Ph.D. Course on *Vorticity, Vortical Flows and Vortex-Induced Vibrations*
Technical University of Denmark, Copenhagen, Denmark
vortex.compute.dtu.dk
August 26-30, 2019

Fluid-Structure Interactions III: Controls

Kerry Hourigan
Fluids Laboratory for Aeronautical and Industrial Research
Monash University, Melbourne, Australia
Otto Mønsted Guest Professor, Technical University of Denmark

MONASH University

FLAIR
Fluids Laboratory for Aeronautical and Industrial Research

Reading Material

Bai, Y., Bai, Q. (ed.) (2005) *Subsea Pipelines and Risers: Vortex-induced Vibrations (VIV) and Fatigue.* Elsevier

Mittal, S. 2001 Control of flow past bluff bodies using rotating control cylinders. J. Fluids Struct. 15 (2), 291–326.

Paidoussis, M.P., Price, S.J. & de Langre, E., Fluid-Structure Interactions: Cross-Flow-Induced Instabilities, Cambridge University Press, 2011.

Williamson, C.H.K. & Govardhan, R., Vortex-induced vibrations, Annu. Rev. Fluid Mech., 36, 413-55, 2004.

Lecture Objectives

Learn:

Surface modifications of cylinders to control FIV

Effect of various passive “controls” or “modifications” on the FIV of spheres

Outline of Presentation

- **Introduction and Motivation**
- **Non-rotating sphere**
  - **Surface trip wire**
  - **Near a free surface**
- **Rotating sphere**
  - **Constant rotation**
  - **Oscillatory rotation**
  - **Rolling on a wall**
- **Summary and Conclusions**

Research questions

1 How does the FIV of an elastically-mounted/tethered sphere in the laminar regime differ from the experimental studies in turbulent regime?

2 How does the proximity of a free surface affect the FIV of a sphere?

3 Does a sphere undergo FIV when rolling on a solid surface?

4 What is the effect of an imposed continuous or rotary transverse rotation effect on the dynamics of VIV of a sphere?

5 What controls are there for the FIV of a sphere?

Modifying Flow-Induced Vibrations.

Physically, ways to reduce VIV

Wake control

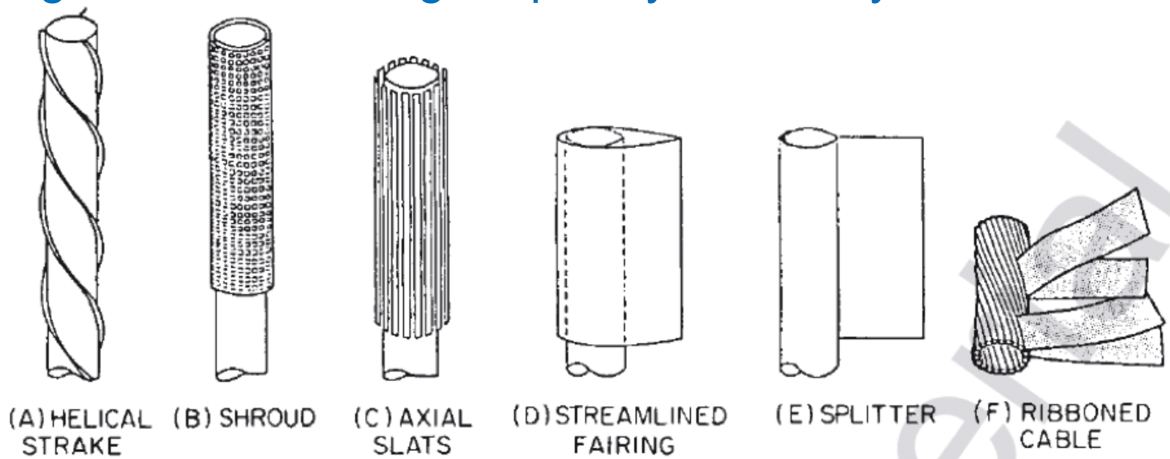
1) Surface modification
2) Trip wire
3) Splitter plate
4) Suction/blowing
5) Synthetic jet
6) Transverse rotation
7) Near free surface?
8) On solid surface?

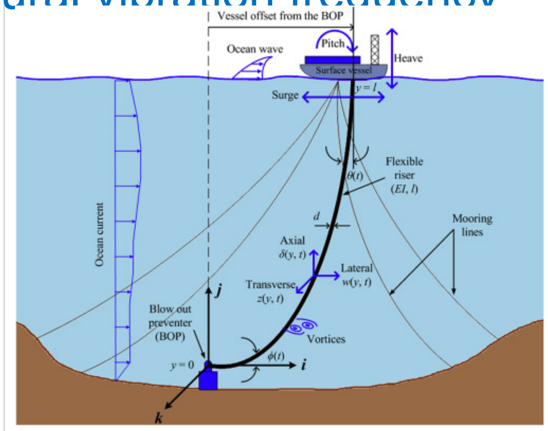
Deviate f_{sh} from f_{nw}

1) Rotary oscillation

VIV controls for 2D bodies

Design vortex shedding frequency to be very different to natural vibration frequency

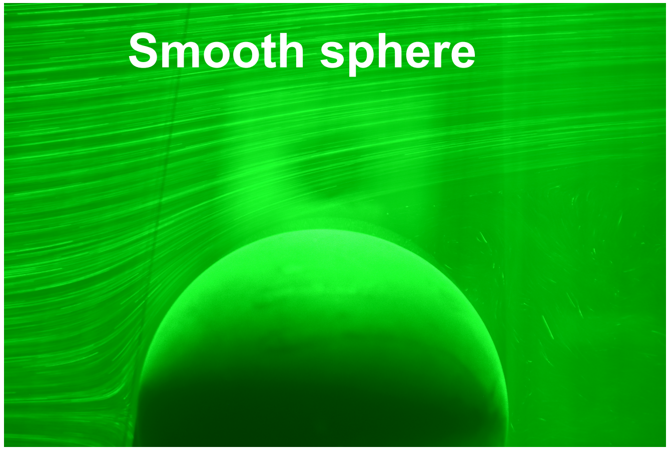


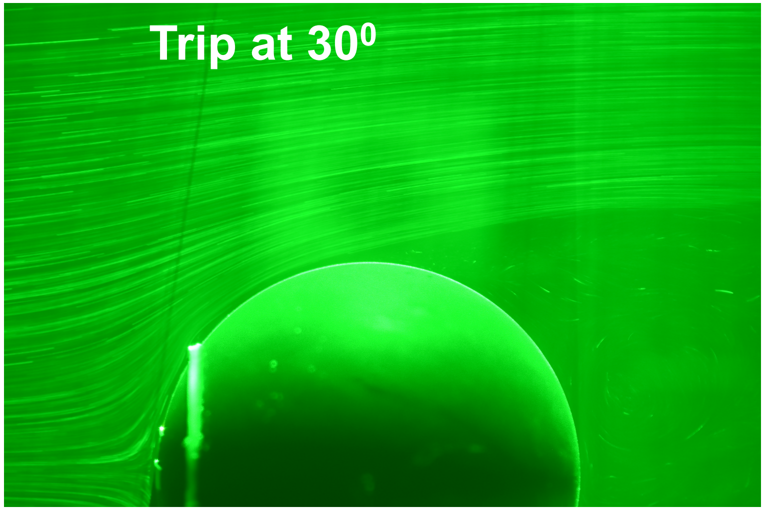


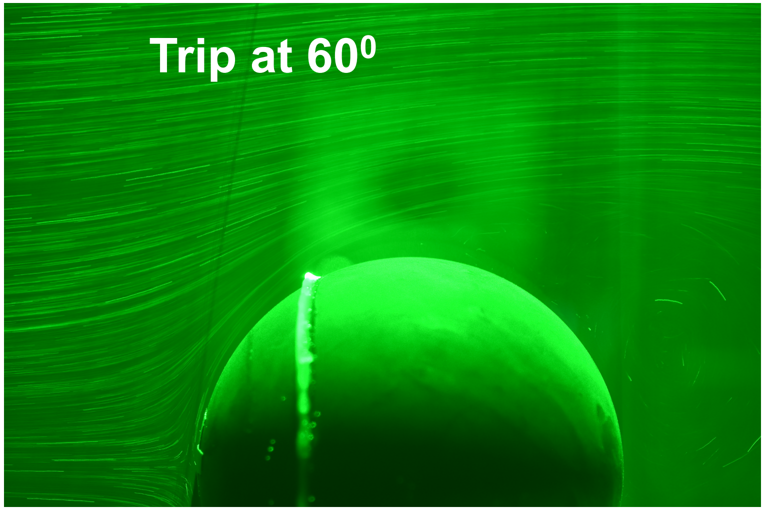
Harris, C. M., Piersol, A.G. (ed.) (2002) *Harris' Shock and Vibration Handbook (5th edition).* McGraw-Hill.

SURFACE TRIP WIRE

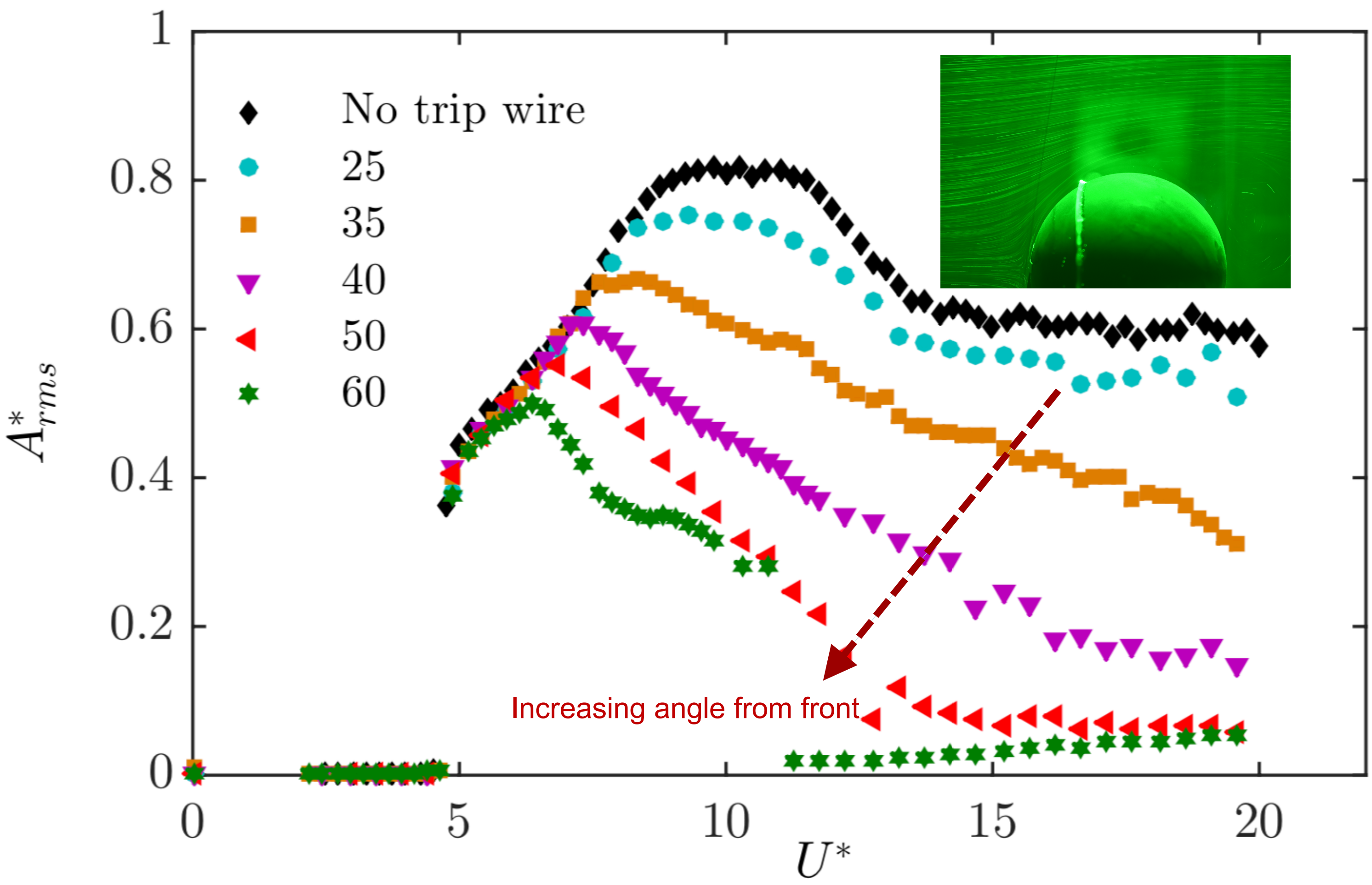
Flow visualization for sphere with ring trip



