Manipulation of Flows

Shervin Bagheri

Linné Flow Centre

Mechanics, KTH, Stockholm

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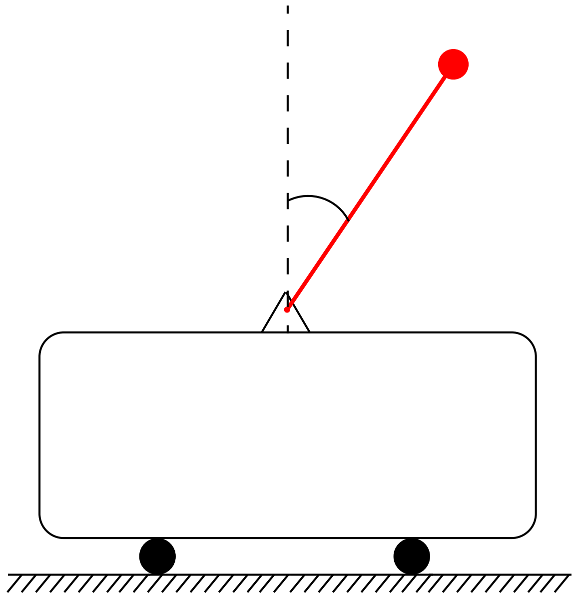
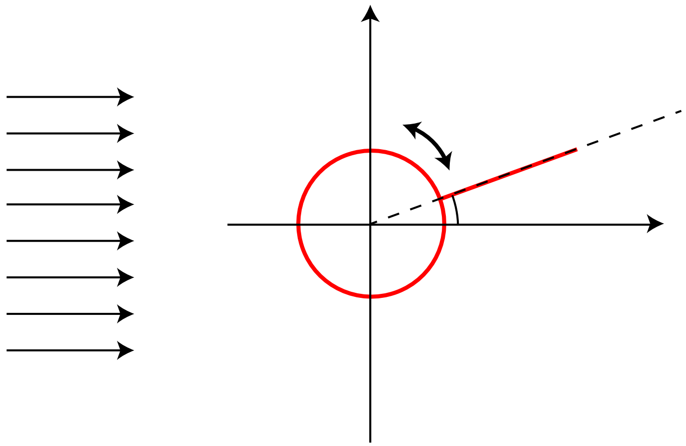
Today's lecture

What is flow manipulation?

Control of inverted pendulum



Inverted pendulum instability in flows



Flow control: objectives, means and constraints

Objectives — Flow mixing, noise reduction, drag reduction

Means — Boundary conditions, flow or fluid properties

Constraints — Dynamics, external, physical

Flow control is everywhere in technology

mixing in multiphase systems
ink-jet printers
fuel injection in engines
shape optimization in aerodynamics
vortex generator/riblets/LEBUs
additive polymers/micro-air bubbles
control of thermoacoustic oscillations
and many more…

