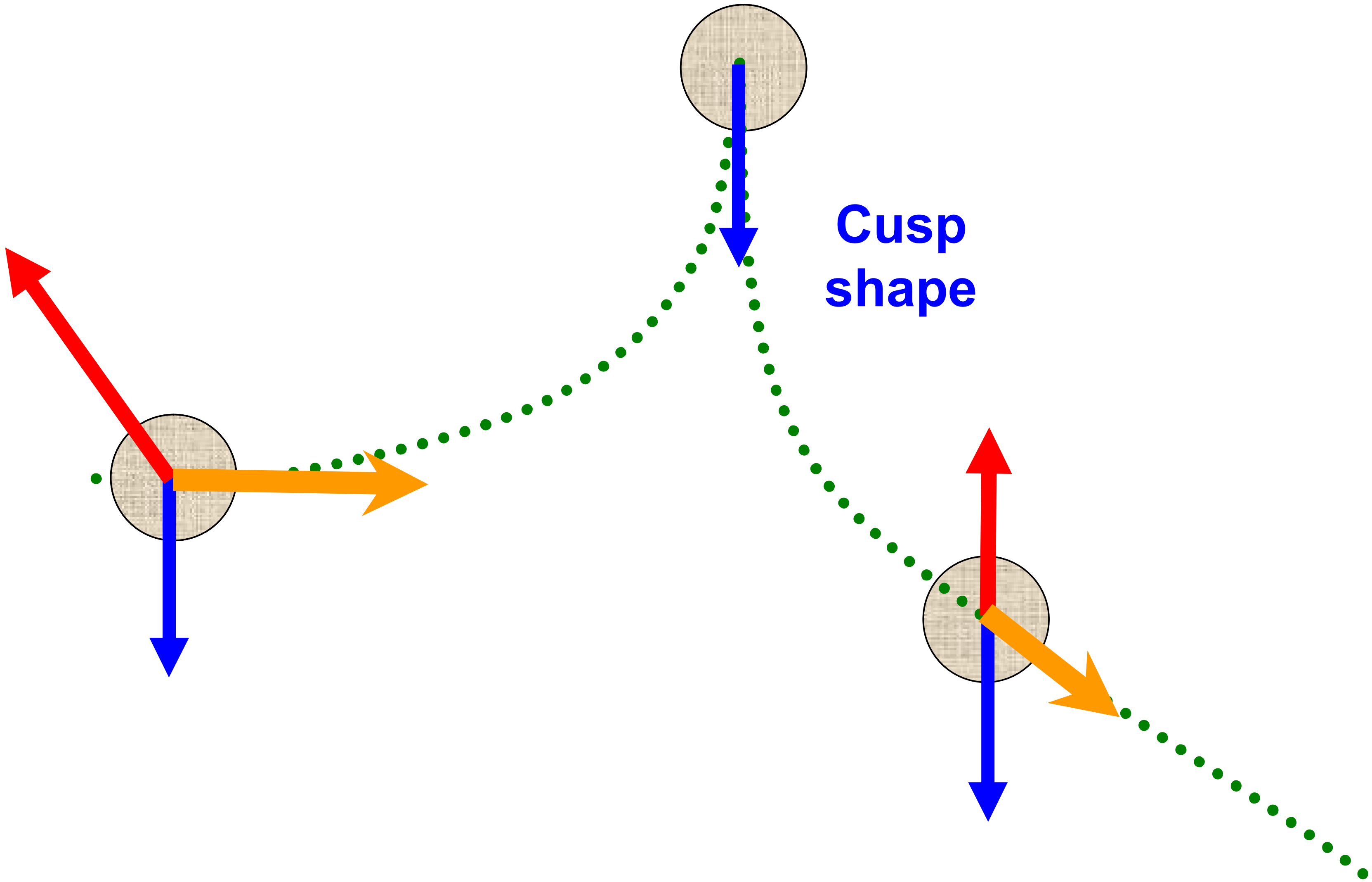
Thouault N. et al. (2012) “Numerical analysis of a rotating cylinder with spanwise discs”.