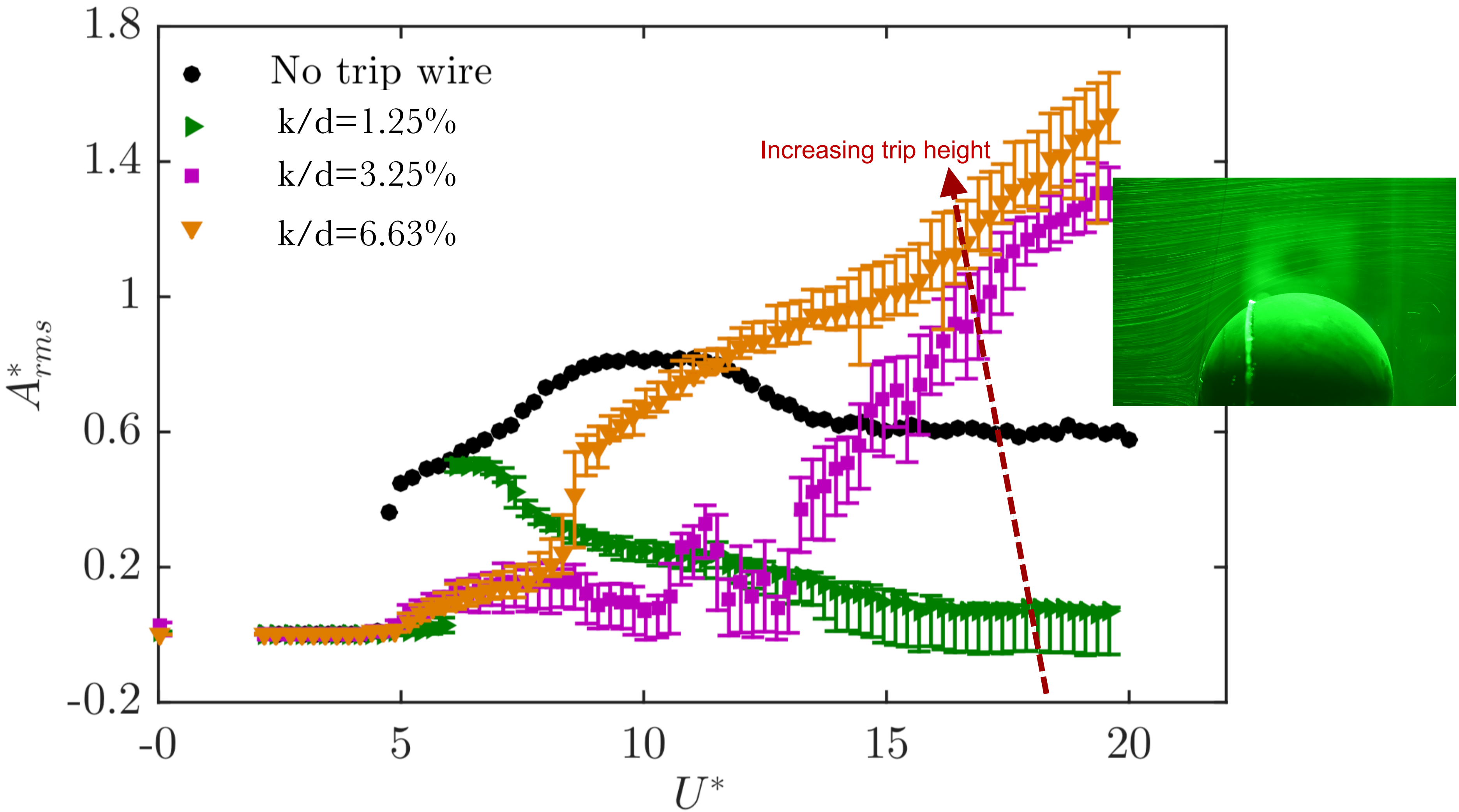




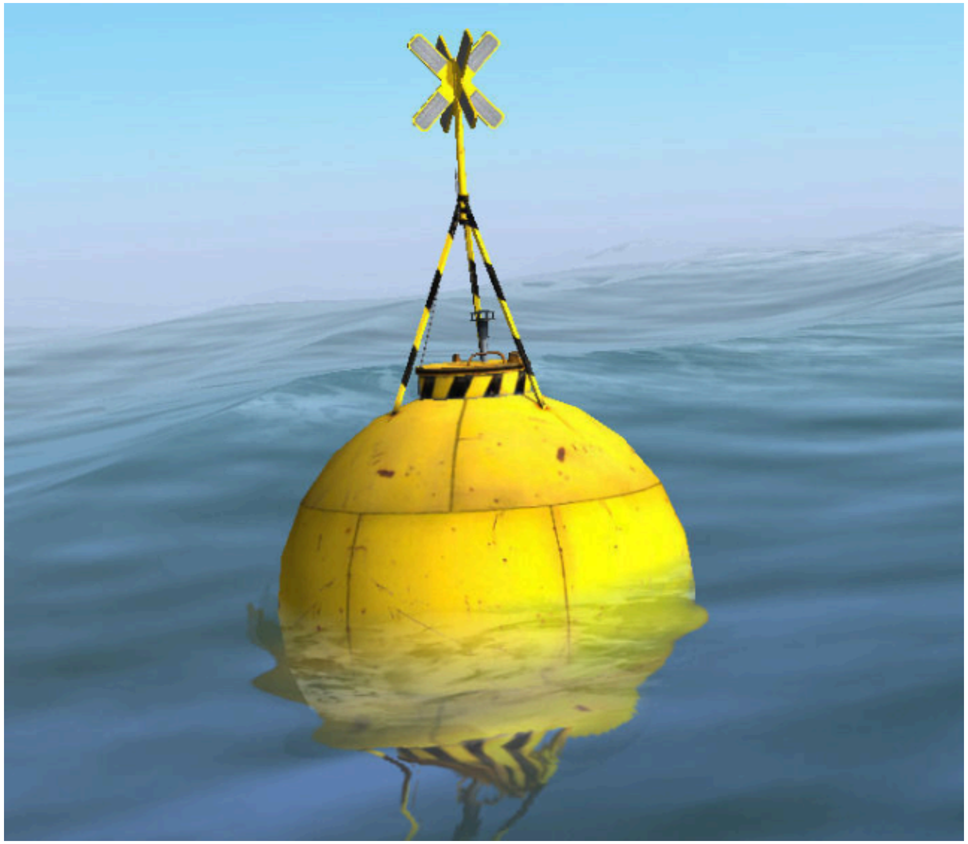
Effect of angular location of trip (k/d=1.25%)



Effect of height of trip at 60°



SPHERE VIV NEAR FREE SURFACE



Water channel facilities

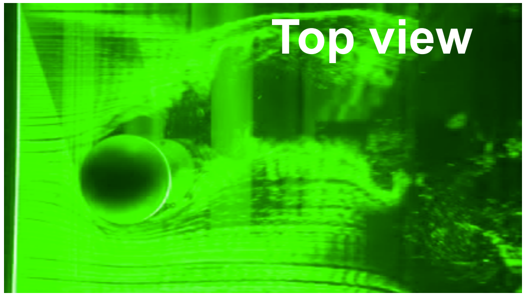
Recirculating free-surface water channel

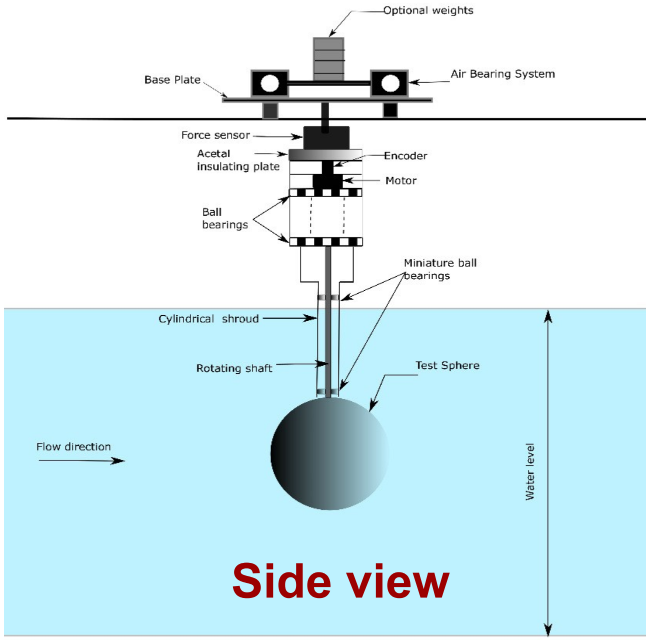
Test section ($W \times D \times L$): 0.6 m $\times$ 0.8 m $\times$ 4.0 m

Free-stream velocity range: 0.04 $\mathrm{ms}^{-1} \leq U \leq$ 0.45 ms^{-1}

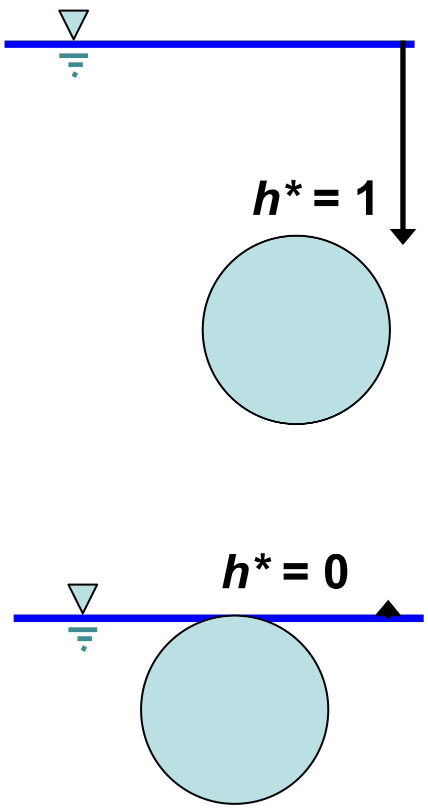
Turbulence levels $\leq$ 1%

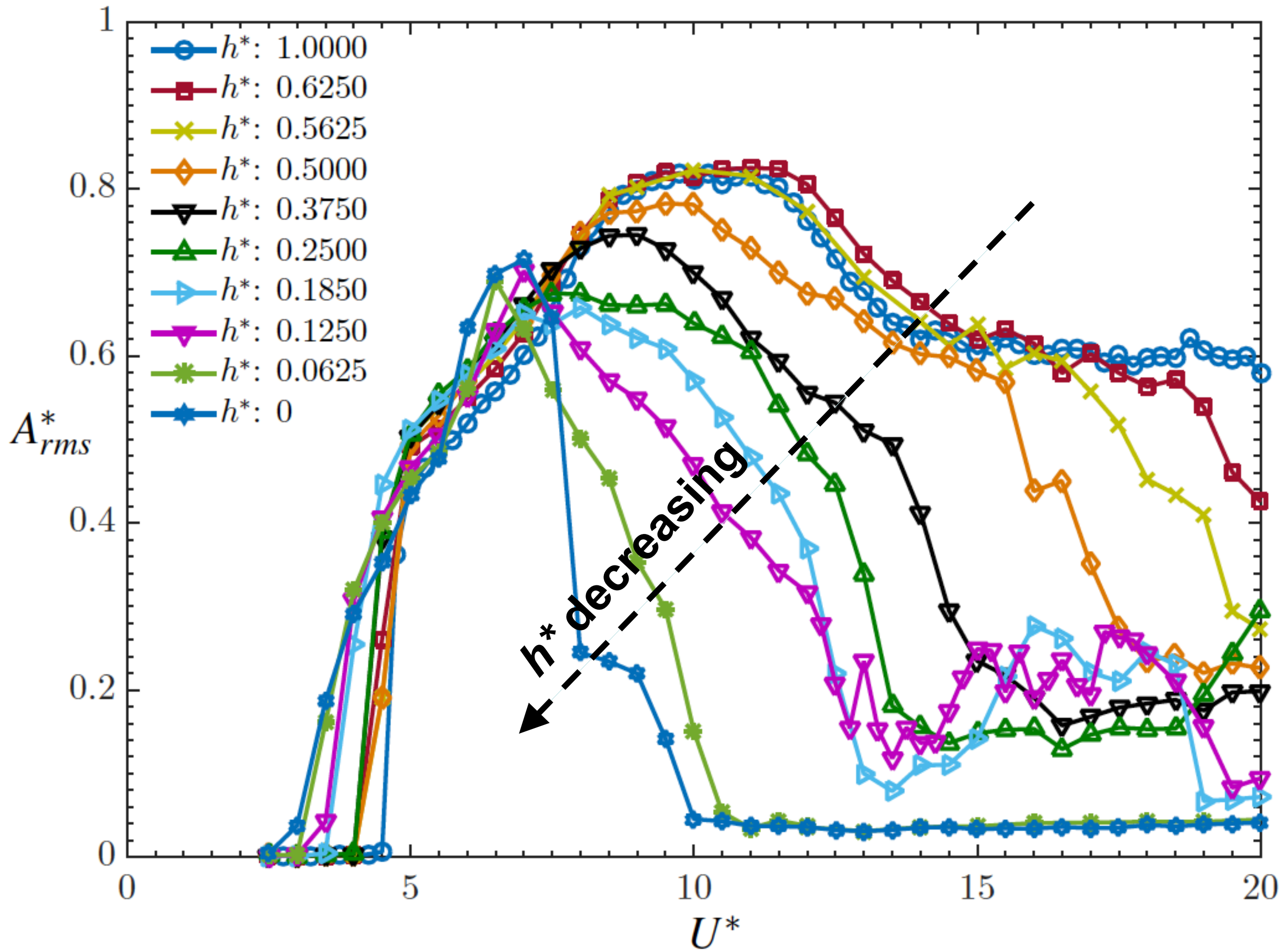
Sphere undergoing FIV
(FLAIR water channel)