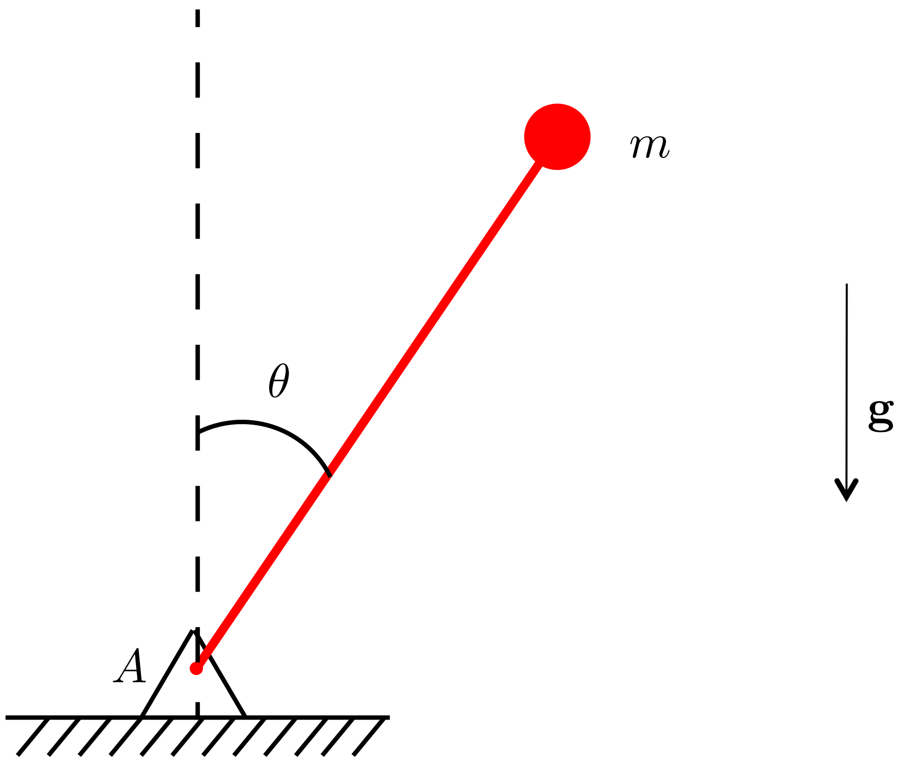
Most are based on trial and error

Most are suboptimal and not robust

For systematic, efficient, robust control we also need a **good model**

Example: inverted pendulum

Pendulum hinged at A is unstable

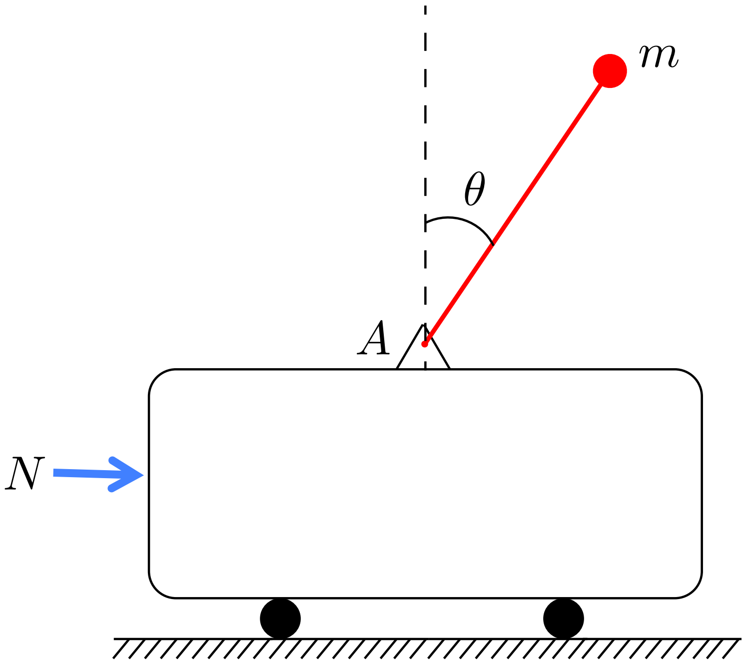


By developing systematic/efficient/robust control of this system we can…

also control unicycles, iBots, robots, Segways,…

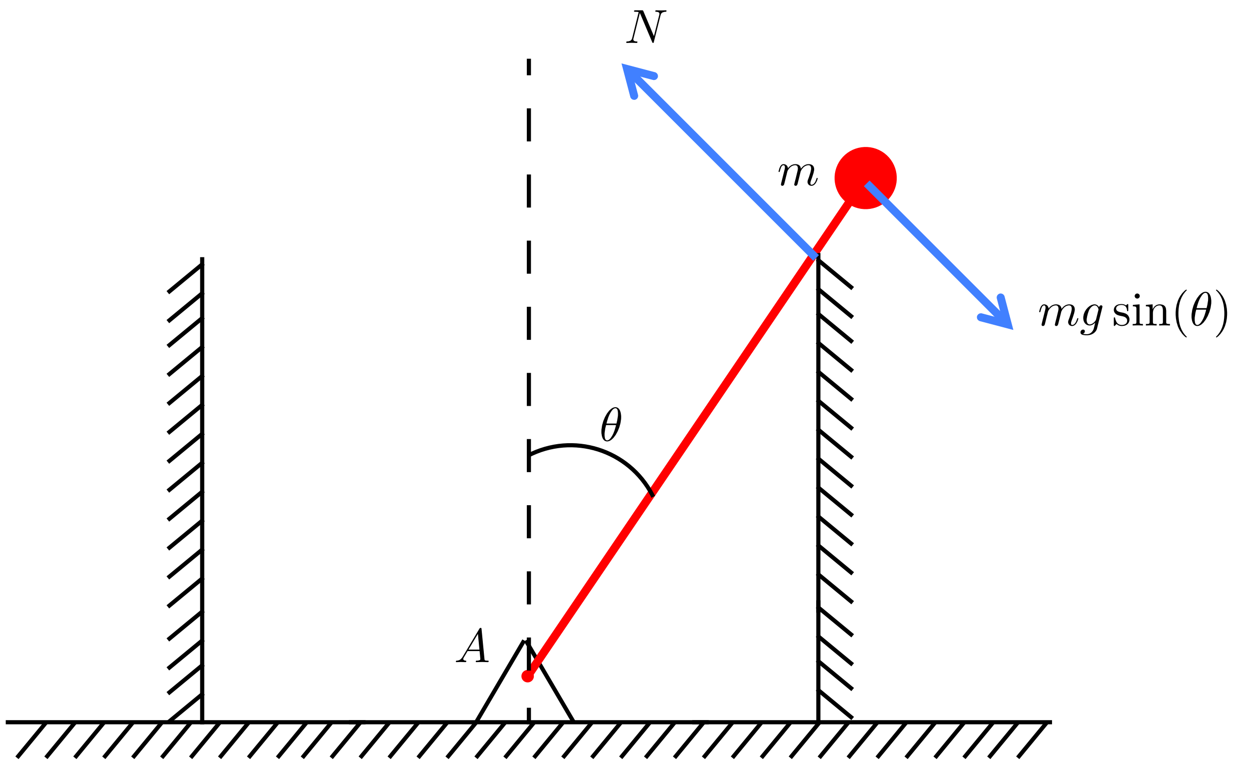
We can control inverted pendulum actively