Typical flight paths

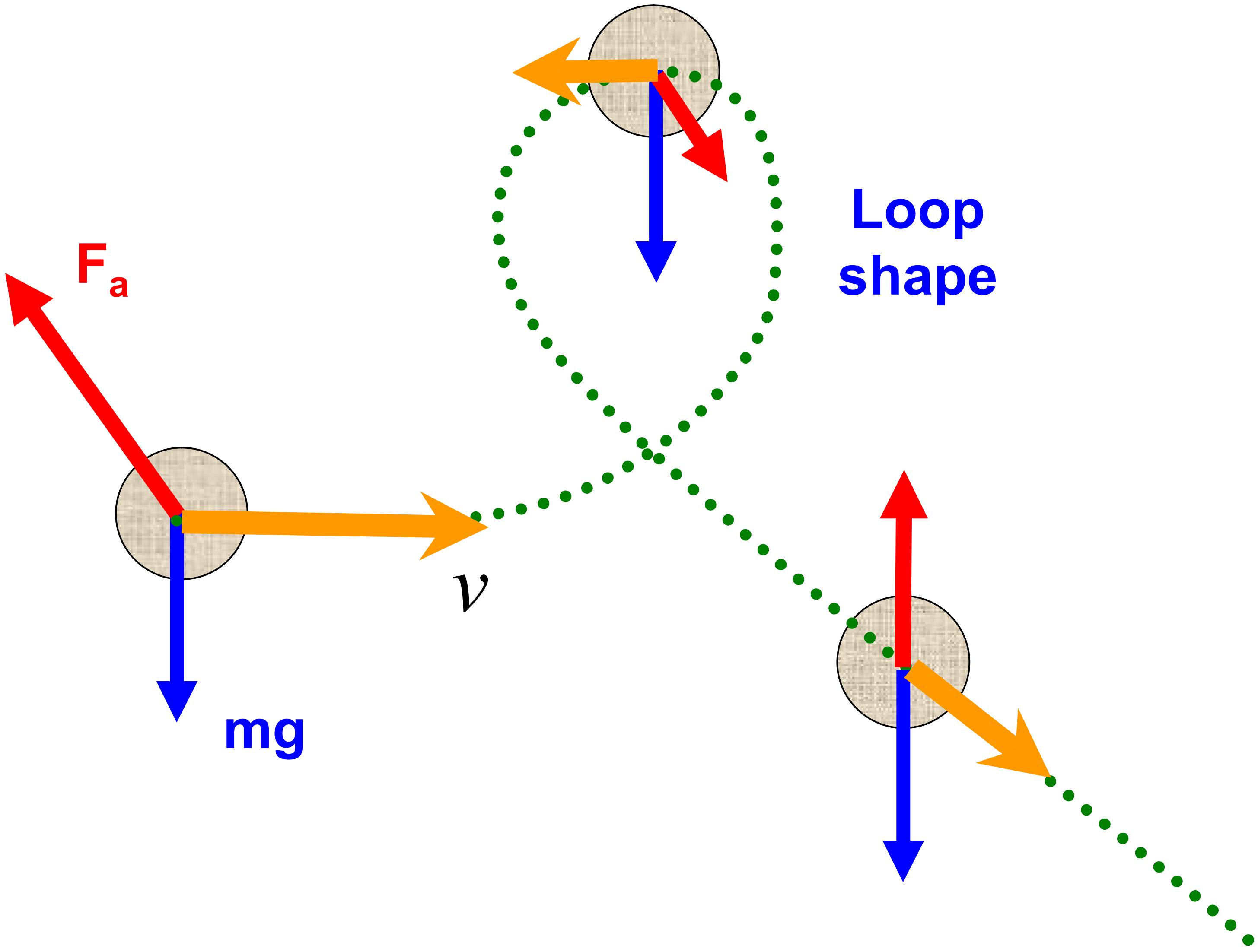
Low initial velocity



Increasing of the initial velocity



High initial velocity



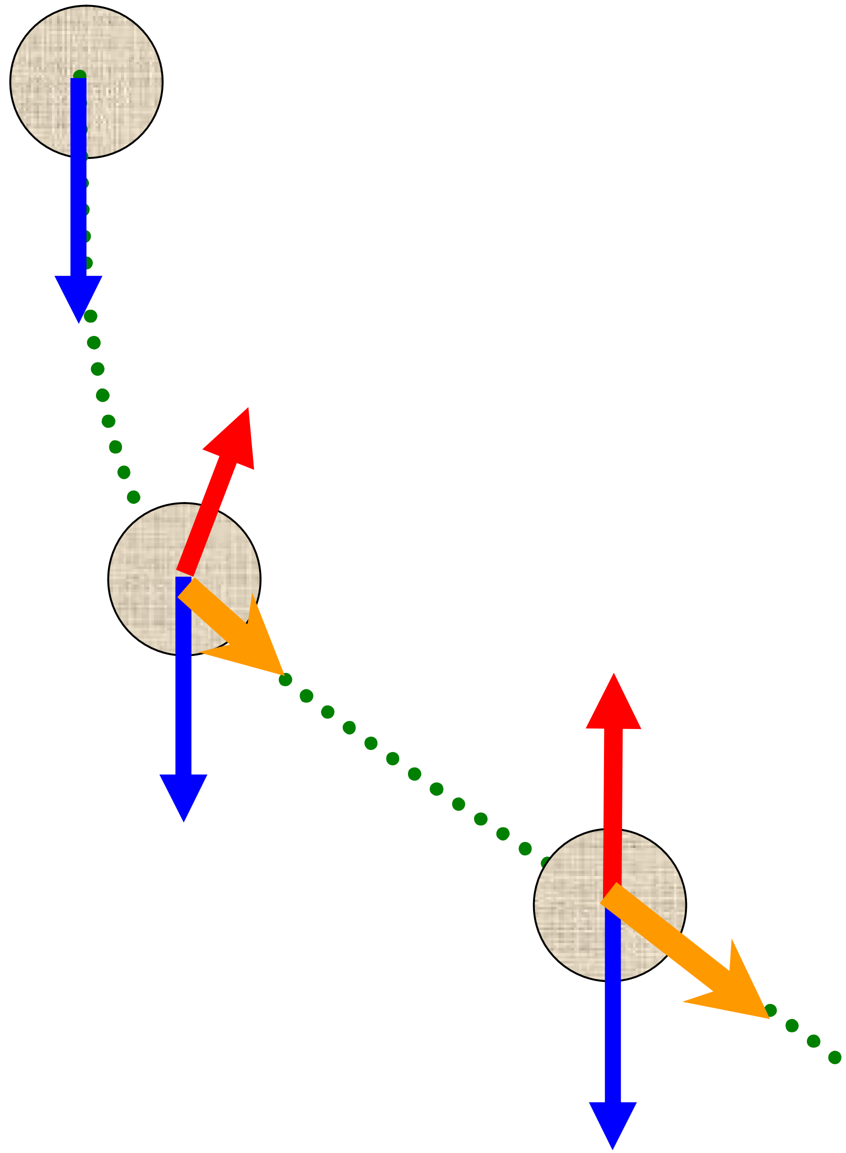
What is "high" and "low" velocity?

$$mg \simeq \rho v^2 S$$

$$v \approx \sqrt{\frac{mg}{\rho S}}$$

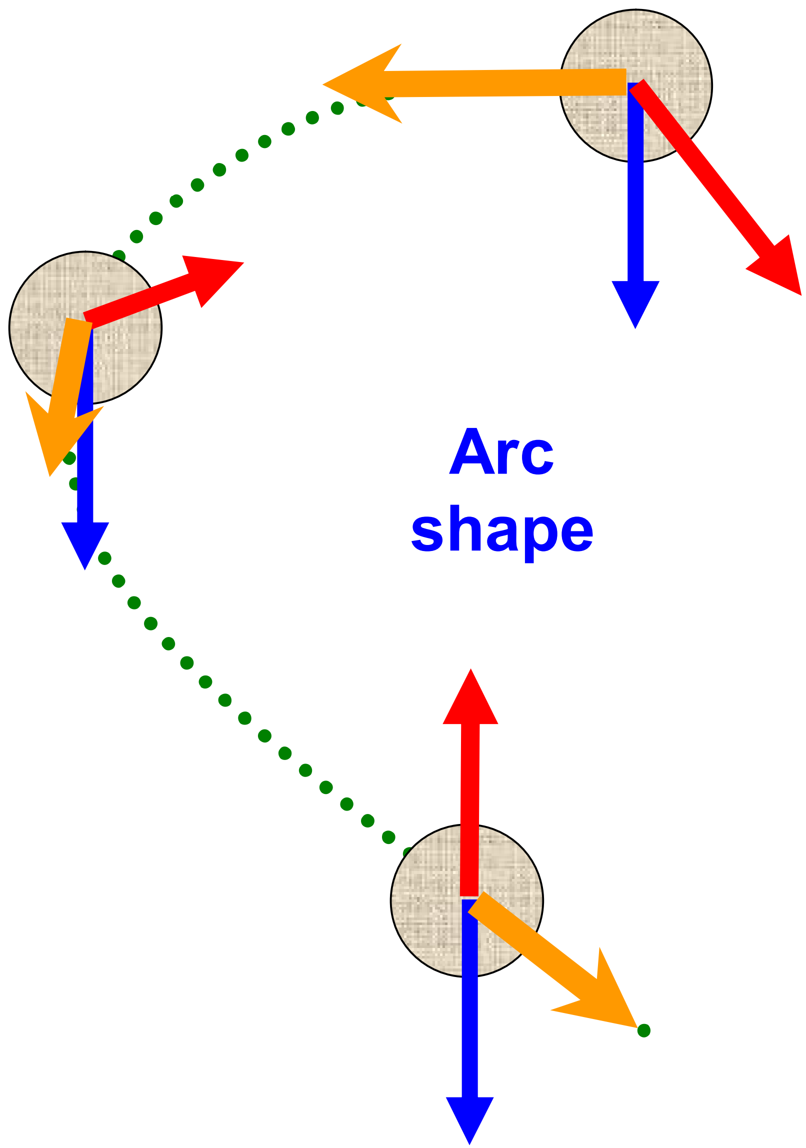
$$v \approx 3 \text{ m/s}$$

Zero initial velocity



Zero initial velocity (240 fps)

