Computational Fluid Dynamics

Lecture 1

February 25, 2025

Levent Aydınbakar

Asst. Prof. Dr.

levent.aydinbakar@btu.edu.tr

Bursa Technical University

Department of Mechanical Engineering

About me

- Education
  - Eskisehir Osmangazi University, Eskisehir, Turkey, BSc in Mechanical Engineering, 2011
  - Cranfield University, Bedfordshire, United Kingdom, MSc in Computational Fluid Dynamics (CFD), 2016
  - Waseda University, Tokyo, Japan, PhD in CFD, 2021
- YLSY Scholarship Program
  - MEXT (JP), Fulbright (US), other country and university programs
- Courses
  - CFD
  - Finite Element Method (FEM)
  - Desing in Mechanical Engineering
  - Fluid Mechanics
  - Computer Programming

About this course

- Attendance
- Installation of software
  - Ubuntu 22.04 (zsh)
  - OpenFOAM 2406
  - ParaView 5.13
  - Salome 9.12
  - LaTeX, Tikz, PgfPlots
  - Python, Gnuplot
- WhatsApp group
  - Scan the QR Code to join the group
- Contact, zoom & office hours
  - e-mail (7/24): levent.aydinbakar@btu.edu.tr
  - Zoom (by e-mail appointment)
    - Anytime appointed
  - Office (by e-mail appointment)
    - Tuesday 10:00-12:00
  - e-mail appointment
    - Appropriately written e-mail
    - Subject and questions given clearly

A simple fluid mechanics problem (find Δp)

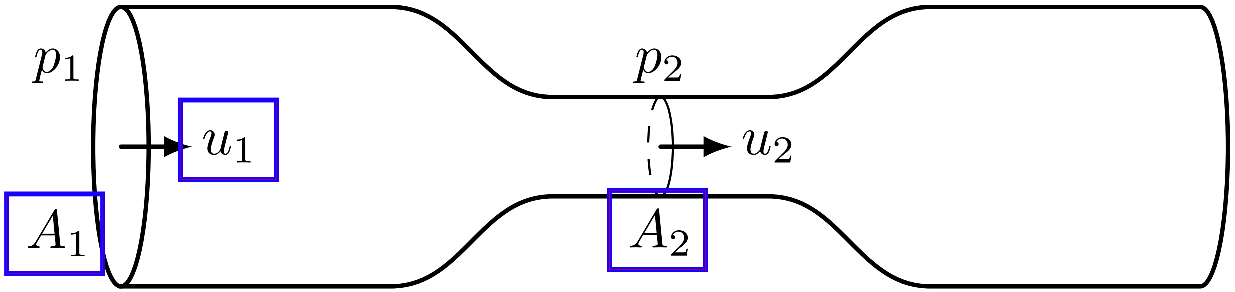

Figure: Flow through a venturi

- The pressure difference $(\Delta p = p_1 - p_2)$ (with some important assumptions)

$p,\ \rho,\ g,\ z,\ u,\ A$ are pressure, density, gravity, height, velocity, area

A simple fluid mechanics problem (find Δp)

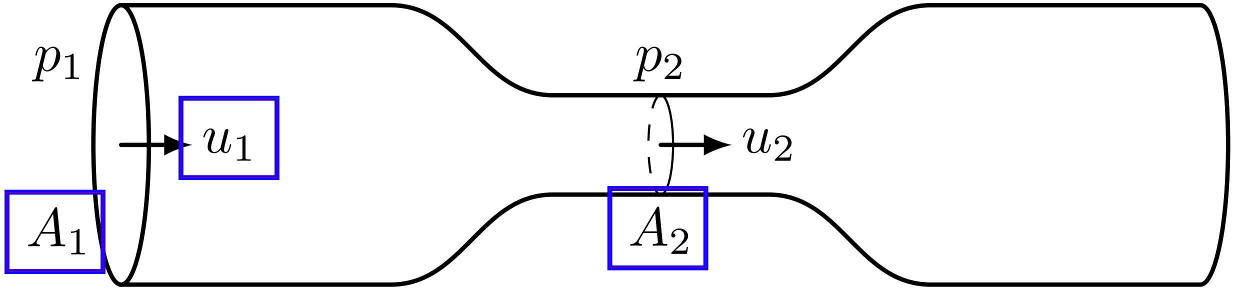

Figure: Flow through a venturi

- The Bernoulli Equation

$$p + \rho g z + \rho \frac{u^2}{2} \equiv \text{Constant}$$

- The Continuity Equation

$$\rho A u \equiv \text{Constant}$$

- The pressure difference $(\Delta p = p_1 - p_2)$ (with some important assumptions)

- Bernoulli Eq. assumes
  - Laminar and steady flow
  - Inviscid flow
  - Incompressible flow

$p,\ \rho,\ g,\ z,\ u,\ A$ are pressure, density, gravity, height, velocity, area

A simple fluid mechanics problem (find Δp)