by feedback control

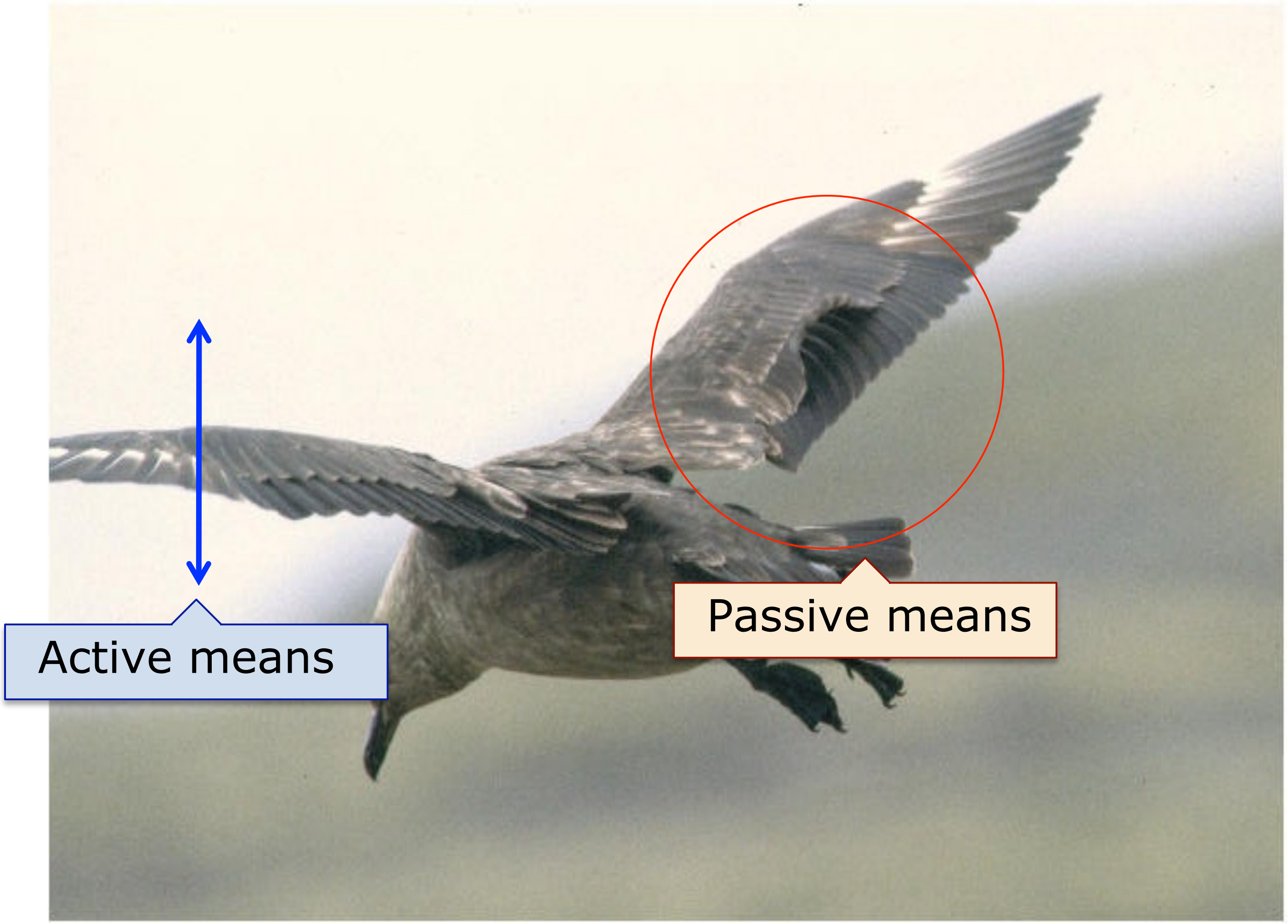


or passively

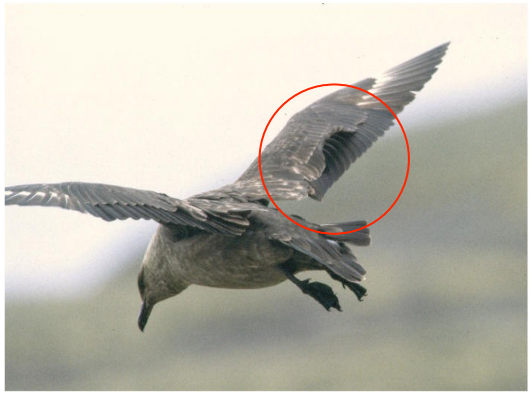
by adding walls yielding zero torque around A



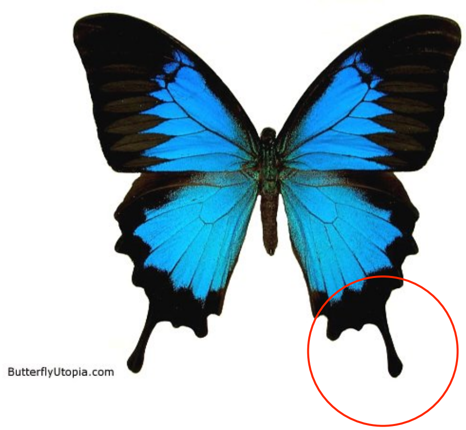
Active and passive control in nature



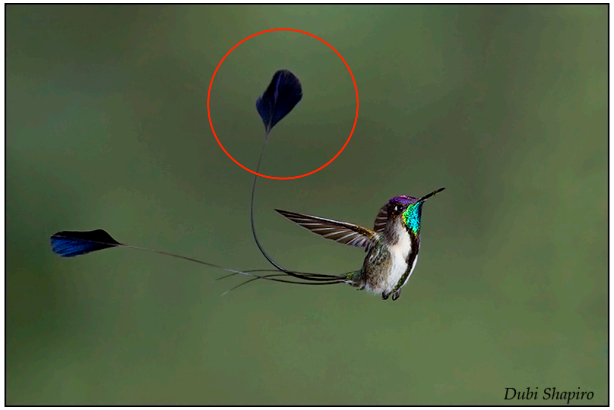
Can passive appendages undergo an inverted-pendulum instability?