Reverse rotation

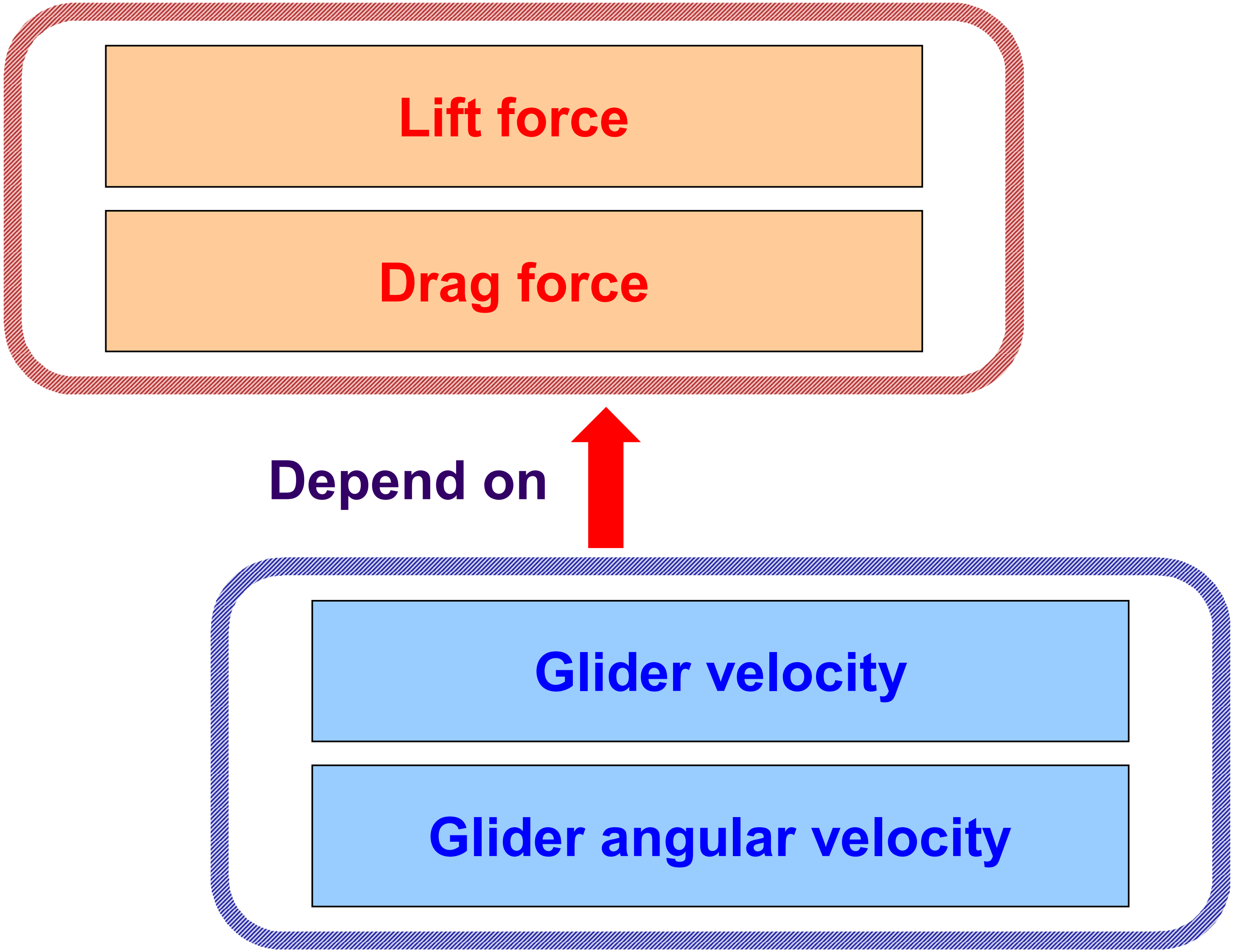


Reverse rotation (120 fps)

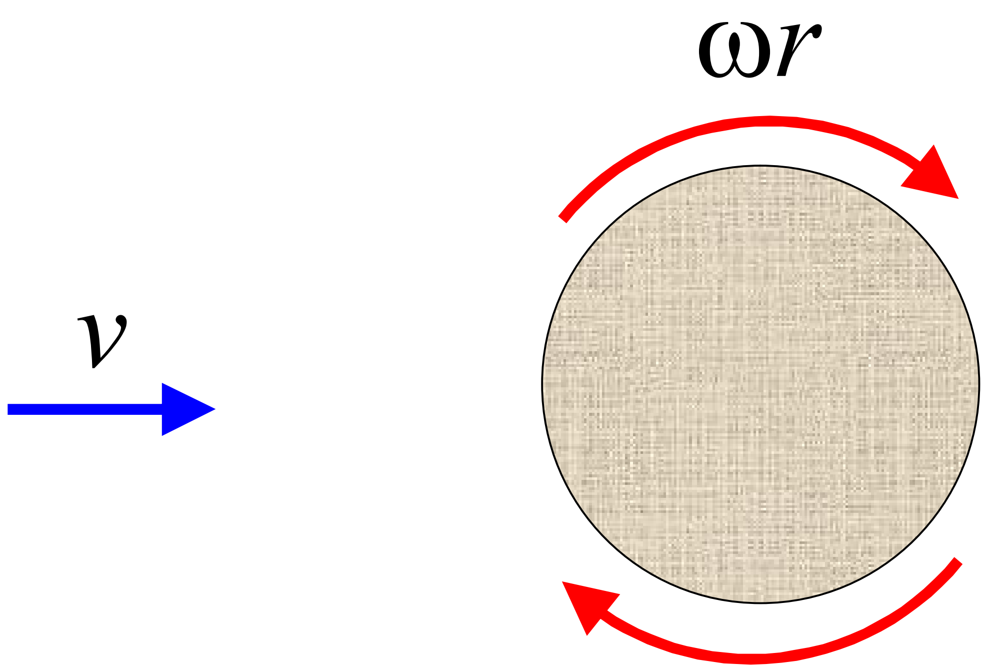
Aerodynamic characteristics

"Investigate its motion…"

Aerodynamic forces



Spinning ratio



$$\alpha = \frac{\omega r}{v} = 0 \div 10$$

Aerodynamic coefficients

Spinning ratio

Drag force

Drag coefficient

$$F_D = C_D(\alpha) \cdot \frac{1}{2}\rho v^2 S$$

$$F_L = C_L(\alpha) \cdot \frac{1}{2}\rho v^2 S$$

Lift force

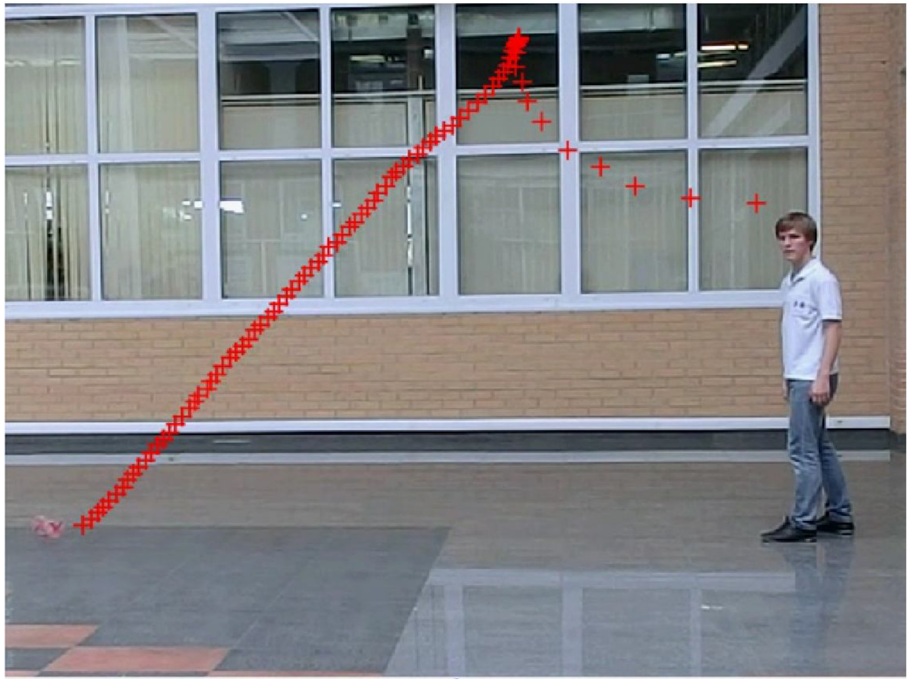
Lift coefficient

Dynamic pressure

Cross section

The main idea

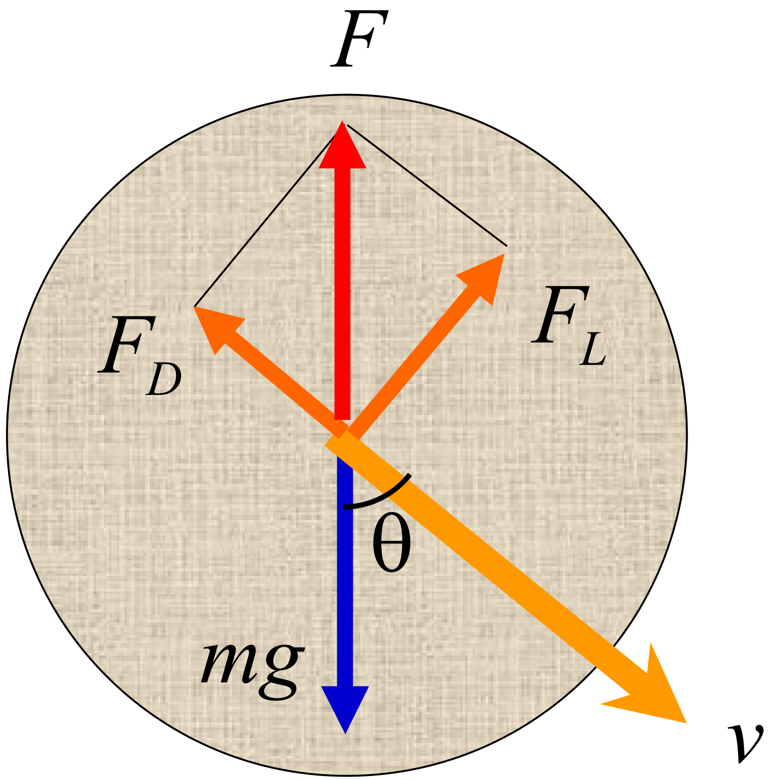
Wind tunnel?