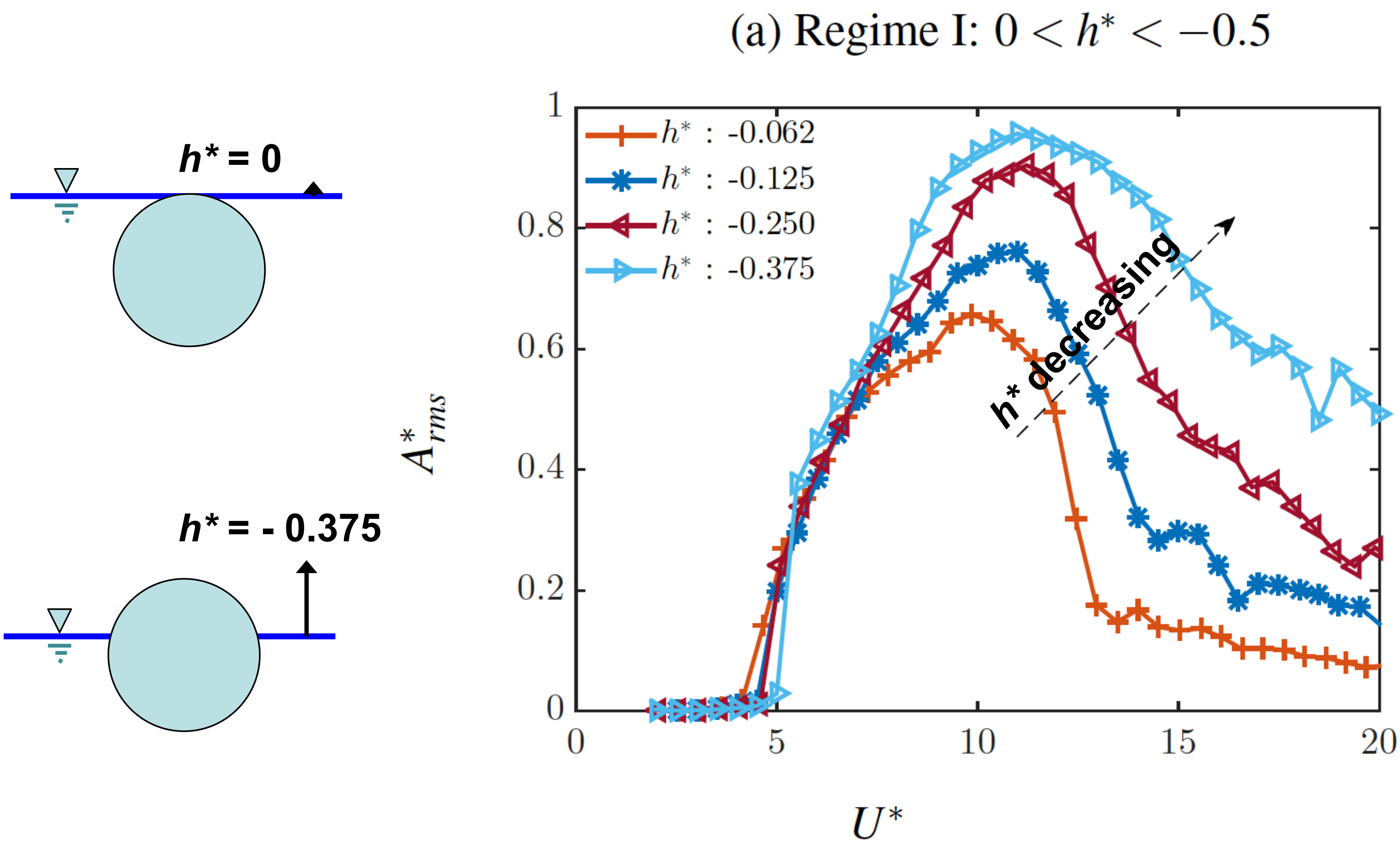


Range of VIV decreases as sphere is located closer to free surface

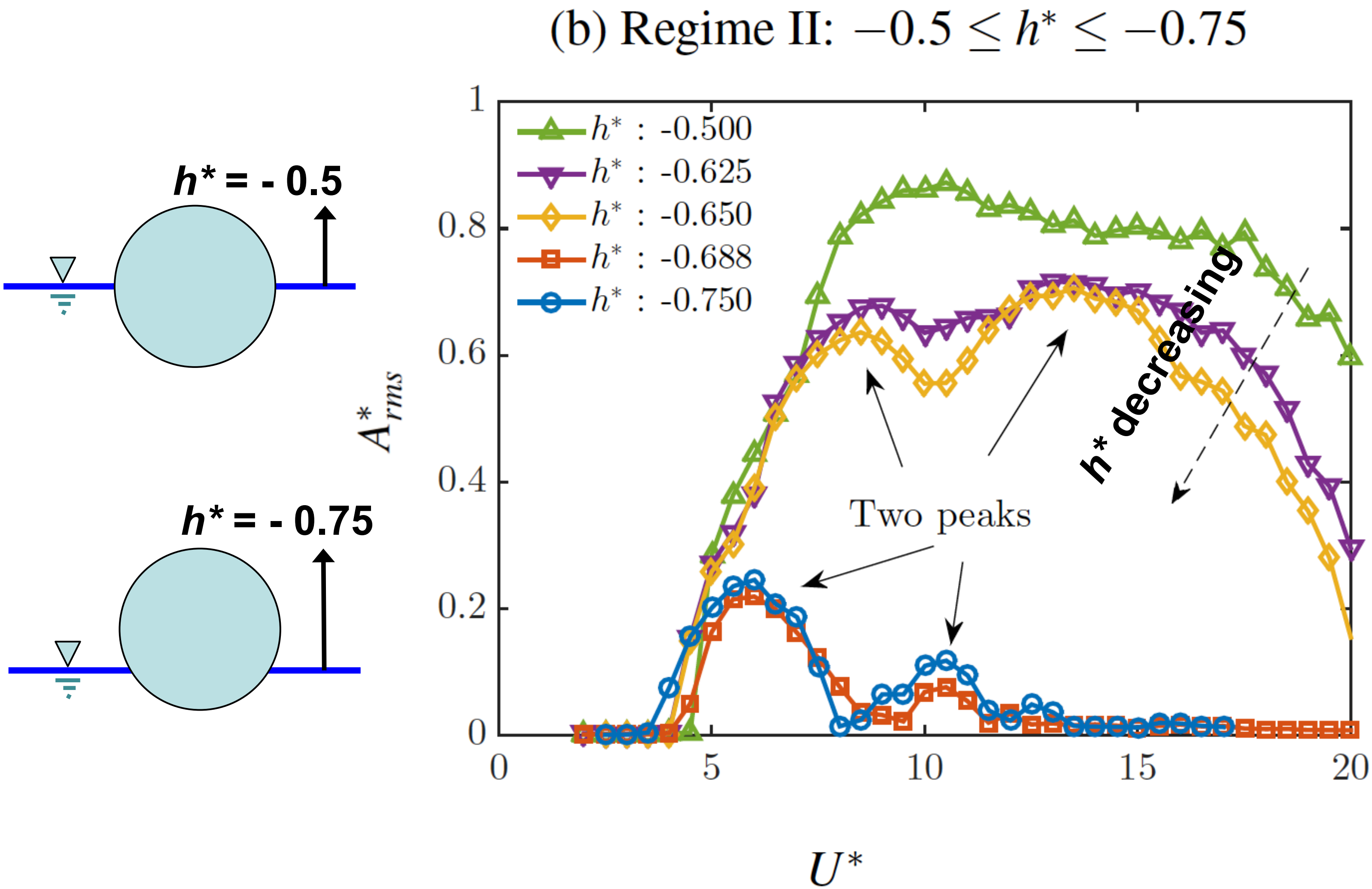




VIV increases as sphere is raised from just fully immersed to 3/8 immersed



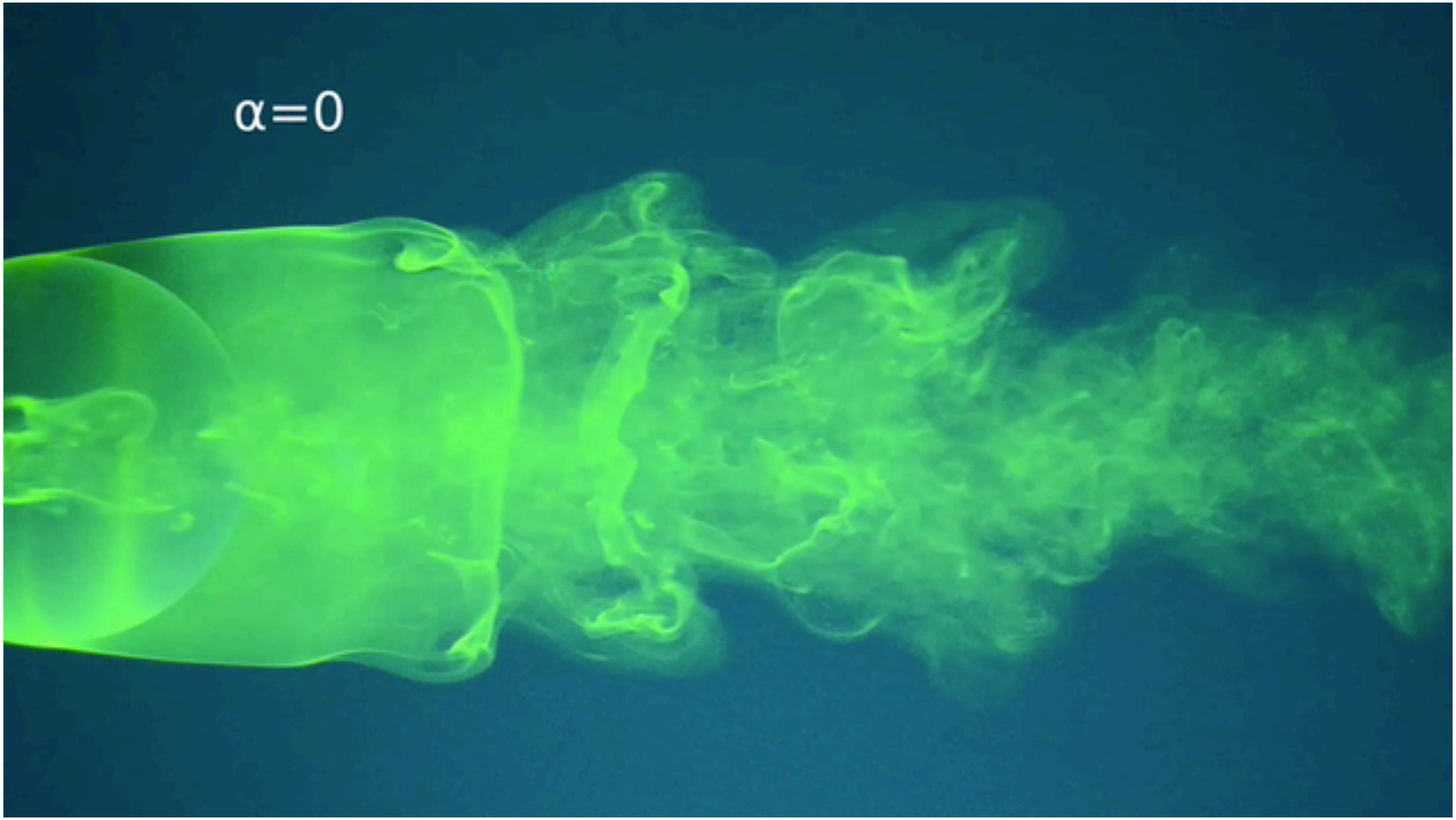
VIV decreases as sphere is raised from 1/2 to 1/4 immersed