Pop-up feathers of birds
Schatz et al, AIAA 2004



Swallowtail butterfly
Park et al, Exp. Mech. 2010

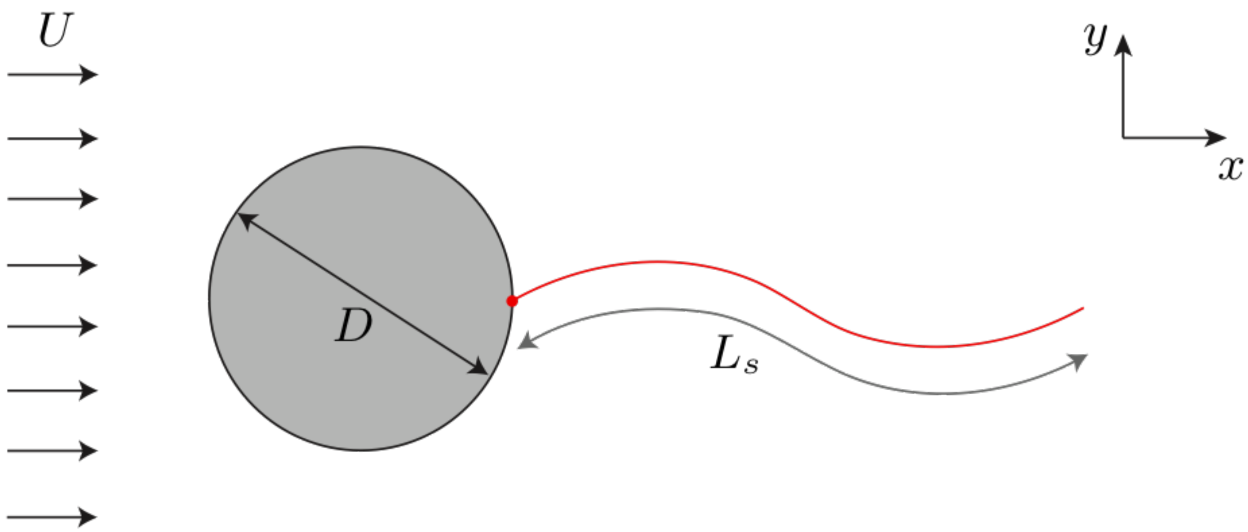


Marvelous Spatuletail
www.bbc.co.uk/nature/life/
Marvellous_Spatuletail

Dandelion plant
Burrows, New Phytol, 1975

Model of a body with a passive appendage

Incompressible stream (U) of fluid with viscosity (ν) past a two-dimensional fixed cylinder of diameter (D) with a passive elastic filament of length (L) attached to its rear end.



What happens?

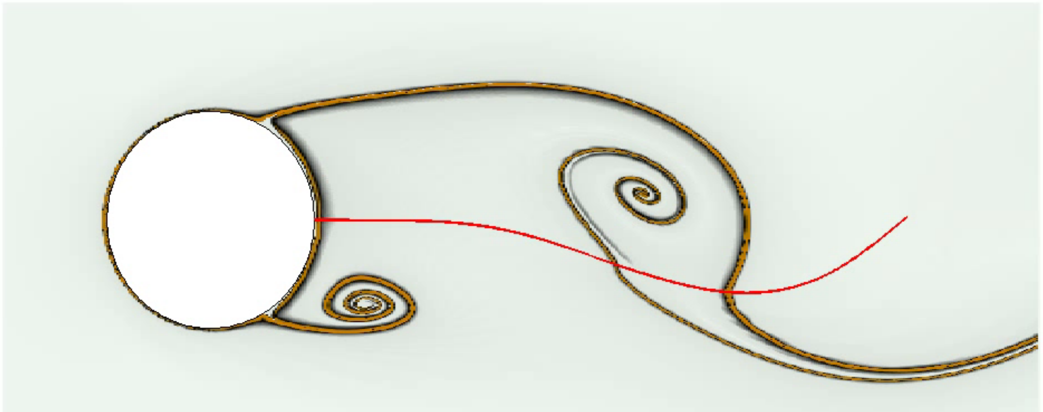
A short/long filament flapping in a cylinder wake