Glidepath!

Constancy of the angular velocity

Balance of forces on a glidepath

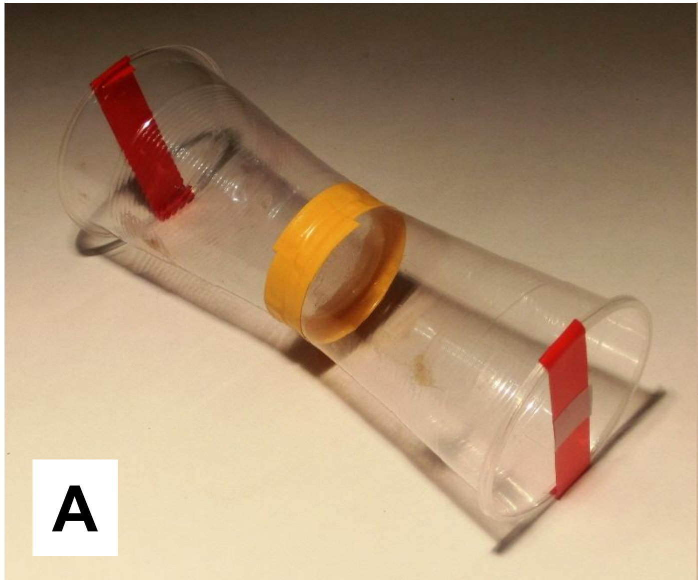


$$F_D = mg\cos\theta$$

$$F_L = mg\sin\theta$$

$$F_D = C_D(\alpha)\cdot\tfrac{1}{2}\rho v^2 S$$

$$F_L = C_L(\alpha)\cdot\tfrac{1}{2}\rho v^2 S$$