ROTATING SPHERE

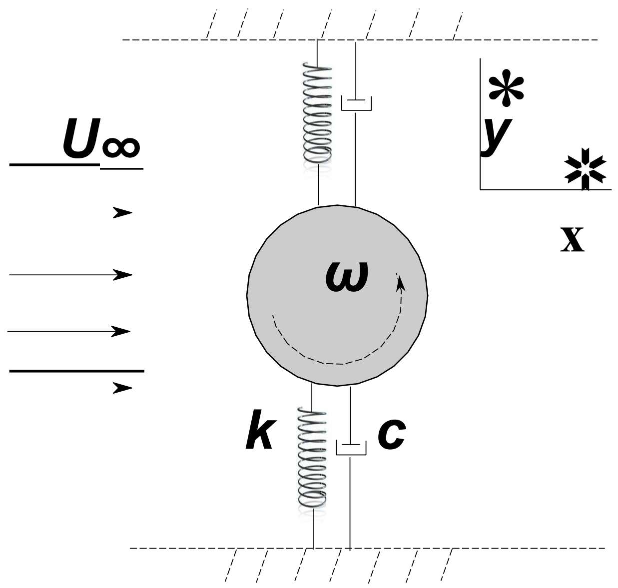
Magnus Effect

Rigidly mounted sphere: Effect of increasing rotation



FIV: CONSTANT-ROTATING SPHERE

Transverse rotation:non-dimensional parameters



Elastically mounted sphere

Top view

$$A^* = A_y/D \quad (1)$$

$$U^* = U/(f_{nw}D) \quad (2)$$

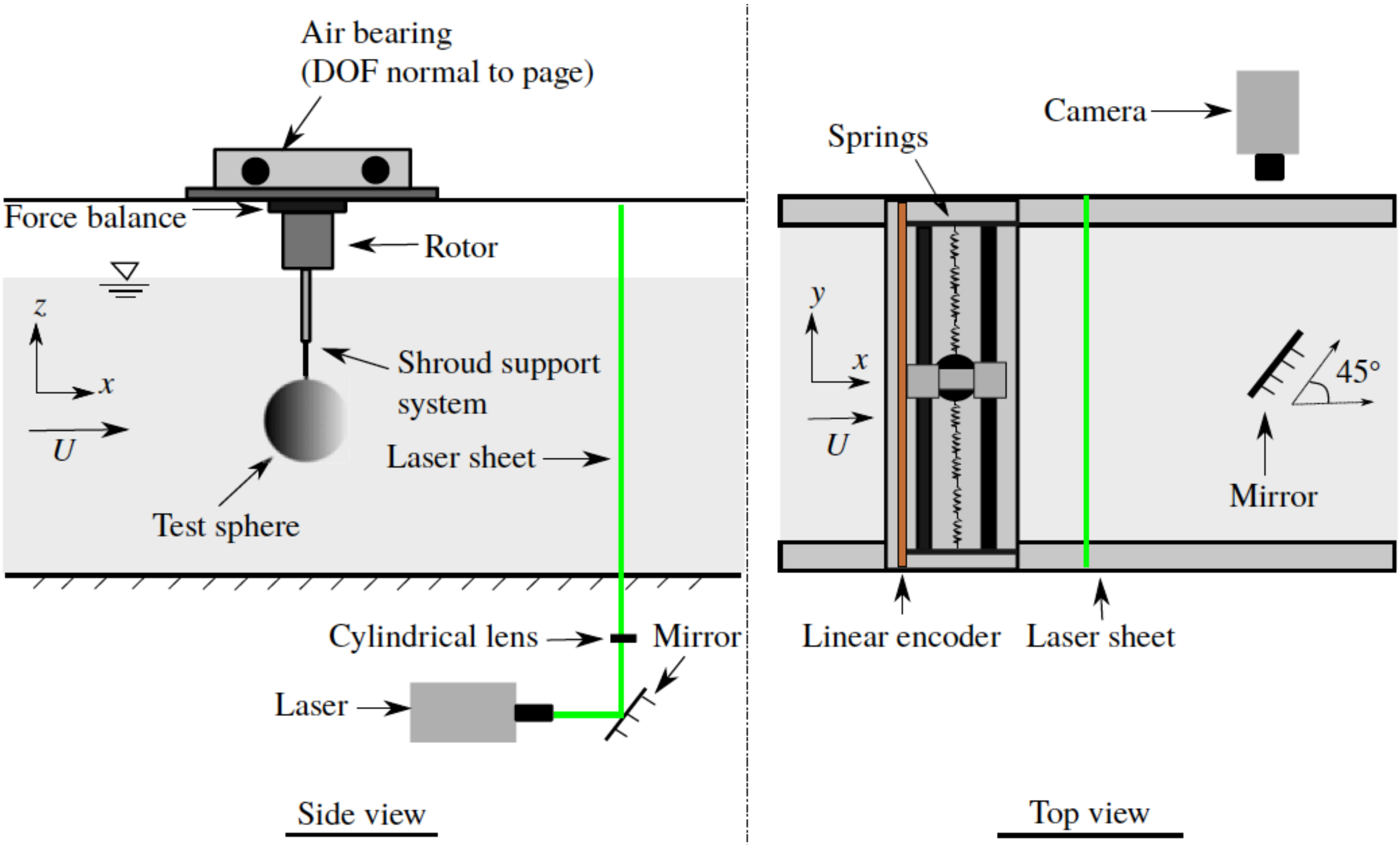
$$m^* = m/(\pi\rho D^3/6) \quad (3)$$

$$\alpha = \frac{D\omega}{2U} \quad (4)$$

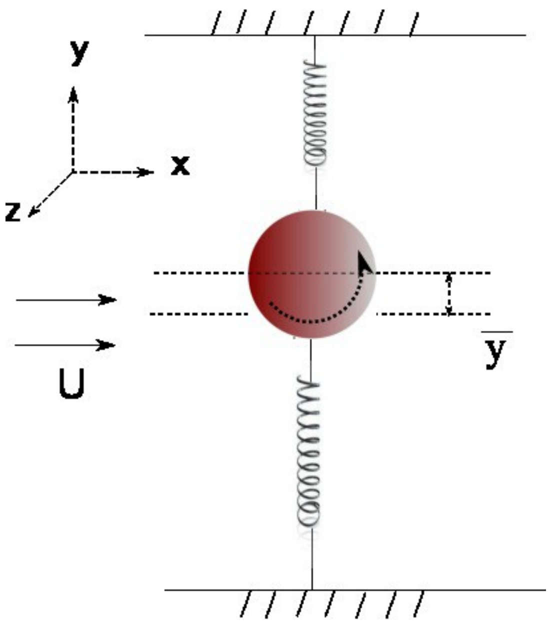
(5)

(6)

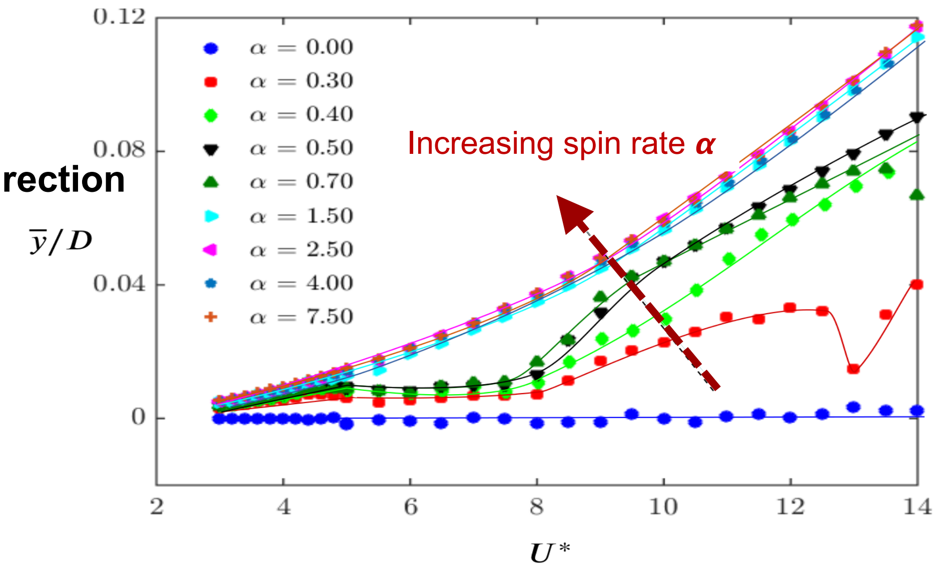
Experimental setup



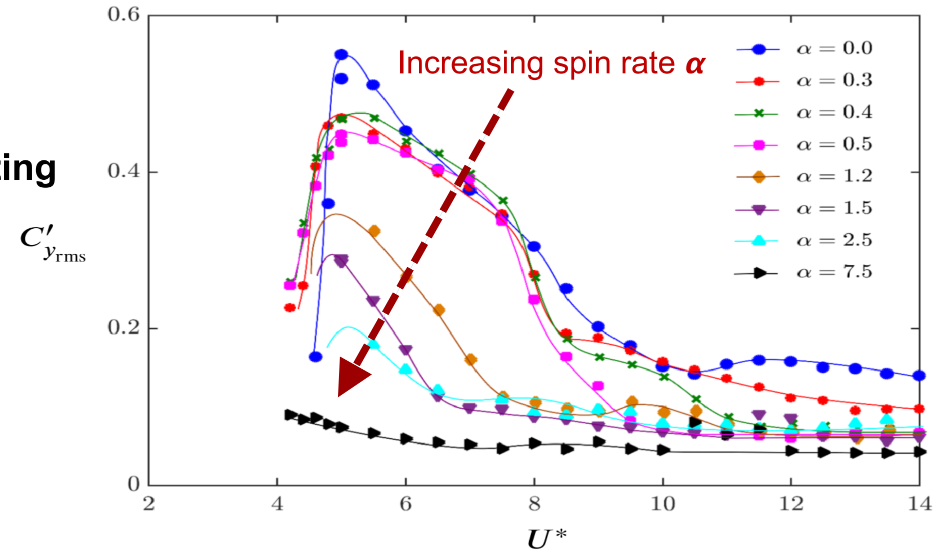
Transverse Rotation: Shift in ȳ, lower $C'_{y_{rms}}$



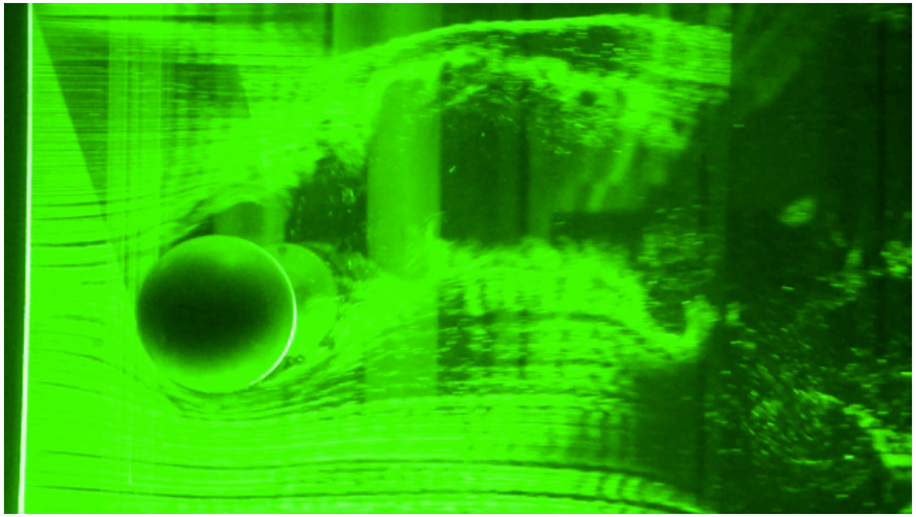
Mean shift in transverse direction



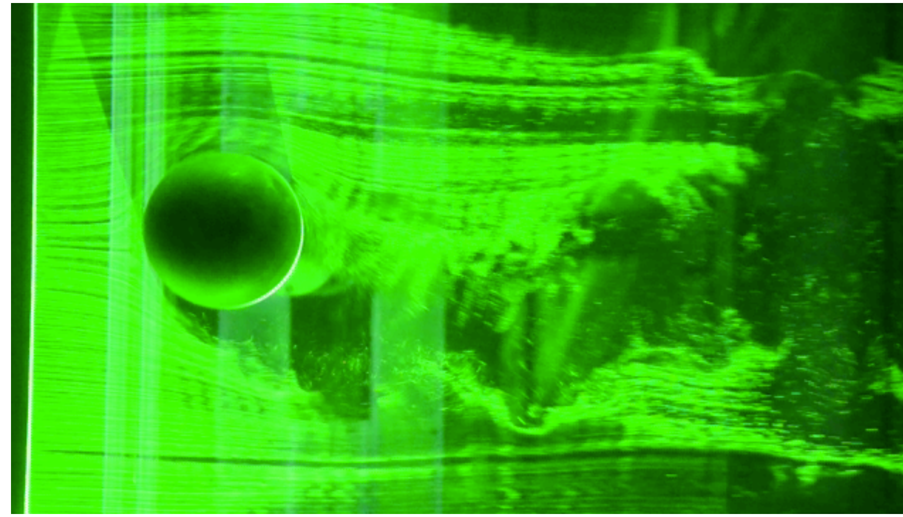
RMS of fluctuating lift coefficient



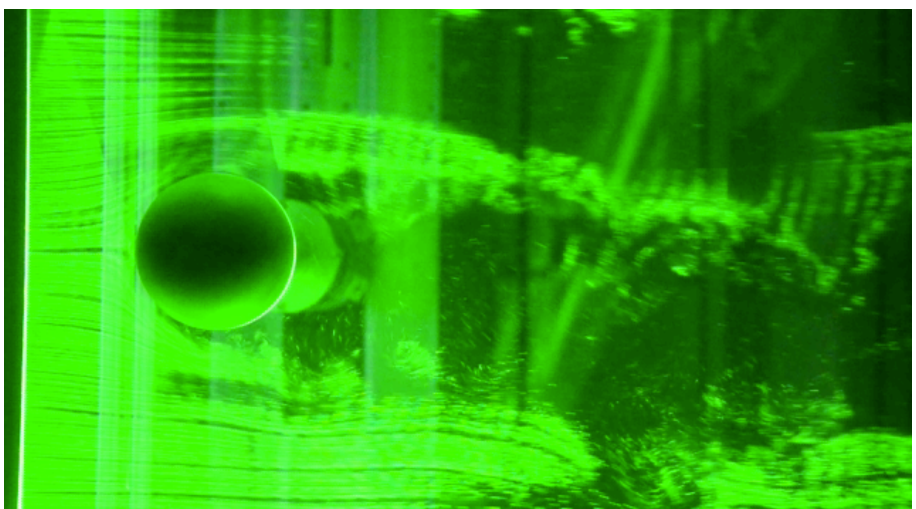
Flexibly mounted rotating sphere: effect of rotation ($U^* = 6$)