Reynolds number: $Re = \frac{UD}{\nu} = 100$

Long Filament
$L/D = 3$

Flaps symmetrically

time = 264.55   L = 3.00



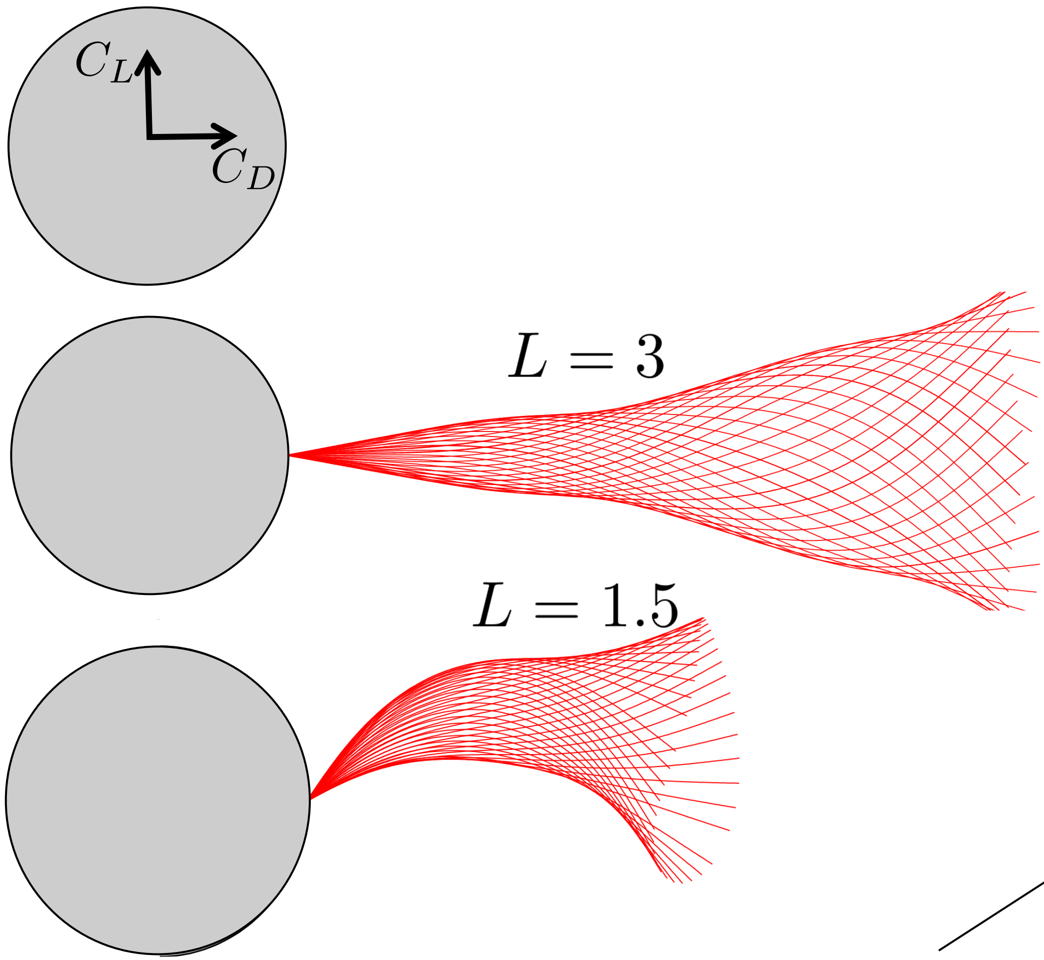
Short Filament
$L/D = 3/2$

Filament gets trapped!

time = 315.05   L = 1.50

Bagheri, Mazzino, Bottaro, PRL, 2012

Drag and lift force on cylinder with/without filament



$\langle C_D \rangle = 1.36$
$\langle C_L \rangle = 0$

$\langle C_D \rangle = 1.28$
$\langle C_L \rangle = 0$

$\langle C_D \rangle = 1.32$
$\langle C_L \rangle = 0.18$

Total drag reduced and net lift force produced

Bagheri, Mazzino, Bottaro, PRL (2012)

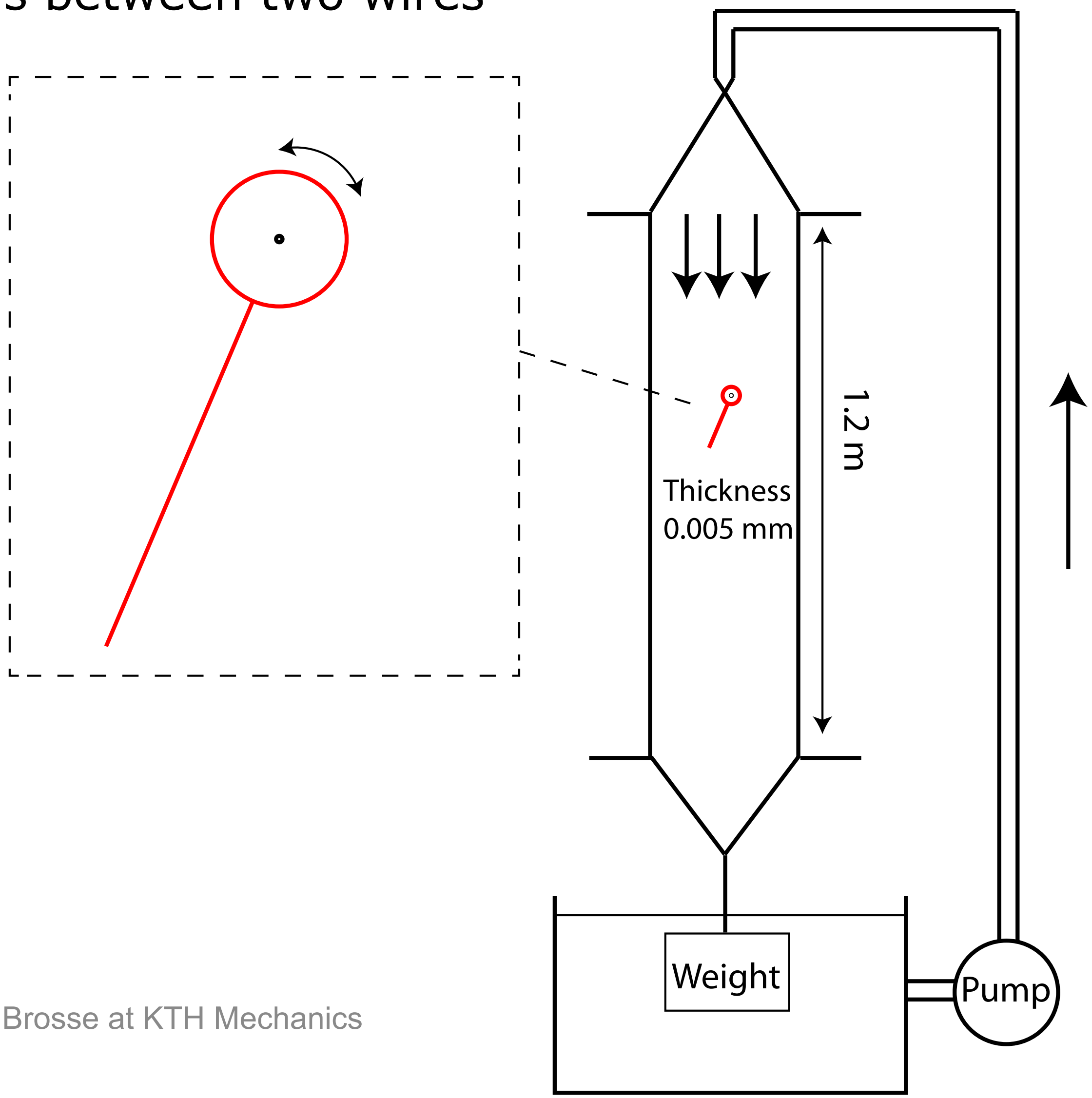
A free-to-rotate cylinder plus plate in a soap film