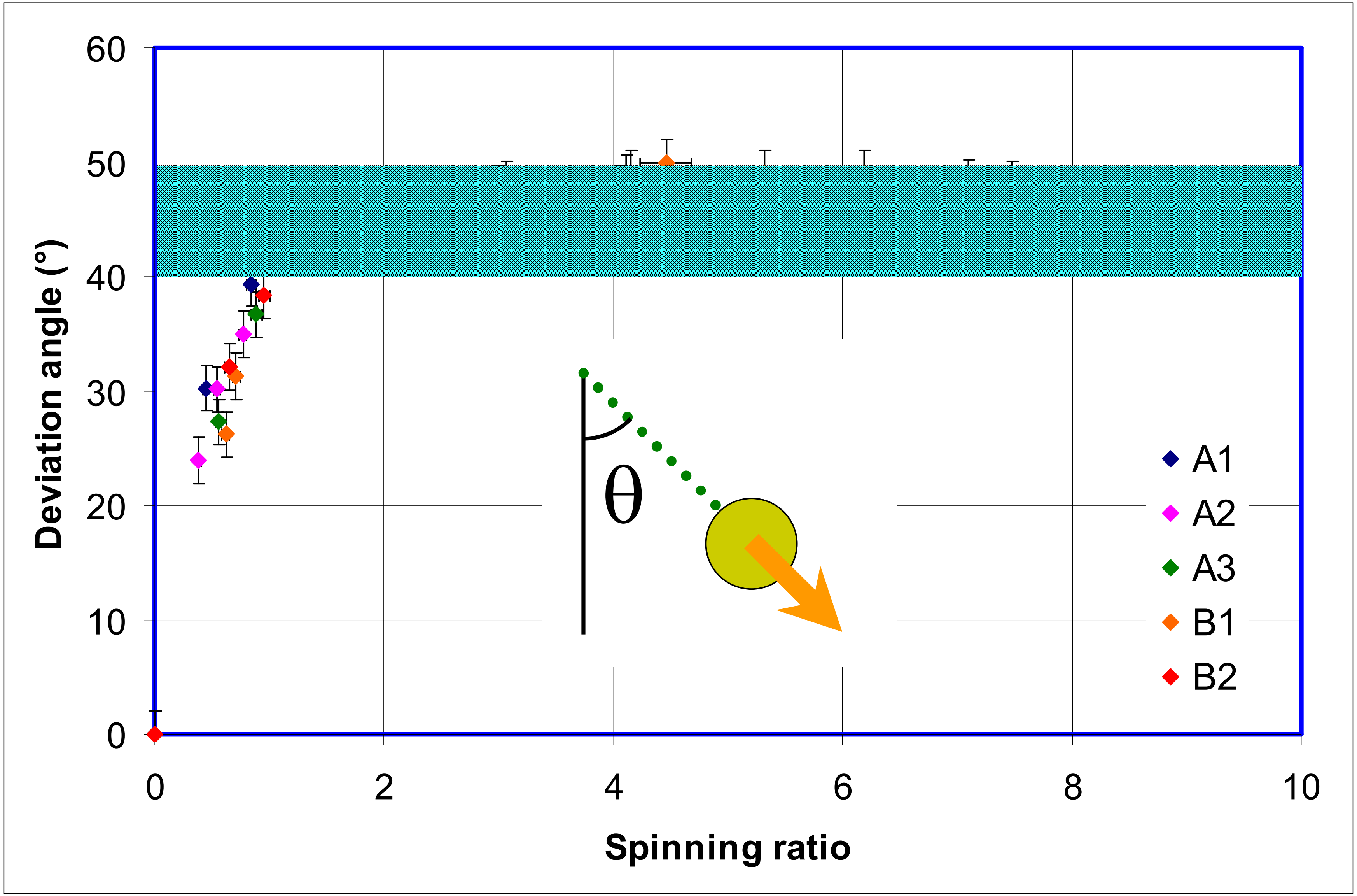
$S = 0.01\ \mathrm{m}^2$

$m = 5.5\ \mathrm{g};\ 10.5\ \mathrm{g};\ 15.5\ \mathrm{g}$

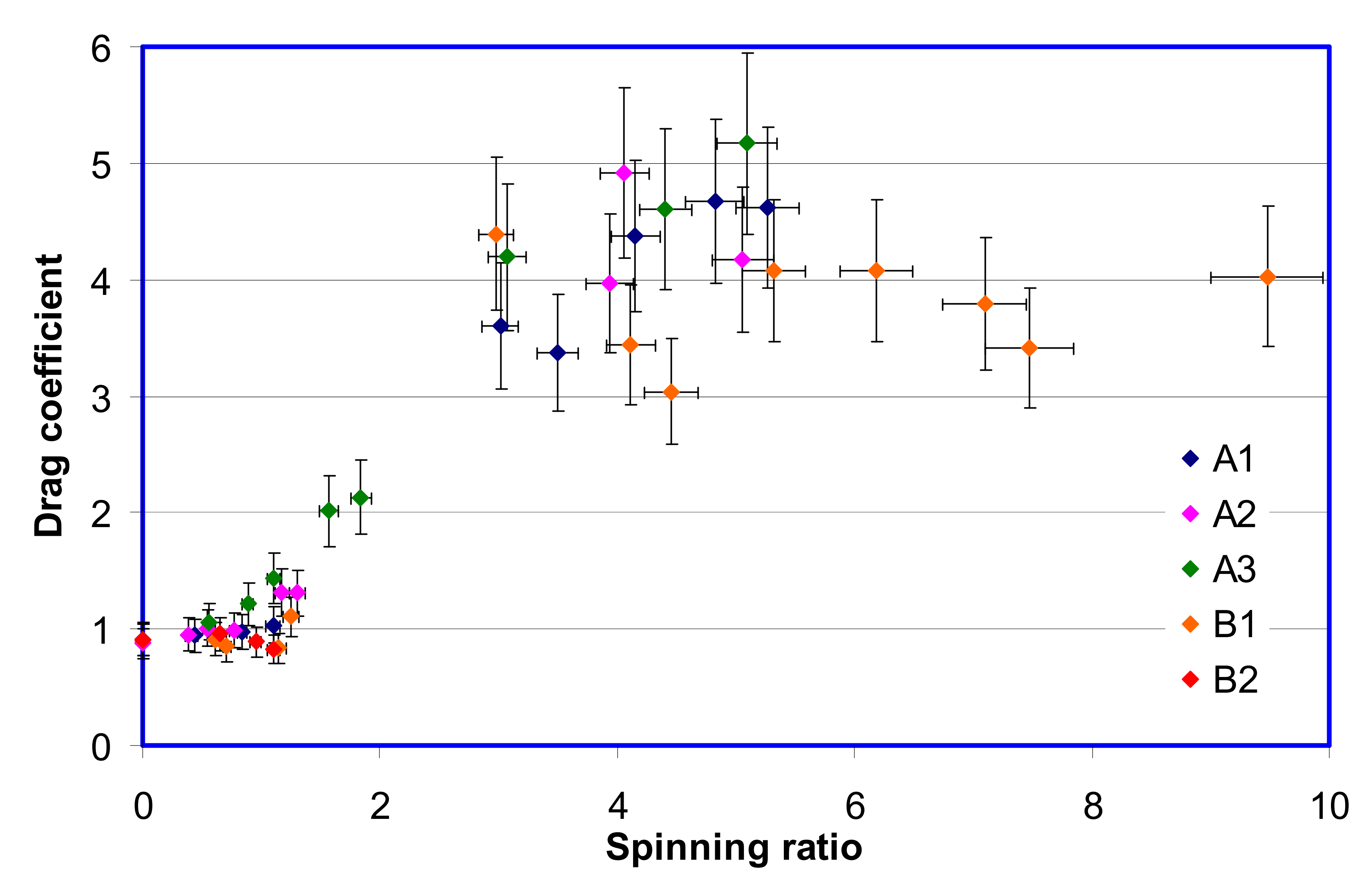
$S = 0.02\ \mathrm{m}^2$

$m = 12\ \mathrm{g};\ 23\ \mathrm{g}$

