Manipulation of Flows

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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...

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

Active means

Passive means
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 ($\nu$) 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

**Short Filament**  
\( L/D = 3/2 \)

Filament gets trapped!
Total drag reduced and net lift force produced

\[ \langle C_D \rangle = 1.36 \]
\[ \langle C_L \rangle = 0 \]

\[ \langle C_D \rangle = 1.28 \]
\[ \langle C_L \rangle = 0 \]

\[ \langle C_D \rangle = 1.32 \]
\[ \langle C_L \rangle = 0.18 \]

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

Asymmetric

Symmetric
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

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

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

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

and

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

\[
y_0 = 0.5 \cos \theta_0,
\]

\[
a = 0.5 \sin \theta_0,
\]

\[
b = 0.5 - y_0 + \hat{B}_{\text{max}}.
\]

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:

- $B_{\text{max}} = 2.05$
- $\theta_0 = 55^\circ$
- $k = 0.18$
Good agreement between experiments and theory

\[ B_{\text{max}} = 2.5 \quad \text{(increased factor 1.3)} \]

\[ \theta_0 = 55^\circ \]

\[ k = 1 \quad \text{(increased factor 5)} \]
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