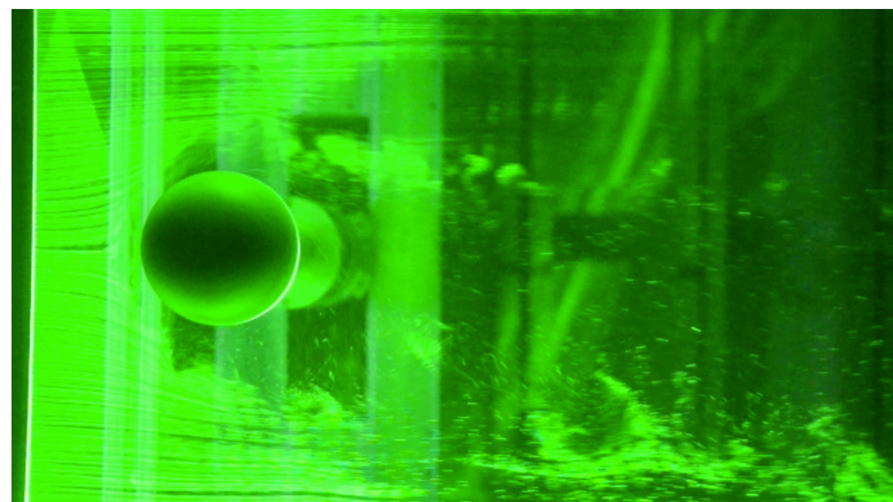
$\alpha = 0$



$\alpha = 1$



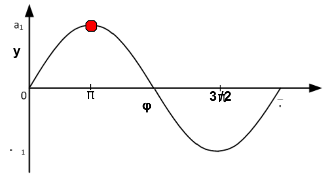
$\alpha = 2.5$

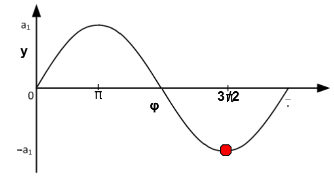


$\alpha = 6$

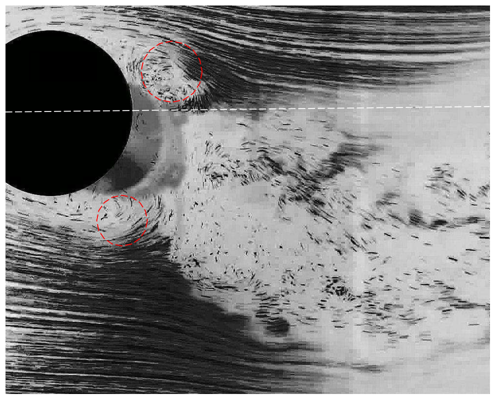
At higher spin rates α, wake stops oscillating