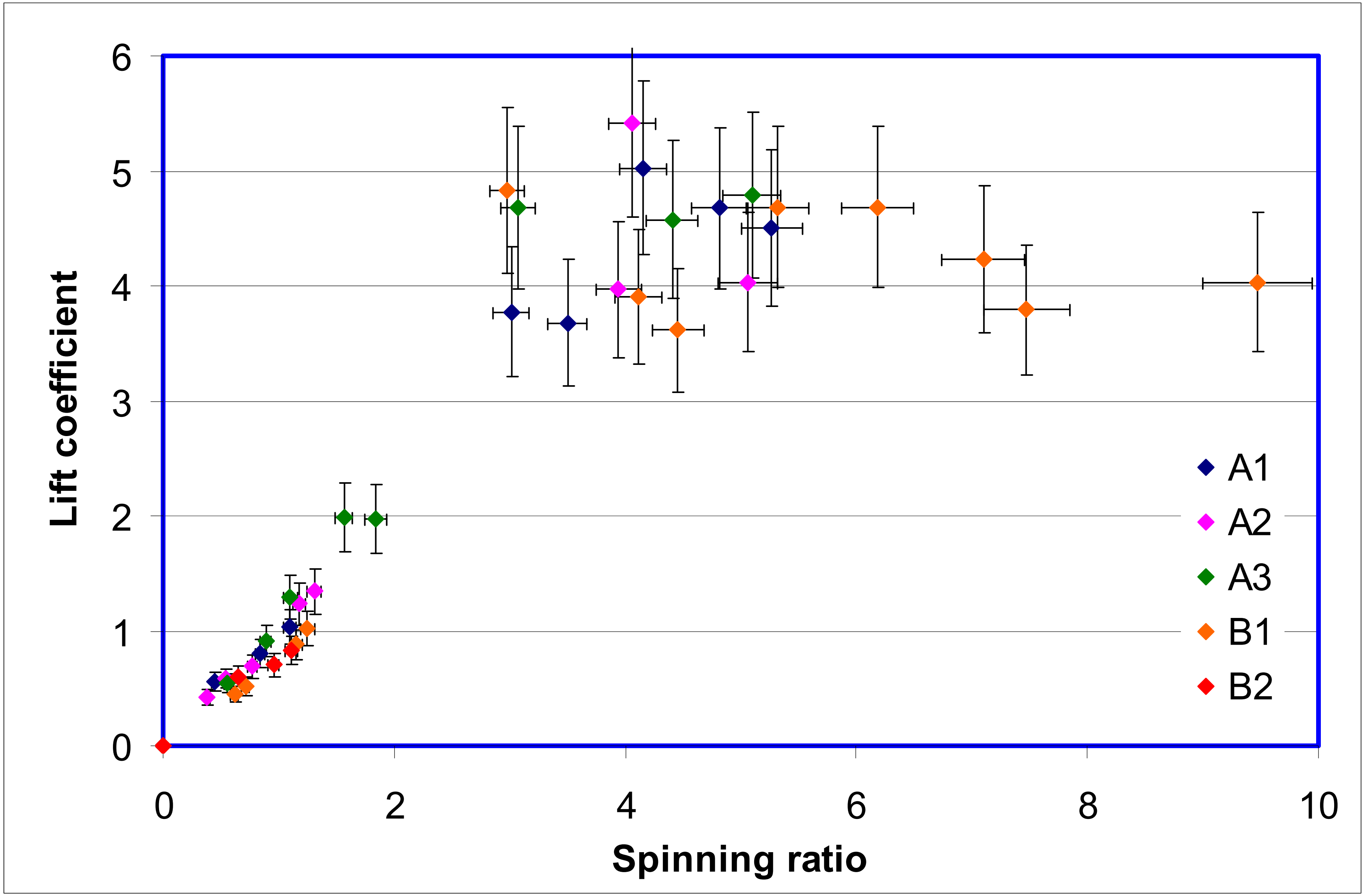
Vertical deviation angle



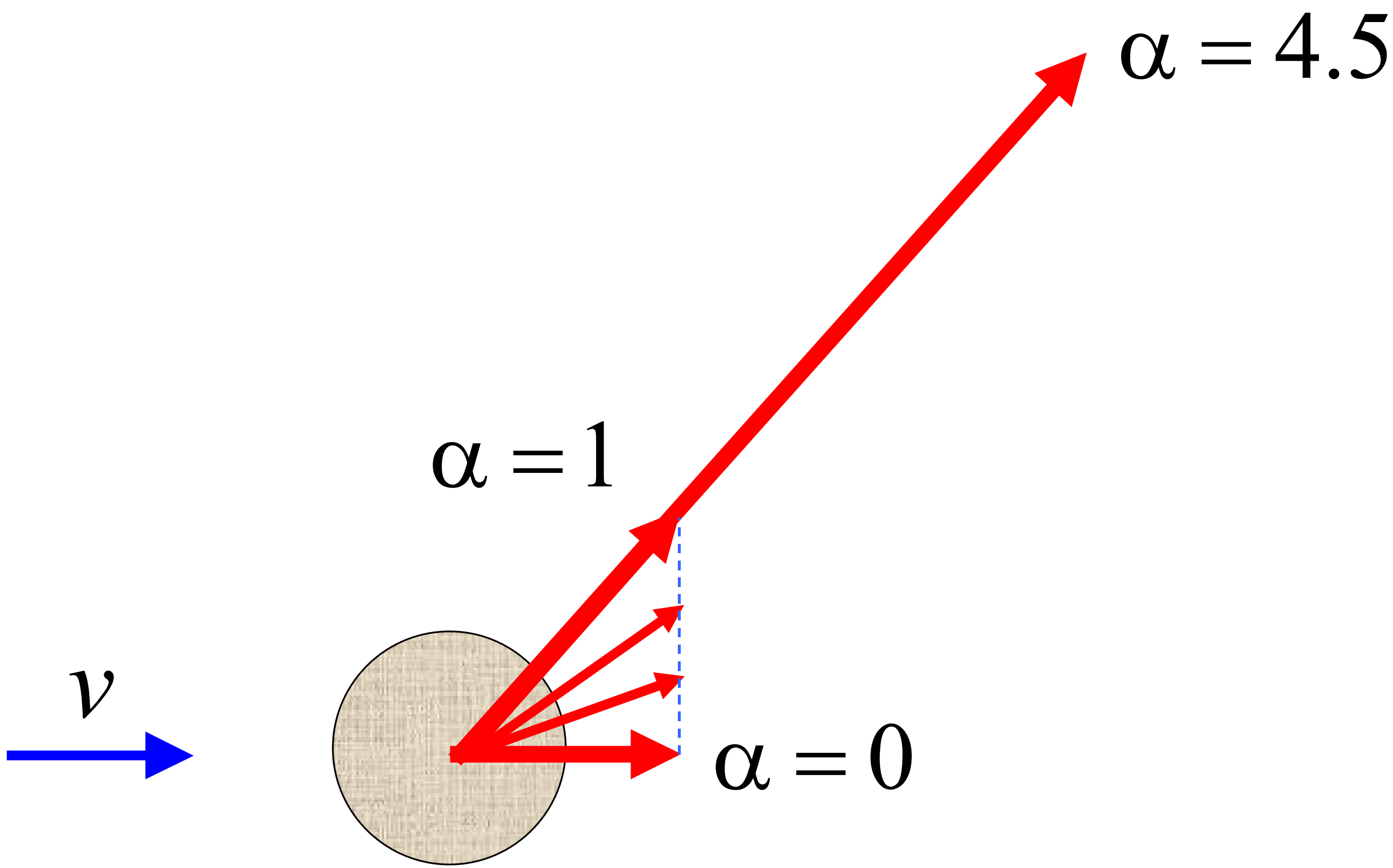
Drag coefficient



Lift coefficient

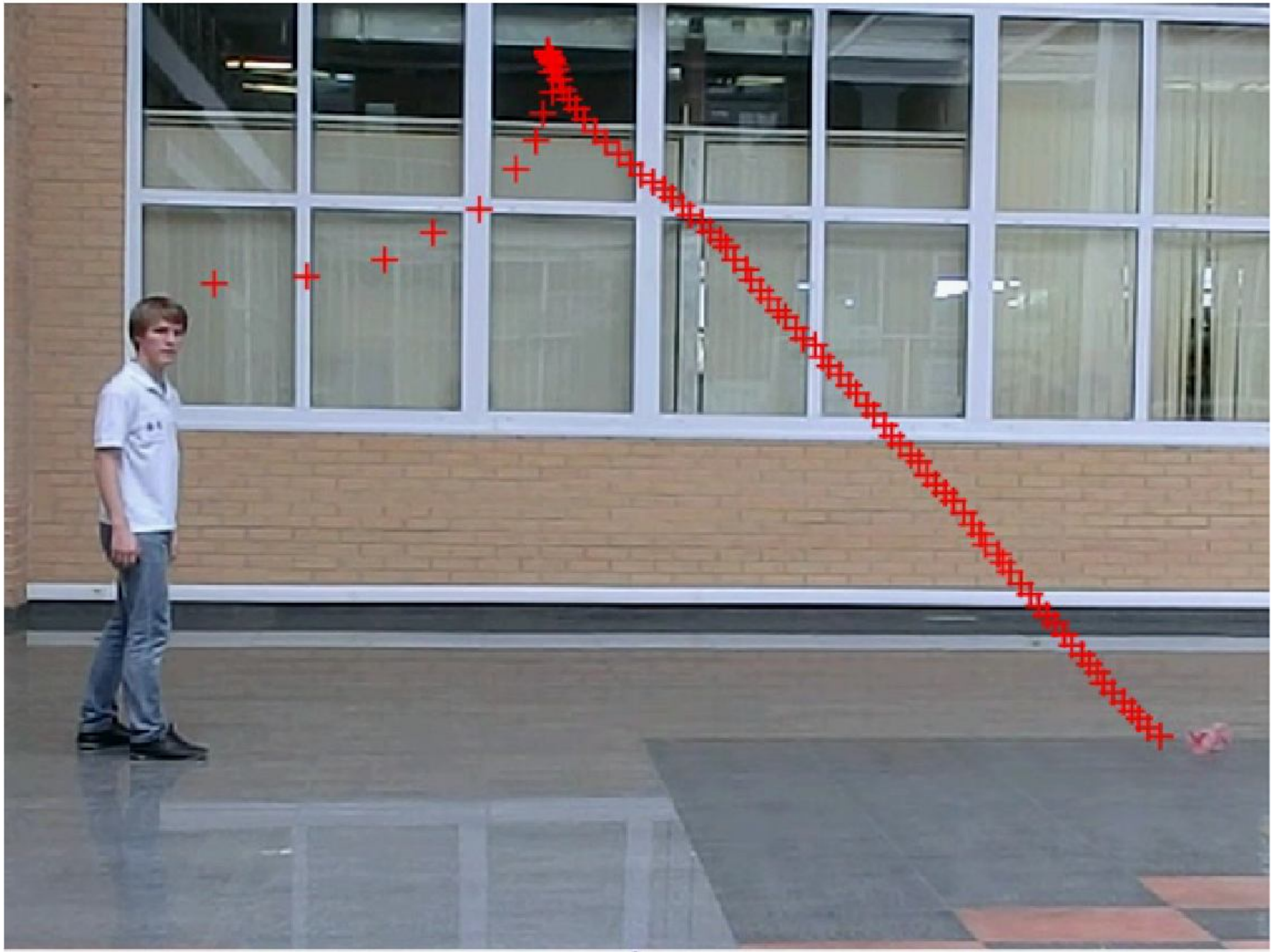


Aerodynamic force

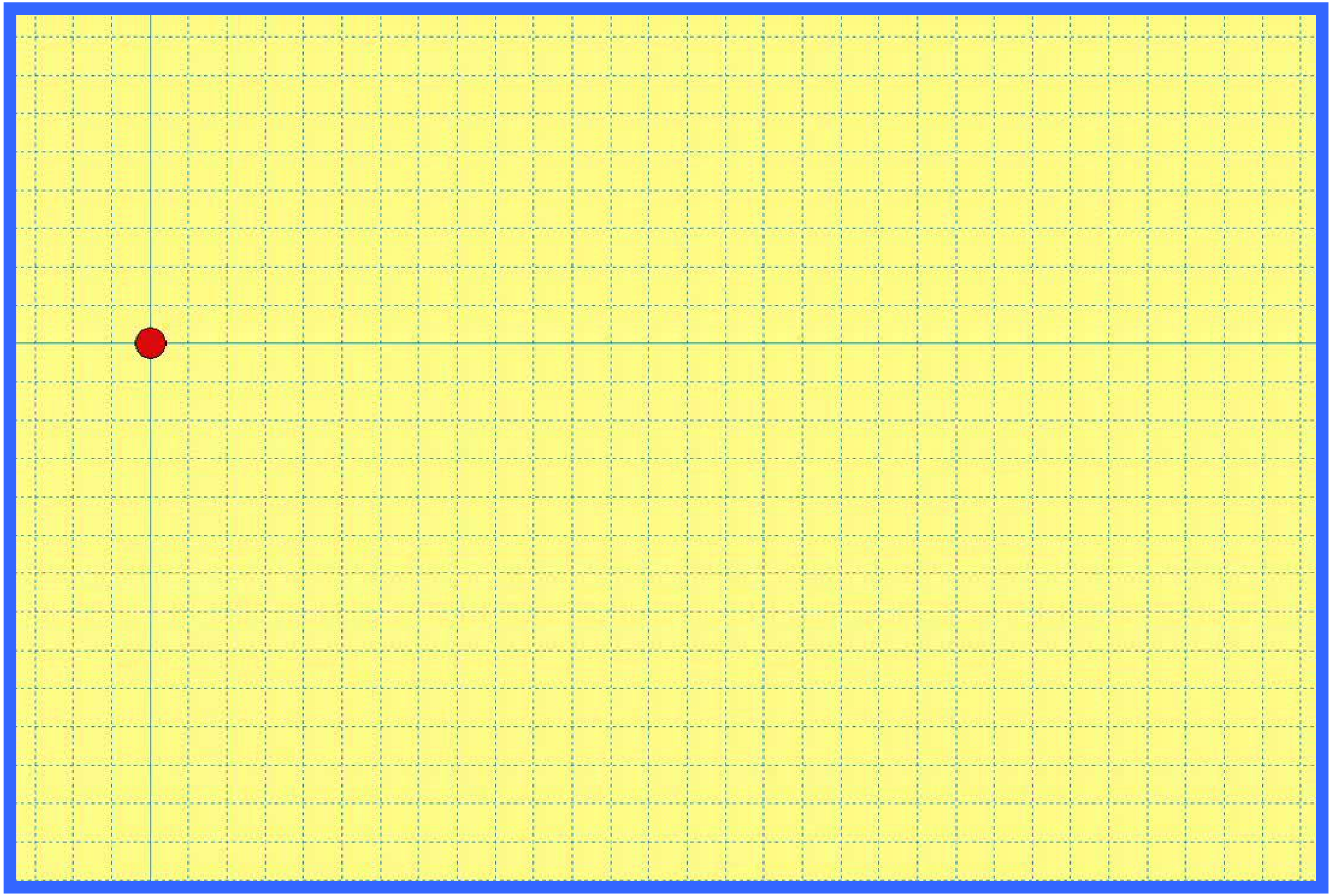