Due to gravity soap film falls between two wires

Cylinder diameter: 6.3mm

Film velocity: 1.9 m/s

Reynolds number: 12000

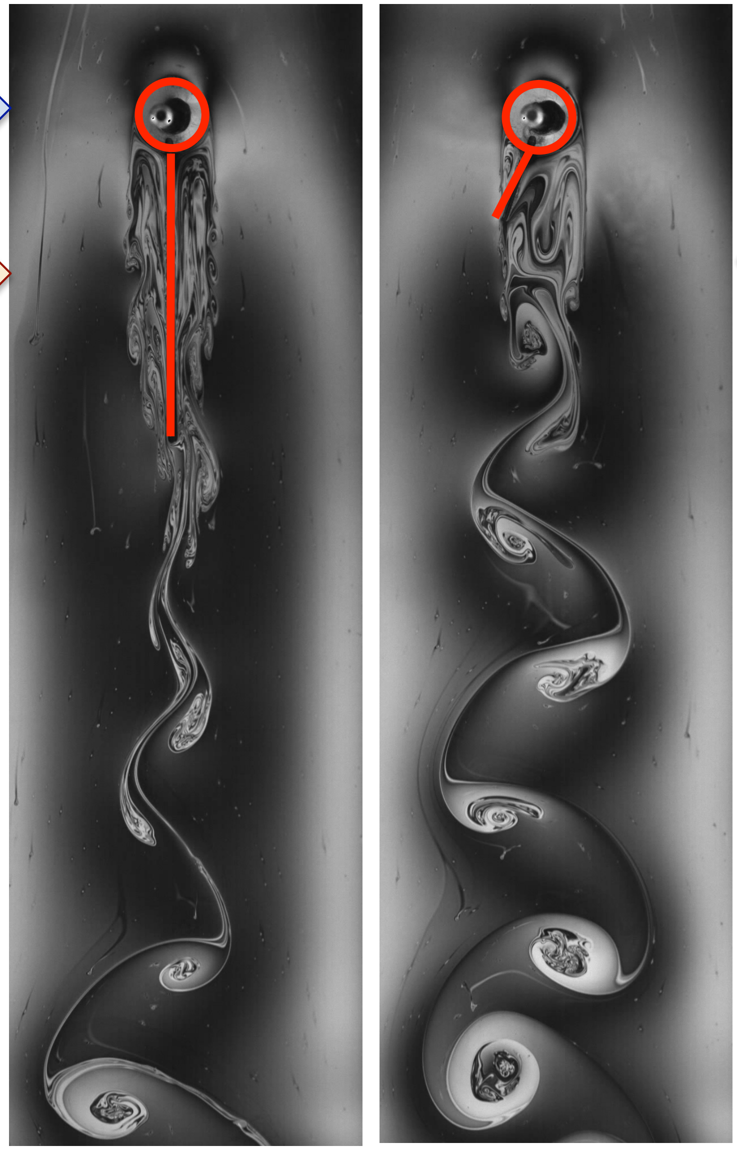


Built by Nicolas Brosse at KTH Mechanics

Observation of turn angle from experiments

Long plate

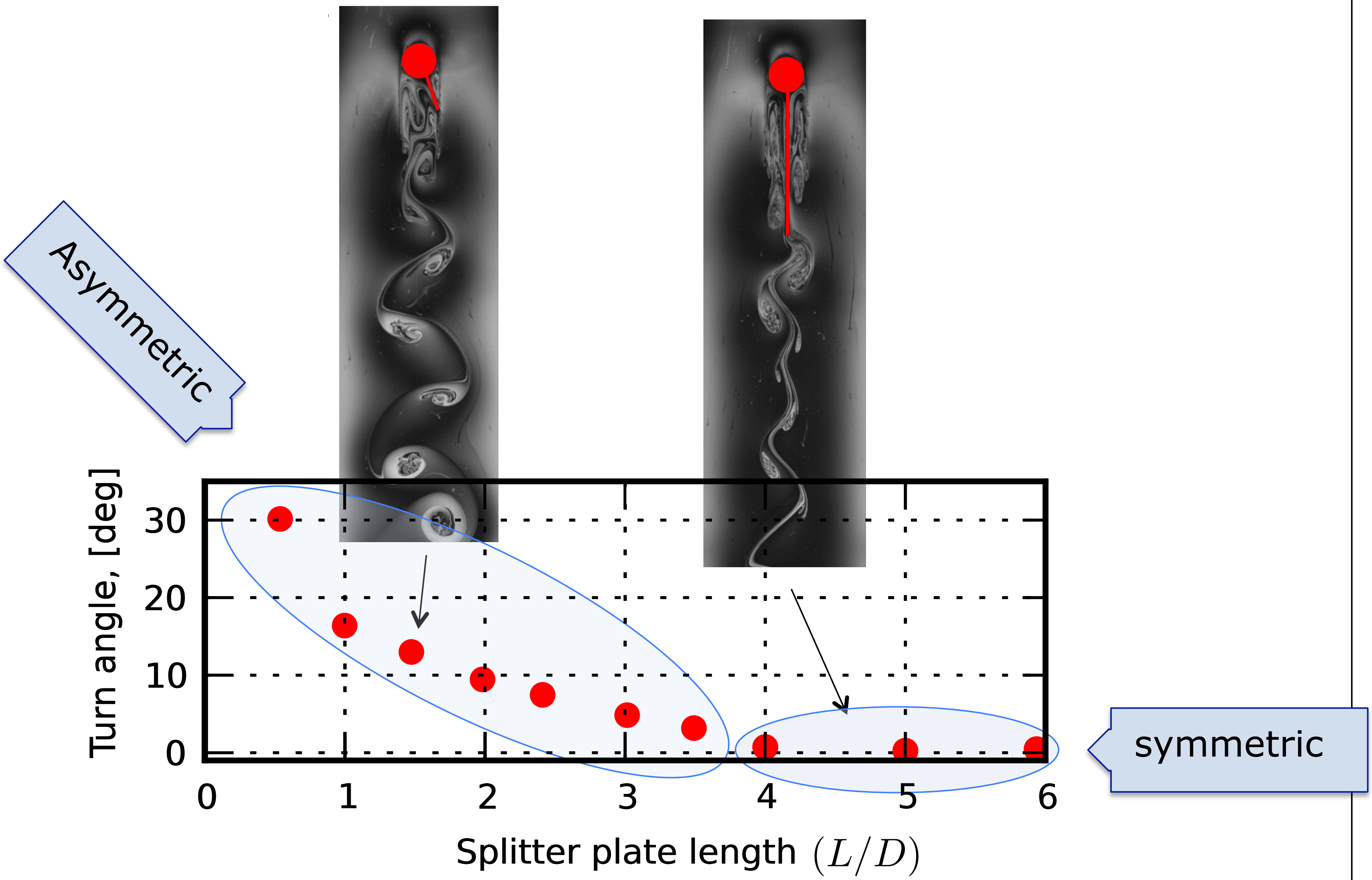
0 degree turn angle



short plate

16 degree turn angle

Bifurcation at a critical splitter plate length



Final analytical expression for the turn angle

For an back-flow region in the form of an ellipse we get