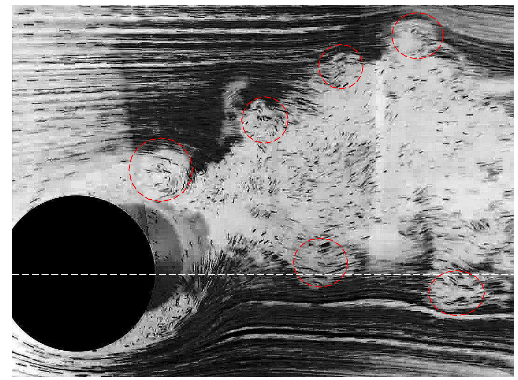
$U^* = 6$



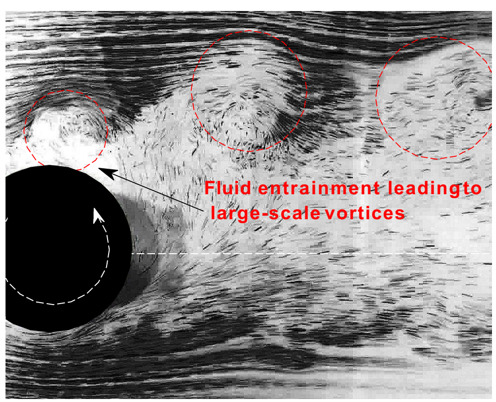


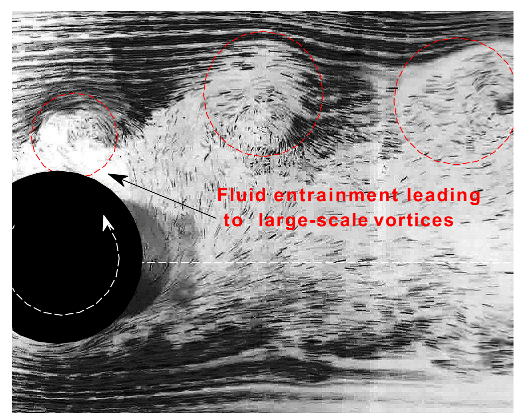
$\alpha = 0$



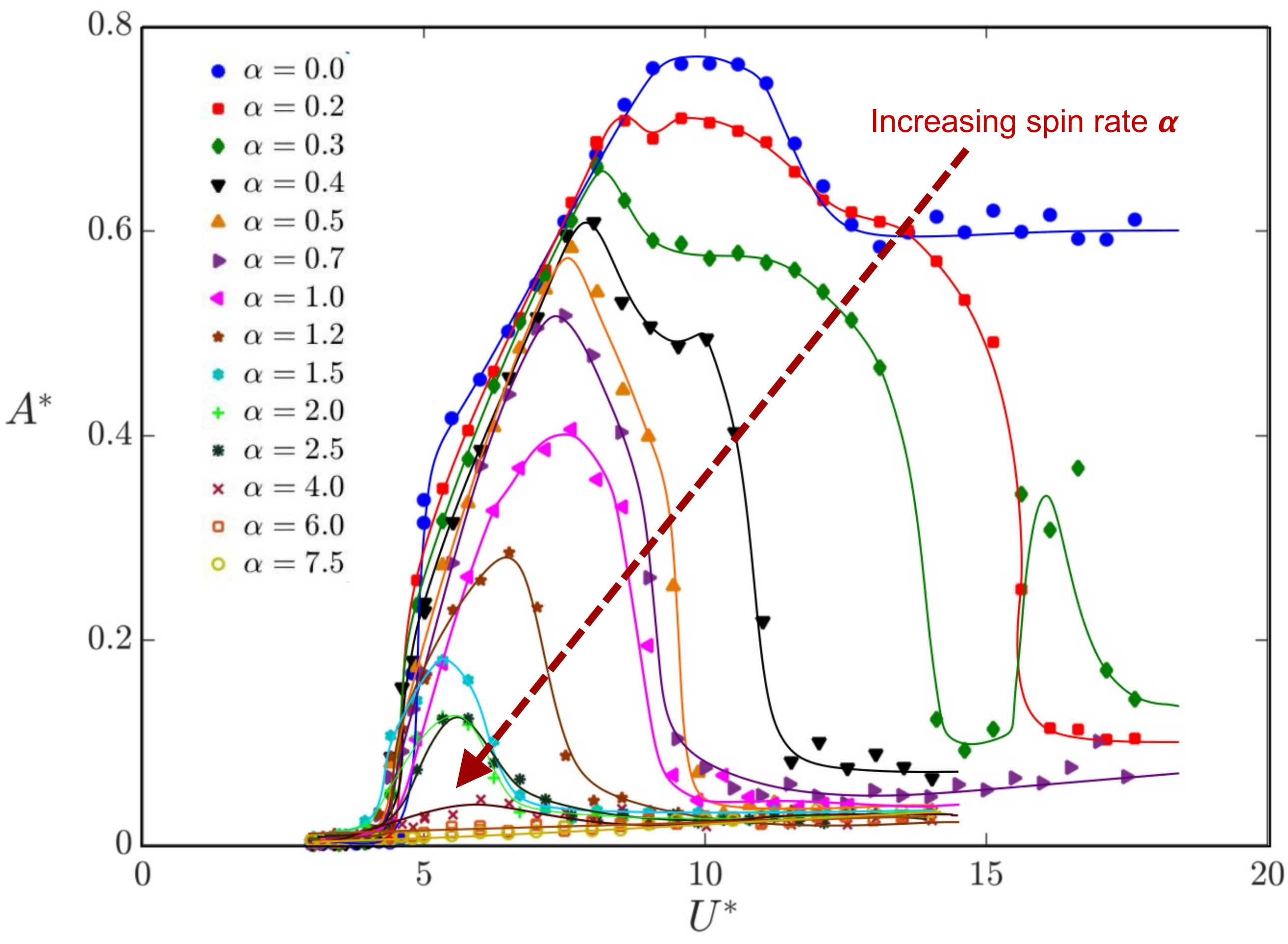


$\alpha = 6$

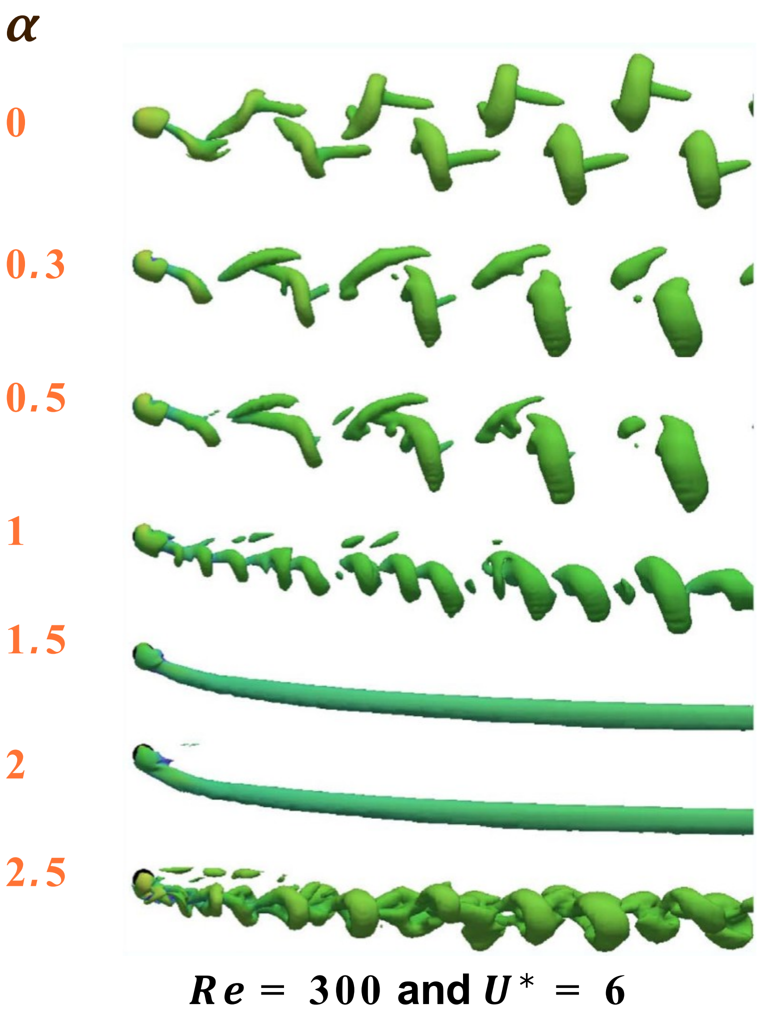


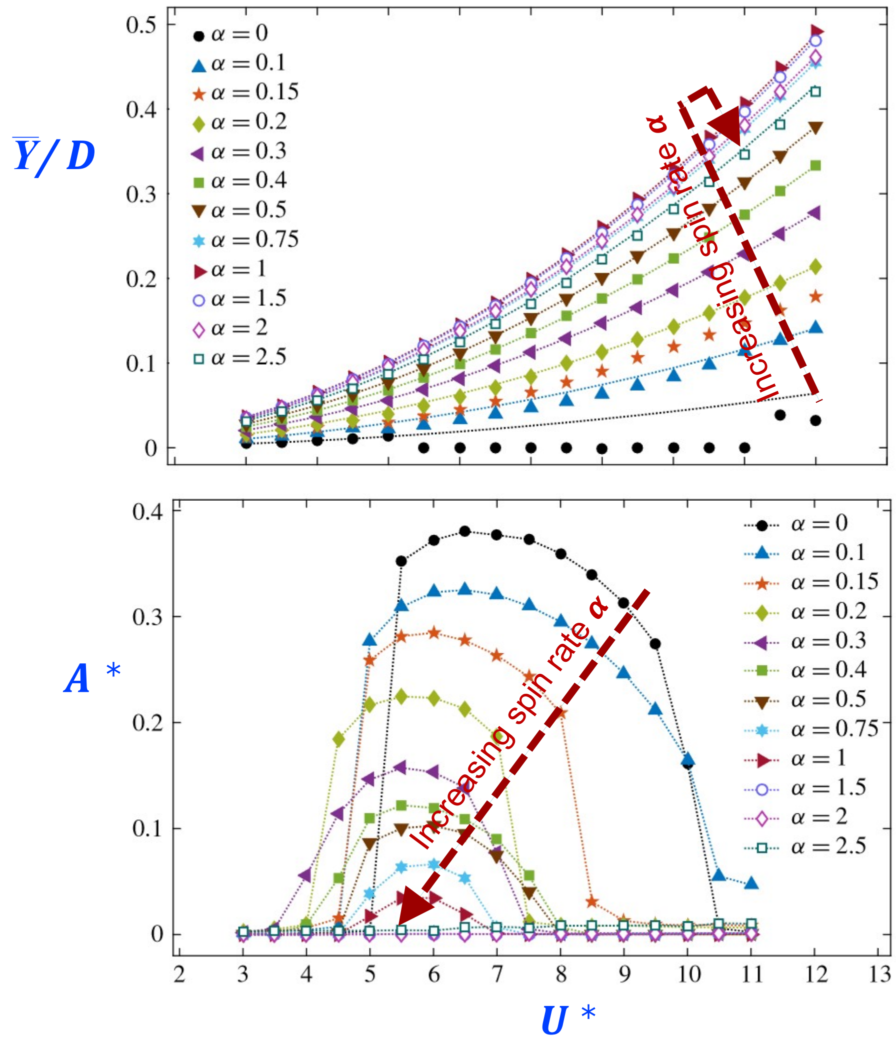


Increasing spin rate reduces vibrations



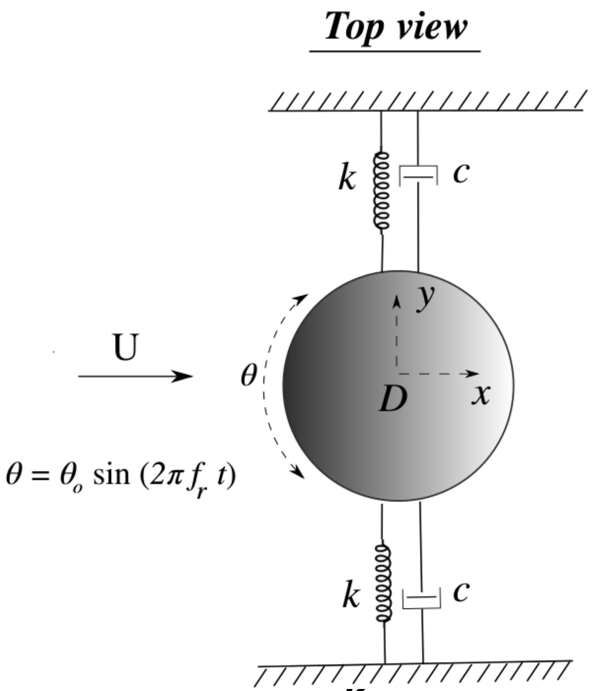
CFD: Effects of sphere rotation on VIV





ROTARY-OSCILLATING SPHERE

Rotary oscillations: non-dimensional parameters



k

c

$$A^* = A_y / D \tag{7}$$

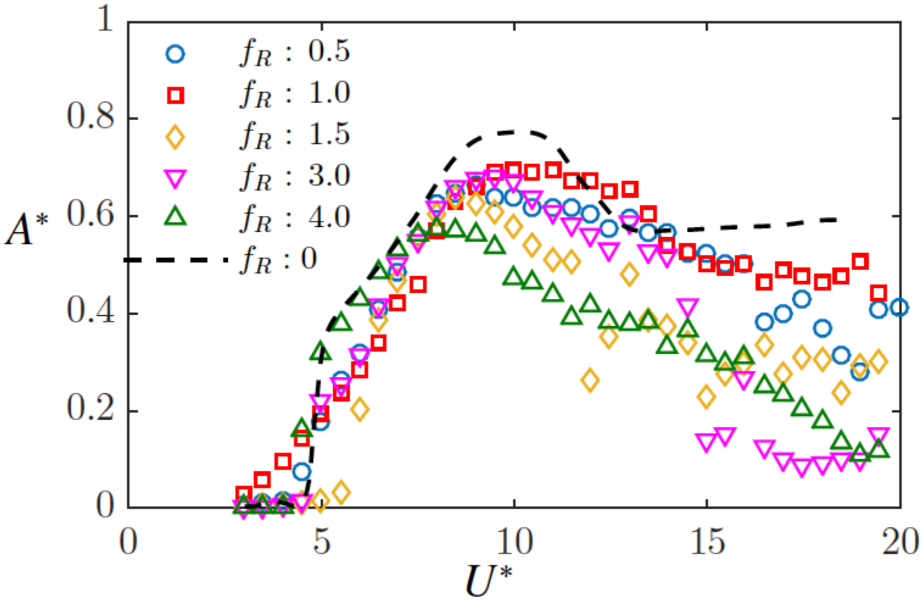
$$U^* = U / (f_{nw} D) \tag{8}$$

$$m^* = m / (\pi \rho D^3 / 6) \tag{9}$$

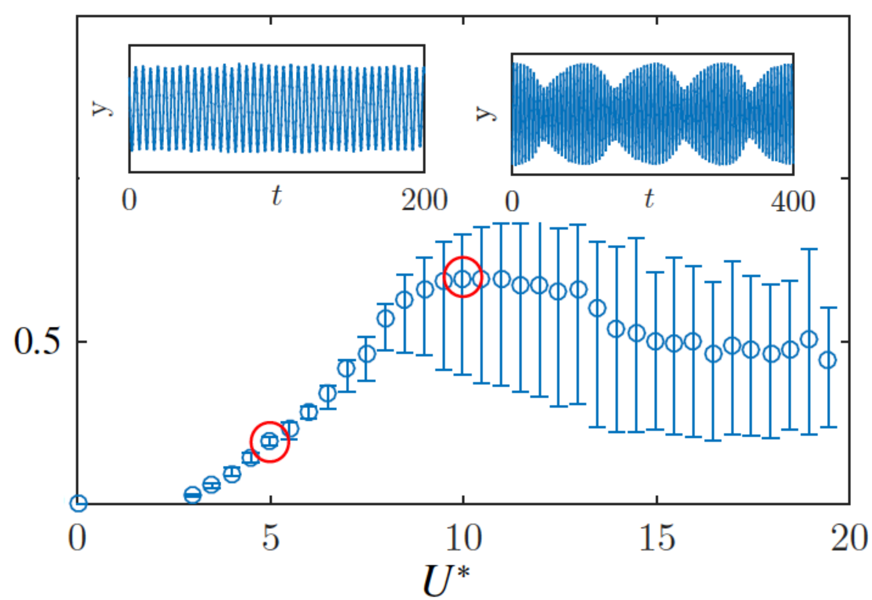
$$\alpha_R = D\dot{\theta}_{max} / 2U \tag{10}$$

$$f_R = f_r / f_{nw} \tag{11}$$

Rotary oscillations: $\alpha_R = 0.5$ for different f_R

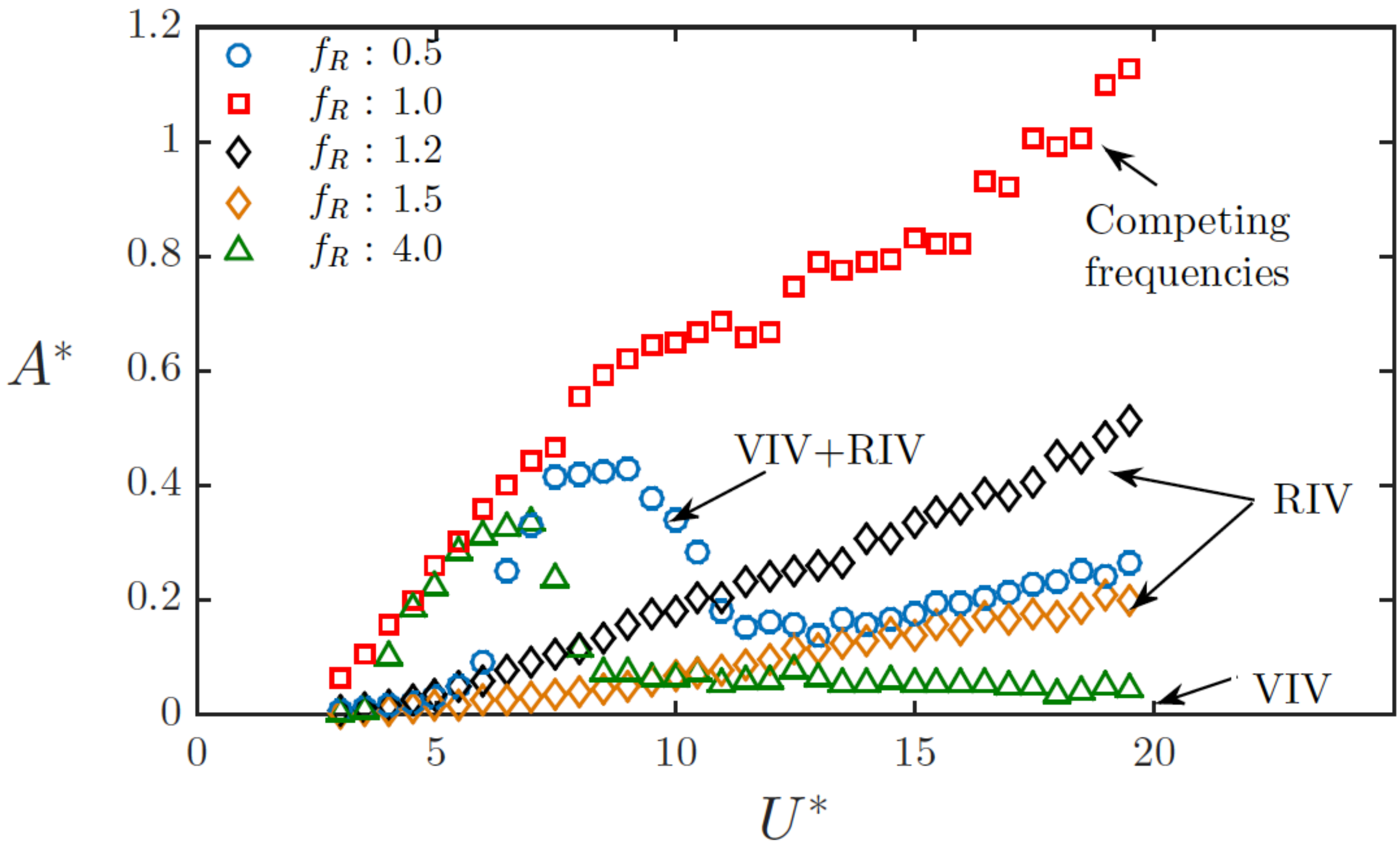


$f_R = 1$



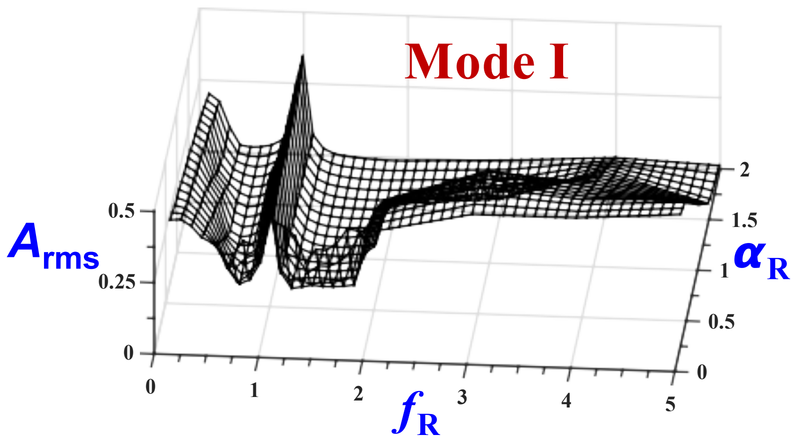
Amplitude response profile similar to unforced case.