Computer simulation

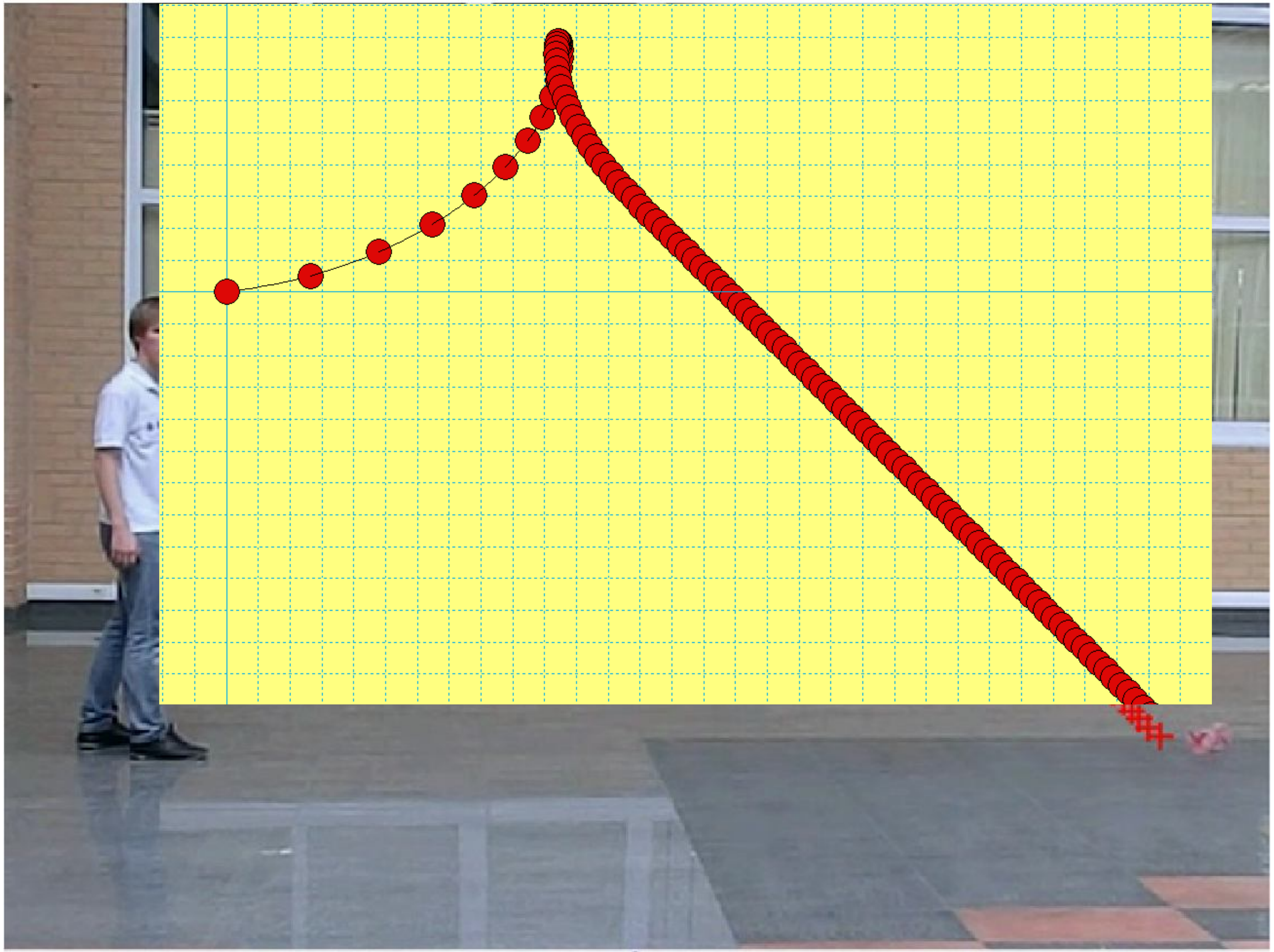
Test flight path



IP simulation

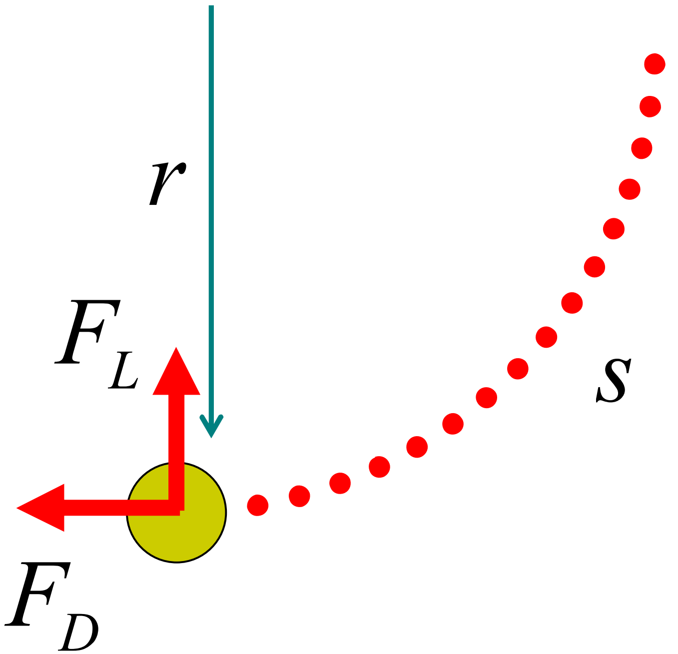


Comparison with experiment



Is it possible to produce more than one loop?

Only one loop!