$$\theta_{1,2} = \pm\arccos\left(-\frac{q_b}{2q_a} + \frac{\sqrt{q_b^2 - 4q_a q_b}}{2q_a}\right)$$

where

$$q_a = \left[0.5 + \hat{B}(\hat{L})\right]^2 (a^2 - b^2)\,,$$

$$q_b = 2b^2 y_0 \left[0.5 + \hat{B}(\hat{L})\right],$$

$$q_c = a^2 b^2 - b^2 y_0^2 - a^2 \left[0.5 + \hat{B}(\hat{L})\right]^2,$$

$$y_0 = 0.5\cos\theta_0,$$

$$a = 0.5\sin\theta_0,$$

$$b = 0.5 - y_0 + \hat{B}_{\max}.$$

and

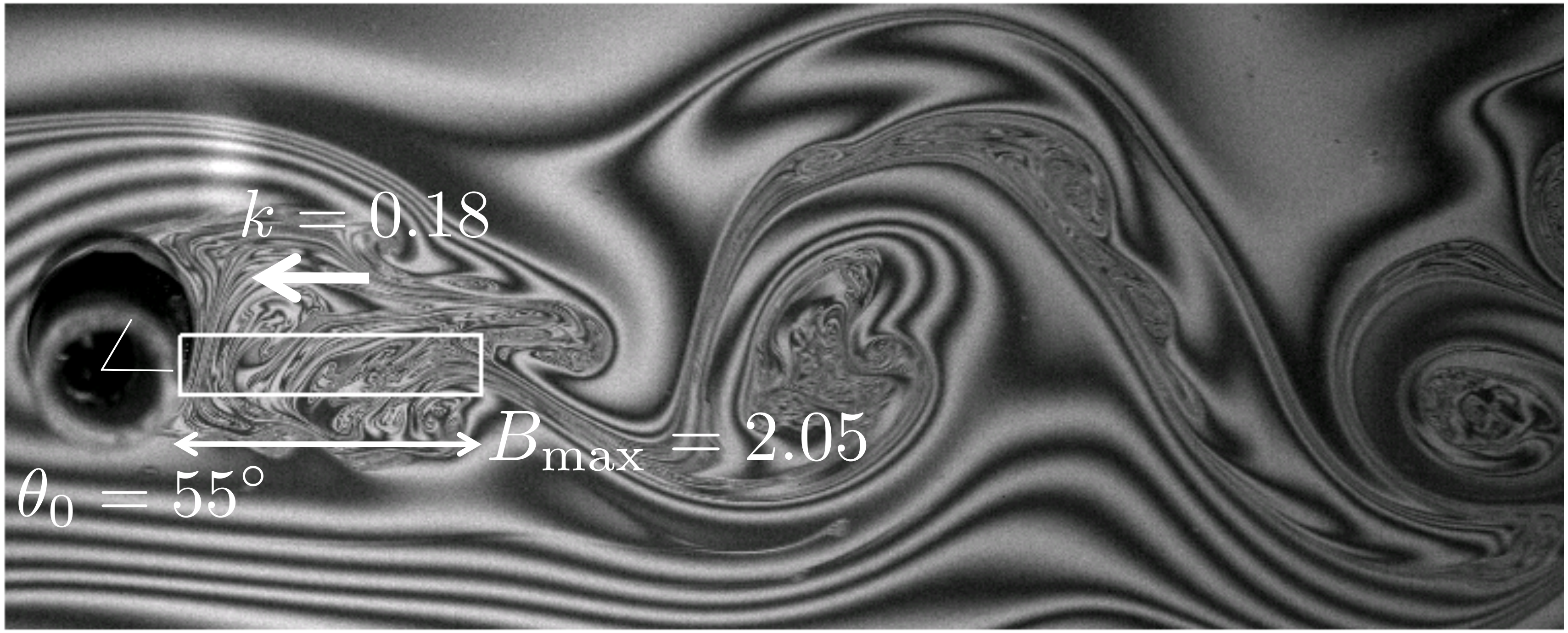
$$\hat{B}(\hat{L}) = \frac{1}{2}\left[\sqrt{\frac{4}{k+1}(\hat{L}^2 + \hat{L}) + 1} - 1\right]$$