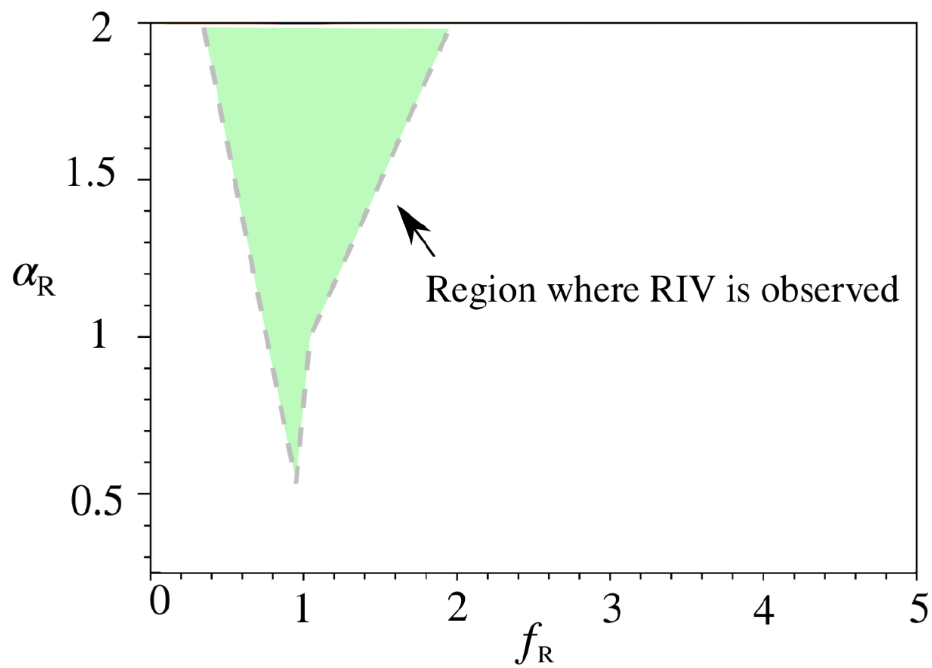
Rotary oscillations: $\alpha_R = 2$ for different f_R

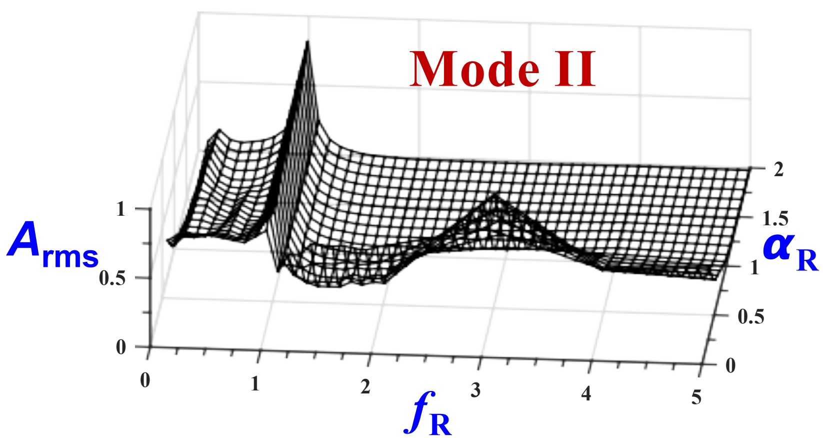


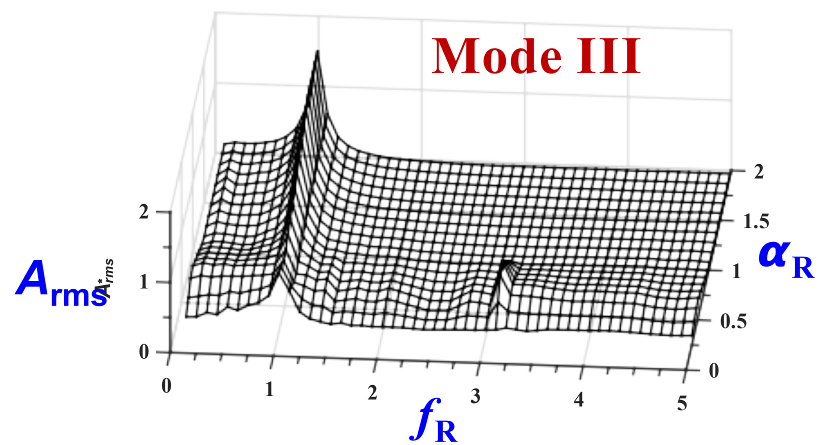
Amplitude response has additional Rotary Induced Vibration (RIV)

Rotary oscillations: Variation with f_R, ç





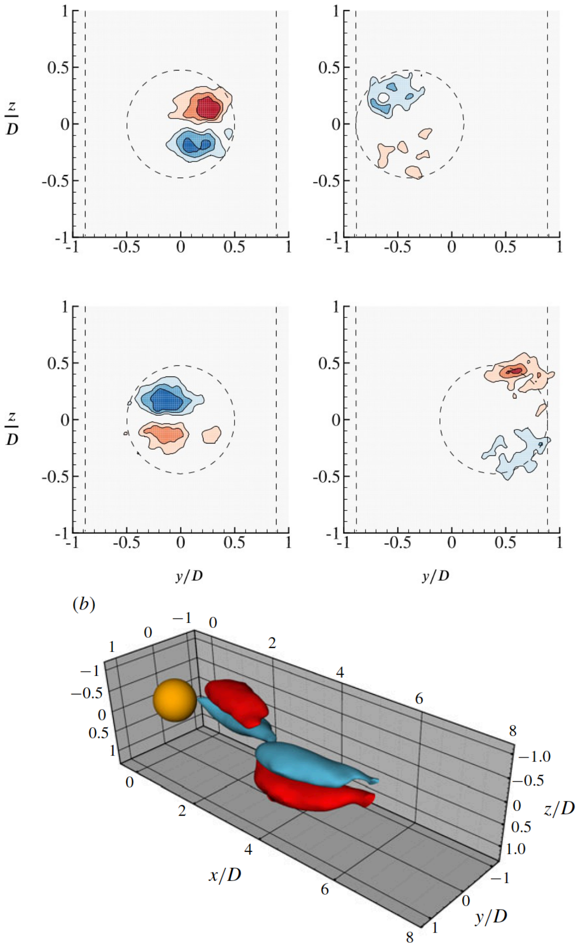




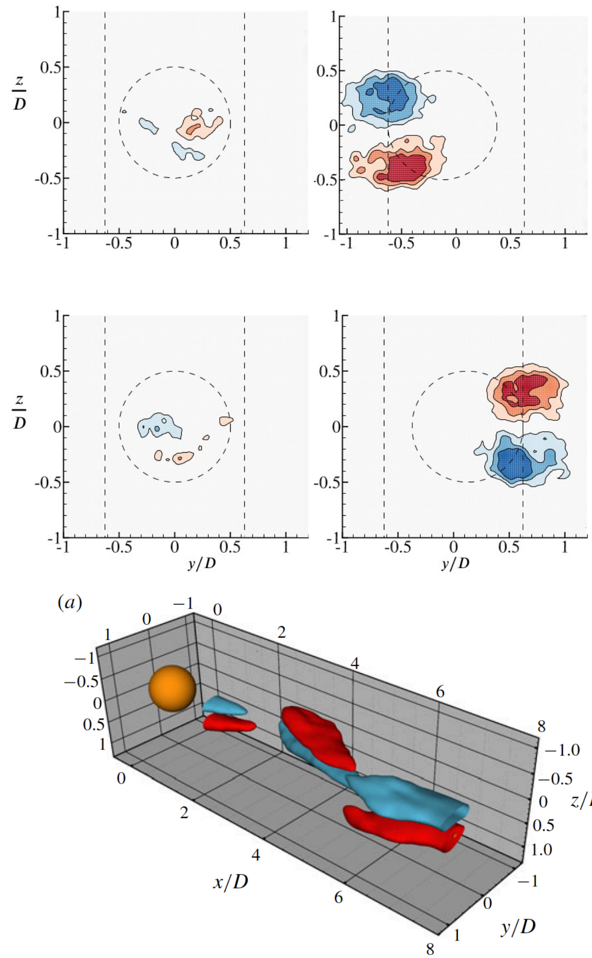
Streamwise vorticity: more intense for larger FIV