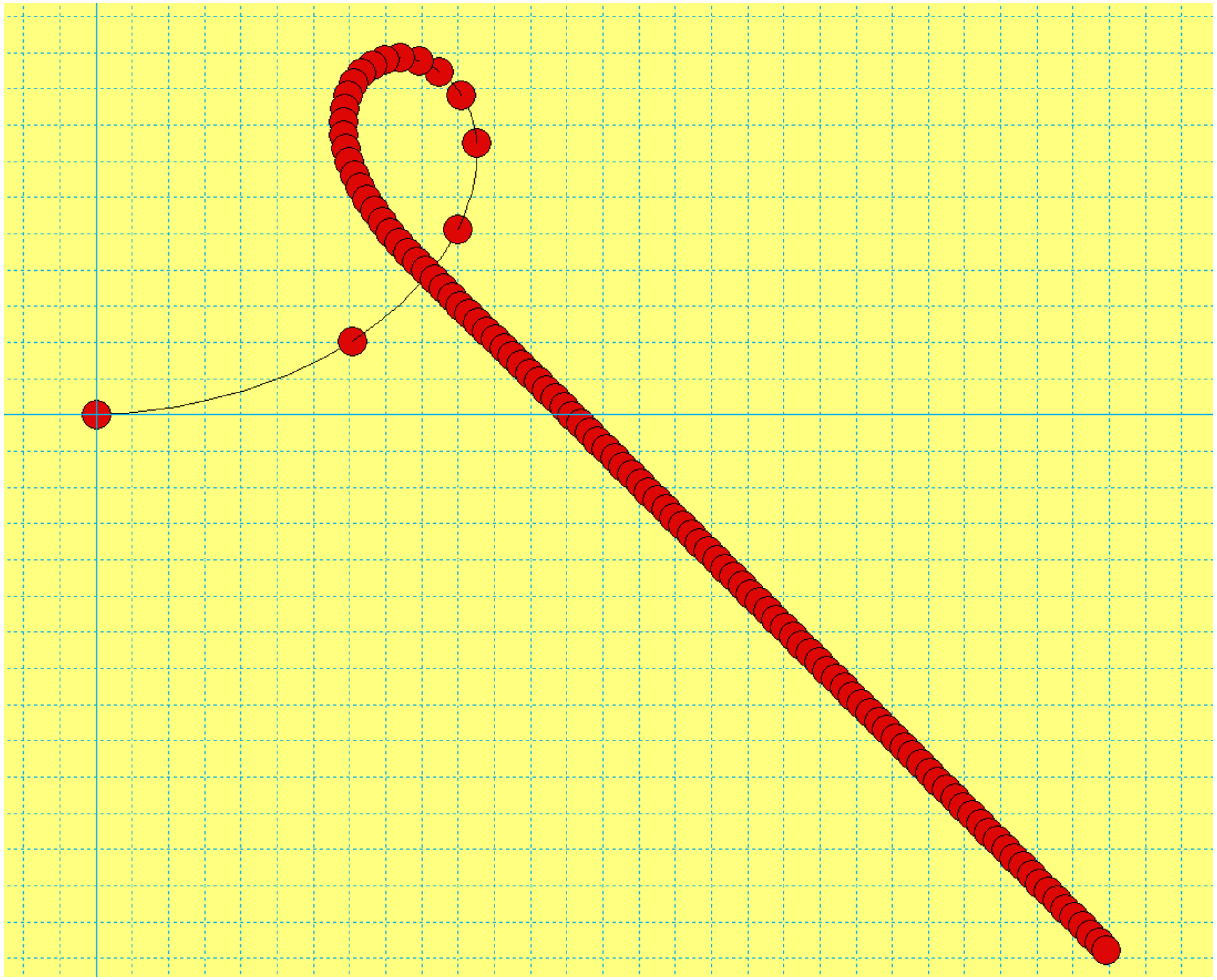
Radius $$r \simeq \frac{mv^2}{F_L}$$

Stopping distance $$s \simeq \frac{mv^2}{F_D}$$

$$\alpha > 1 \Rightarrow F_L \simeq F_D$$

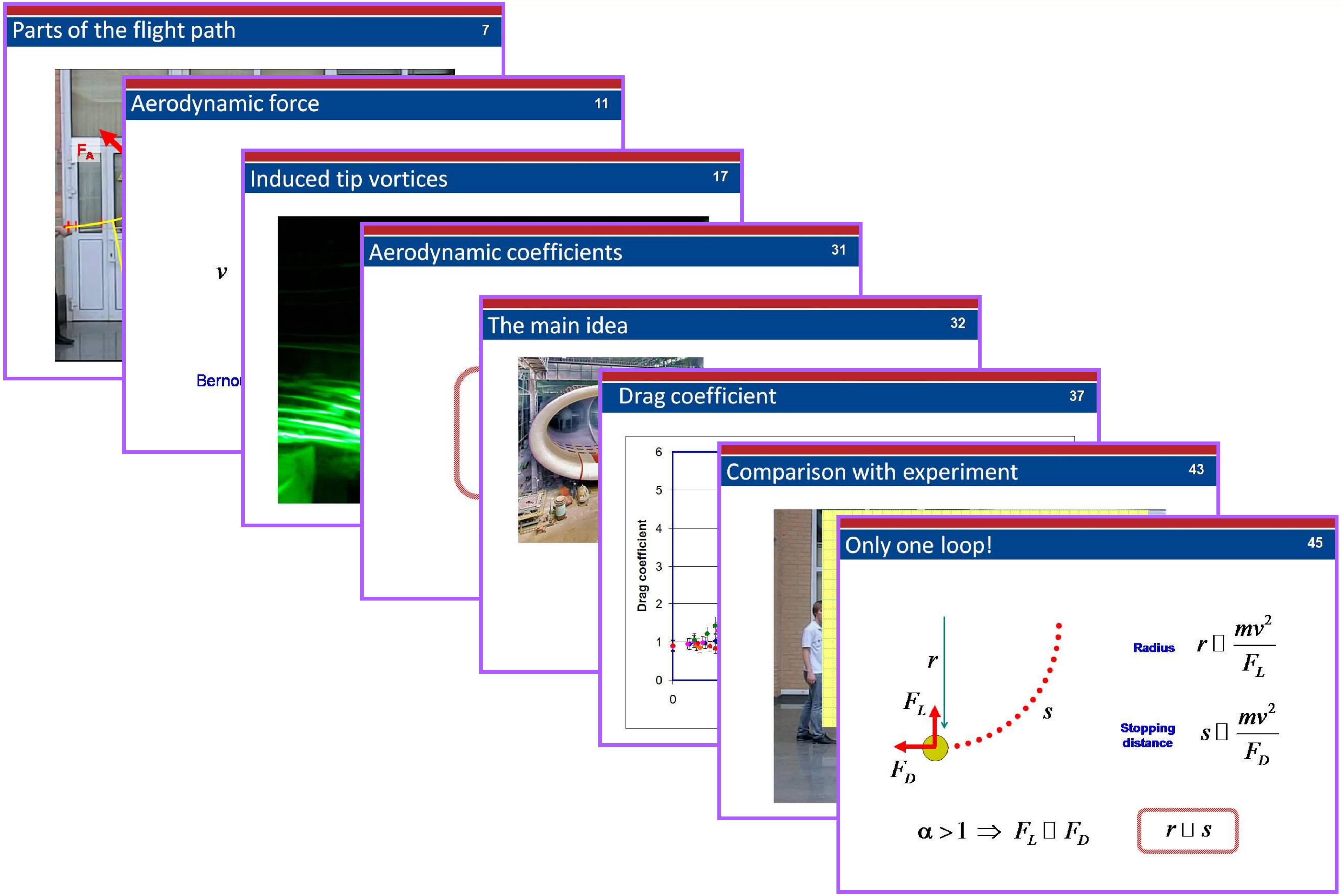
$$r \simeq s$$

Velocity increased 3 times more…



Summary

Main results



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- Swanson W.M. (1961) “The Magnus effect: A summary of investigations to date”. *Trans. ASME D* **83**, 461–470.
- Mittal S., Kumar B. (2003) “Flow past a rotating cylinder”. *J. Fluid Mech.* **476**, 303–334.
- Thouault N. et al. (2012) “Numerical analysis of a rotating cylinder with spanwise discs”. *AIAA*, **50**, 271–283.
- Seifert J. (2012) “A review of the Magnus effect in aeronautics”. *Progr. Aero. Sci*. **55**, 17–45.

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Thank you for your attention!