Determined by three parameters

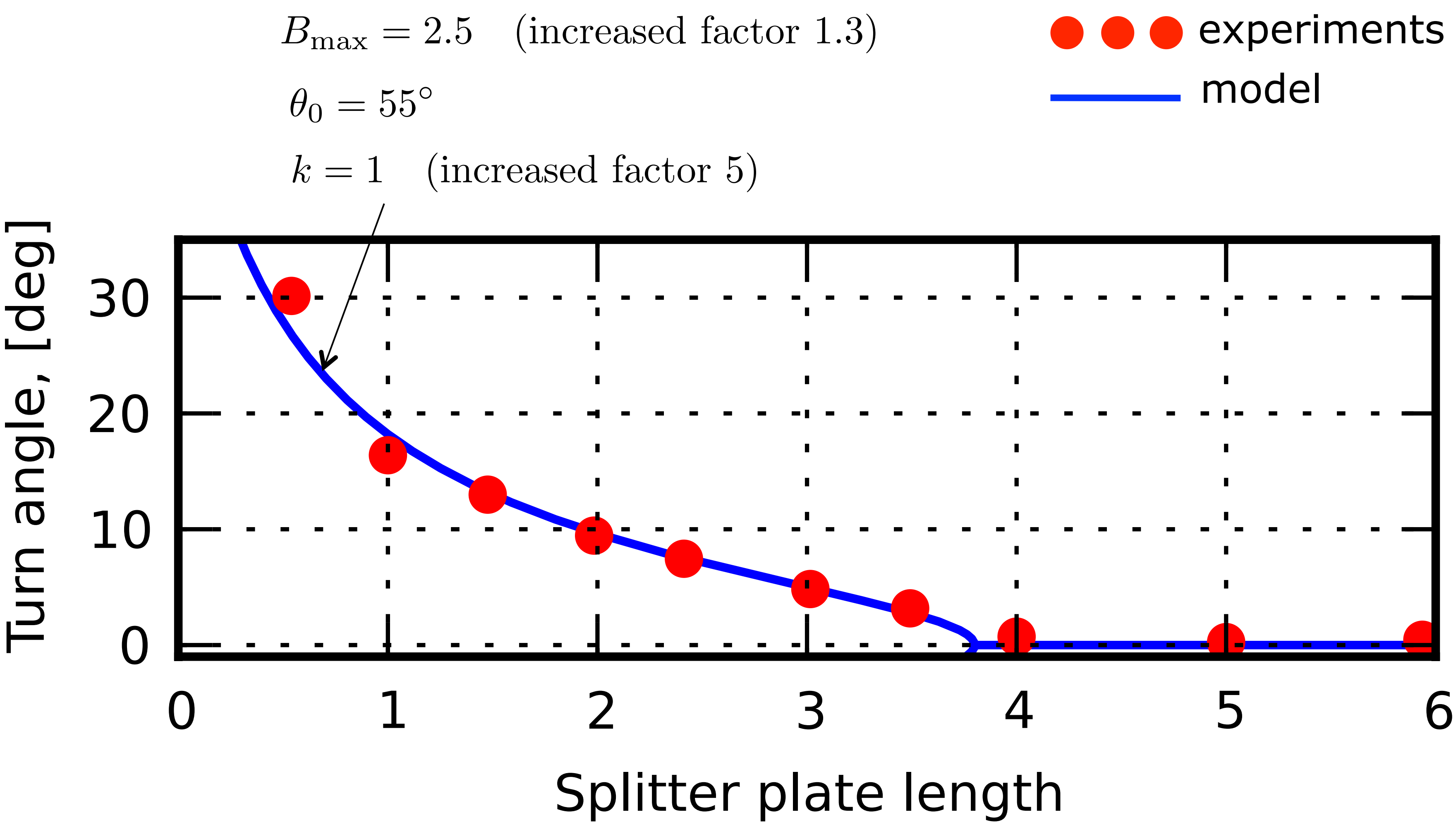
Model developed by Ugis Lacis at KTH Mechanics

Estimating parameters from experiments

Estimates give the order of magnitude of the three parameters



Good agreement between experiments and theory



Lacis, Brosse et al, submitted

Summary of today's lecture

- For systematic efficient flow manipulation we need a model for control
- A good model for control is a simple model (not Navier-Stokes) that isolates an underlying mechanism of a more complex phenomenon
- Complex systems can be decomposed to many simple models + interfaces between models
- Inverted pendulum instability is an example of simple mechanism incorporated in a complex nonlinear fluid-structure interaction problem
- How to find a model? Next Lecture!

If you can’t come to next lecture you can talk to

Ugis Lacis

- Can model from “physical intuition”

Nicolo Fabbiane

- Can model from signal measurements of a fluid flow

Reza Dadfar

- Can model from huge numerical/experimental data