$\alpha_R = 1$, $U^* = 6$

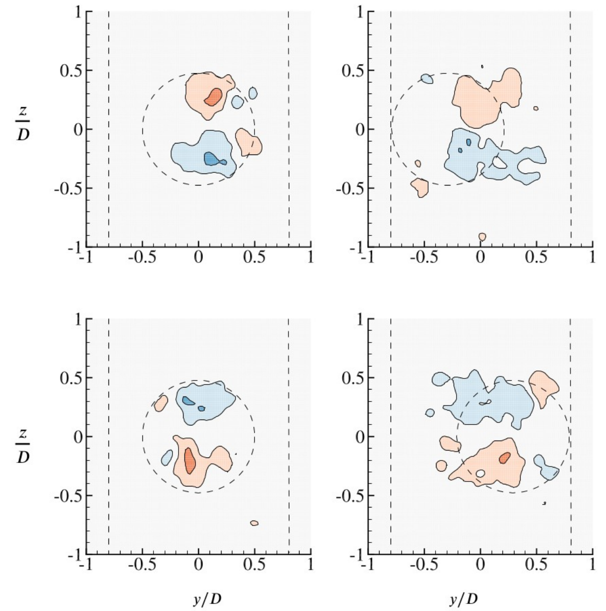
$f_R = 0$



$f_R = 1.1$

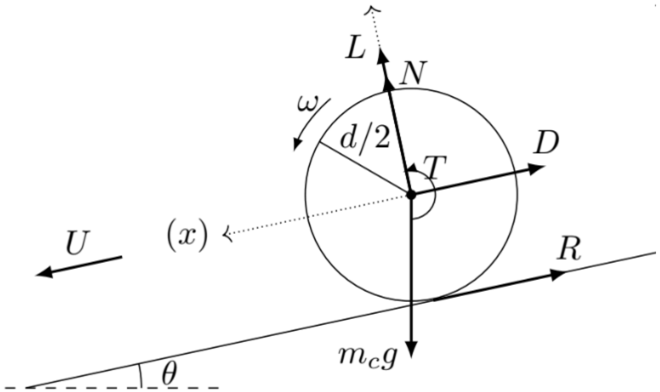


$f_R = 3$

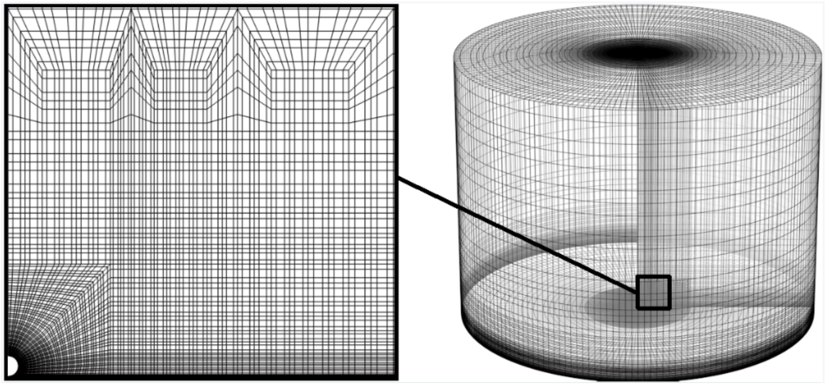


VIV OF A ROLLING SPHERE

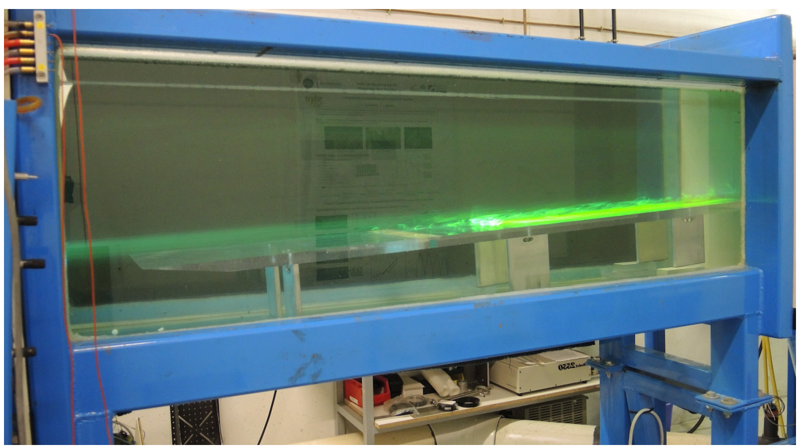
Observed and predicted drag coefficient



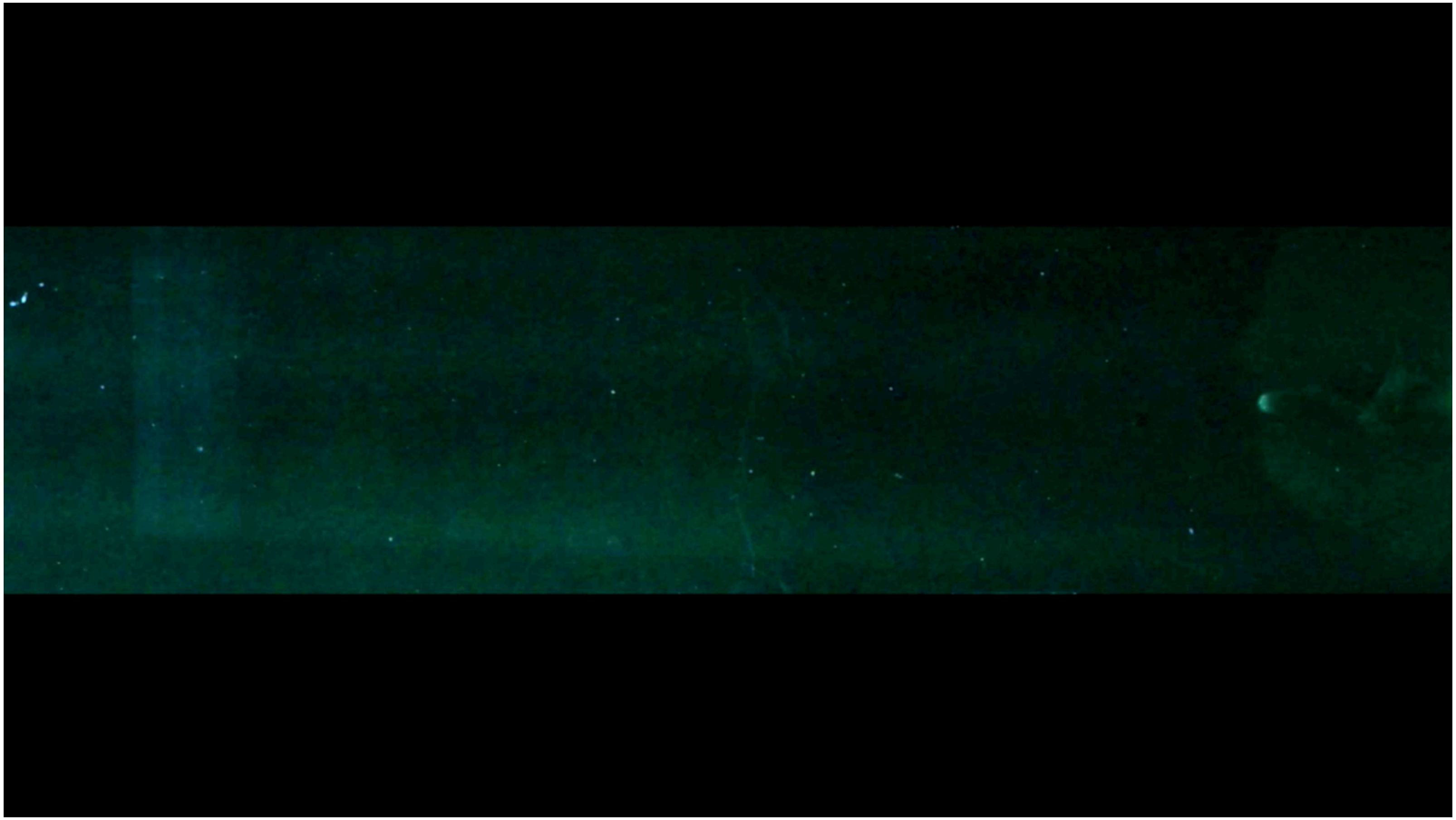
CFD: Spectral Element Mesh



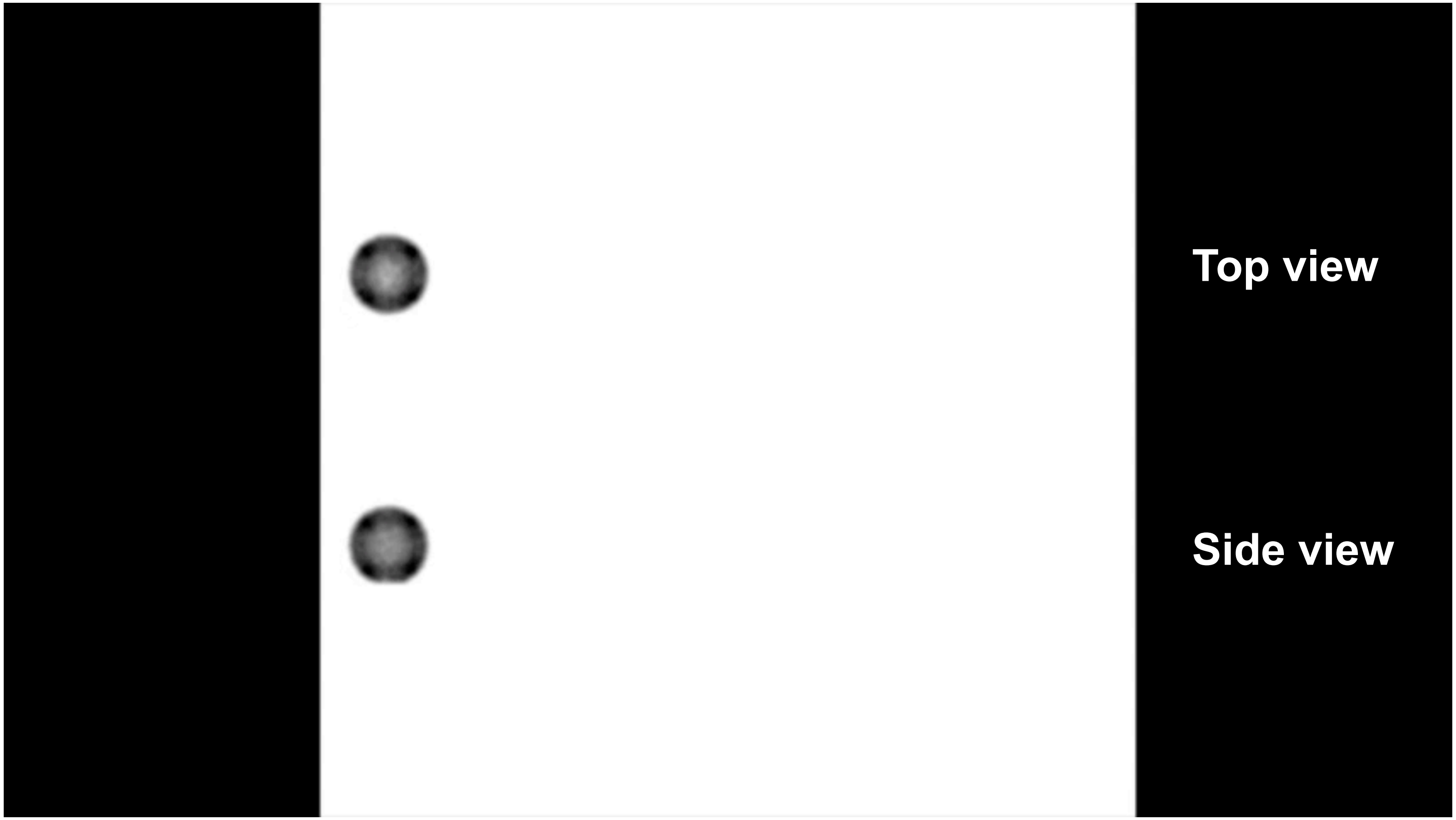
Experiment: Rig in Marseille



Dye visualisation of a rolling sphere

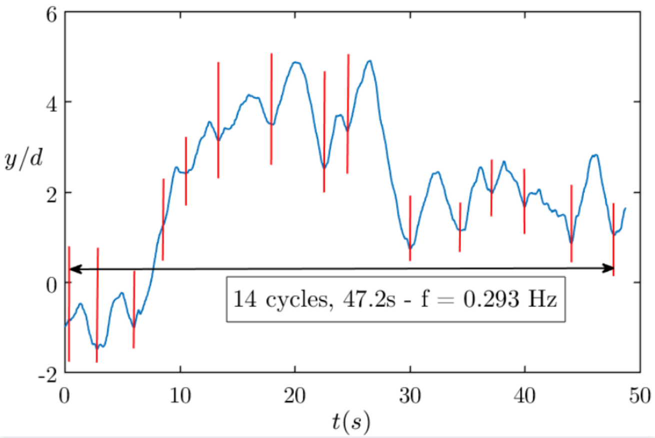


CFD Prediction of Rolling Sphere

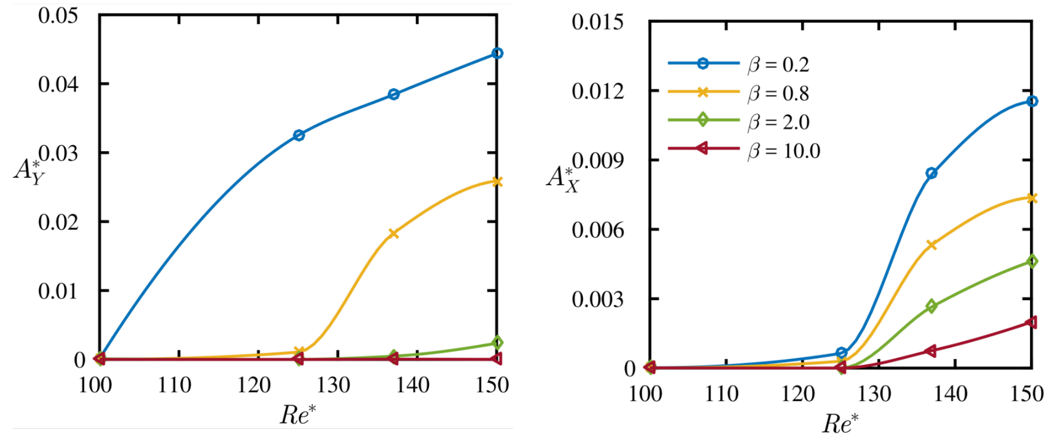


Predicted lateral oscillations, mean lift & drag

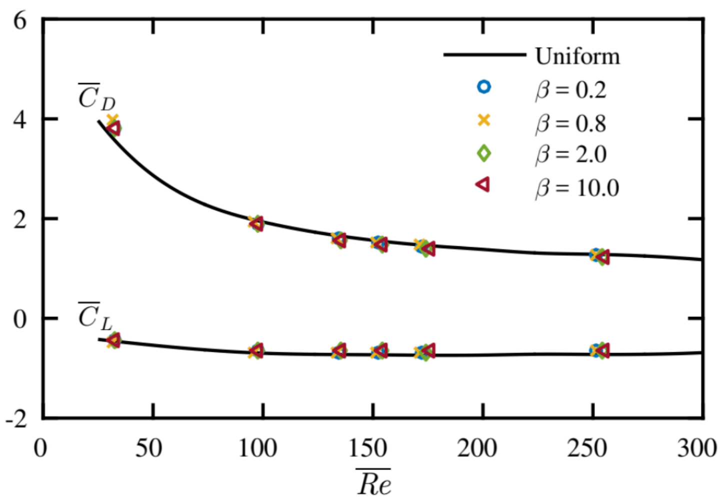
Typical path of a sphere



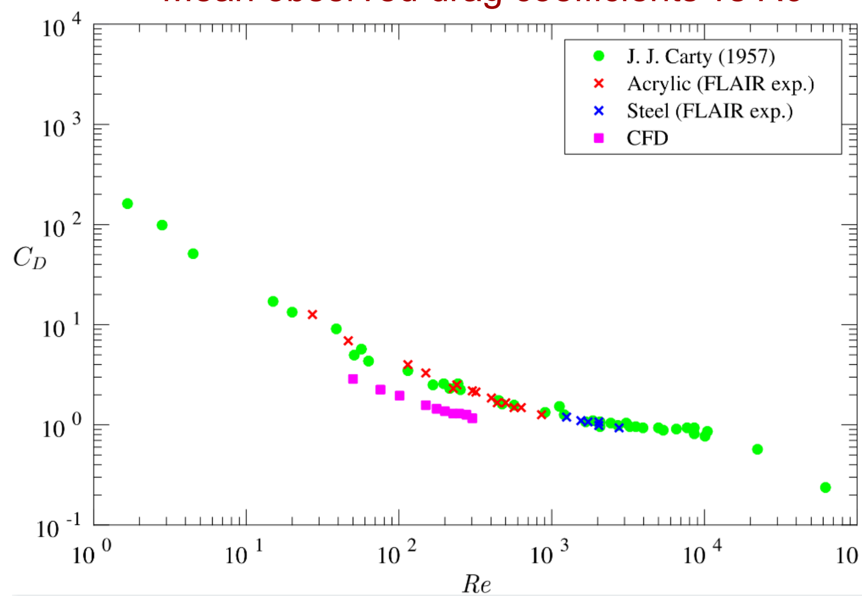
Lateral A^*_Y and streamwise A^*_X oscillation amplitudes vs *Re* for different mass ratios β



Mean lift and drag coefficients vs *Re*



Mean observed drag coefficients vs *Re*



Summary & Conclusions

Non-rotating sphere

Surface trip wire: Effect of angle and height on FIV

Near a free surface: As sphere is raised, FIV decreases until sphere touches surface, then increases until about 3/8 submerged, then decreases

Rotating sphere

Constant rotation: Magnus effect, FIV reduction for all U* as spin rate increases

Rotary oscillation: Complex response, FIV reduction or augmentation, depending on oscillation amplitude and frequency, including galloping-like response

Rolling on a wall: FIV increases as m* decreases