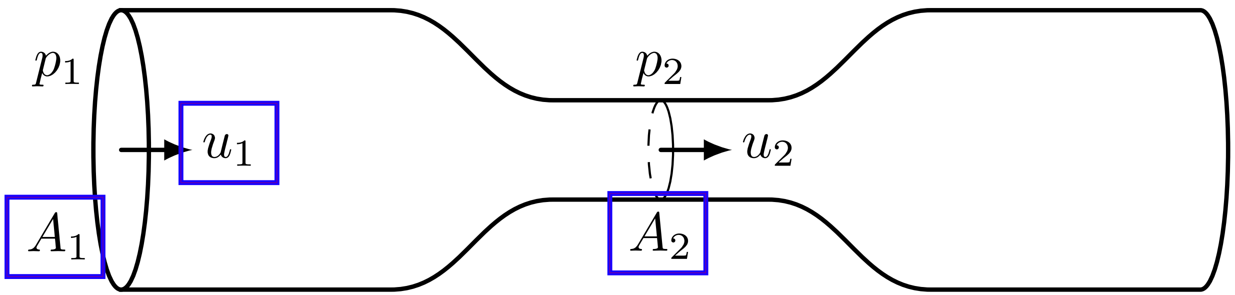

Figure: Flow through a venturi

- The Bernoulli Equation

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- The Continuity Equation

$$\rho A u \equiv \text{Constant}$$

- The pressure difference $(\Delta p = p_1 - p_2)$ (with some important assumptions)

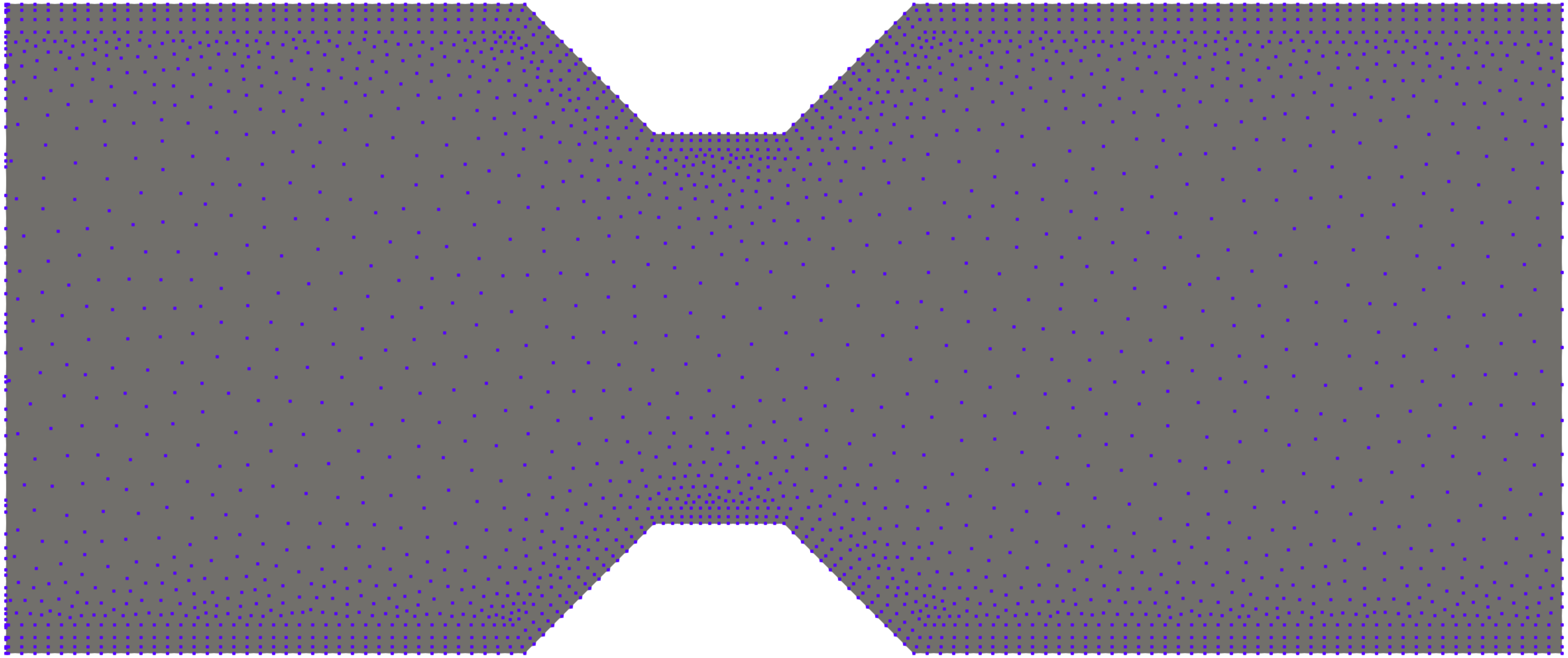
$$\Delta p = \frac{\rho u_1^2}{2} \left(\frac{A_1^2}{A_2^2} - 1 \right)$$

- Bernoulli Eq. assumes
  - Laminar and steady flow
  - Inviscid flow
  - Incompressible flow

$p,\ \rho,\ g,\ z,\ u,\ A$ are pressure, density, gravity, height, velocity, area

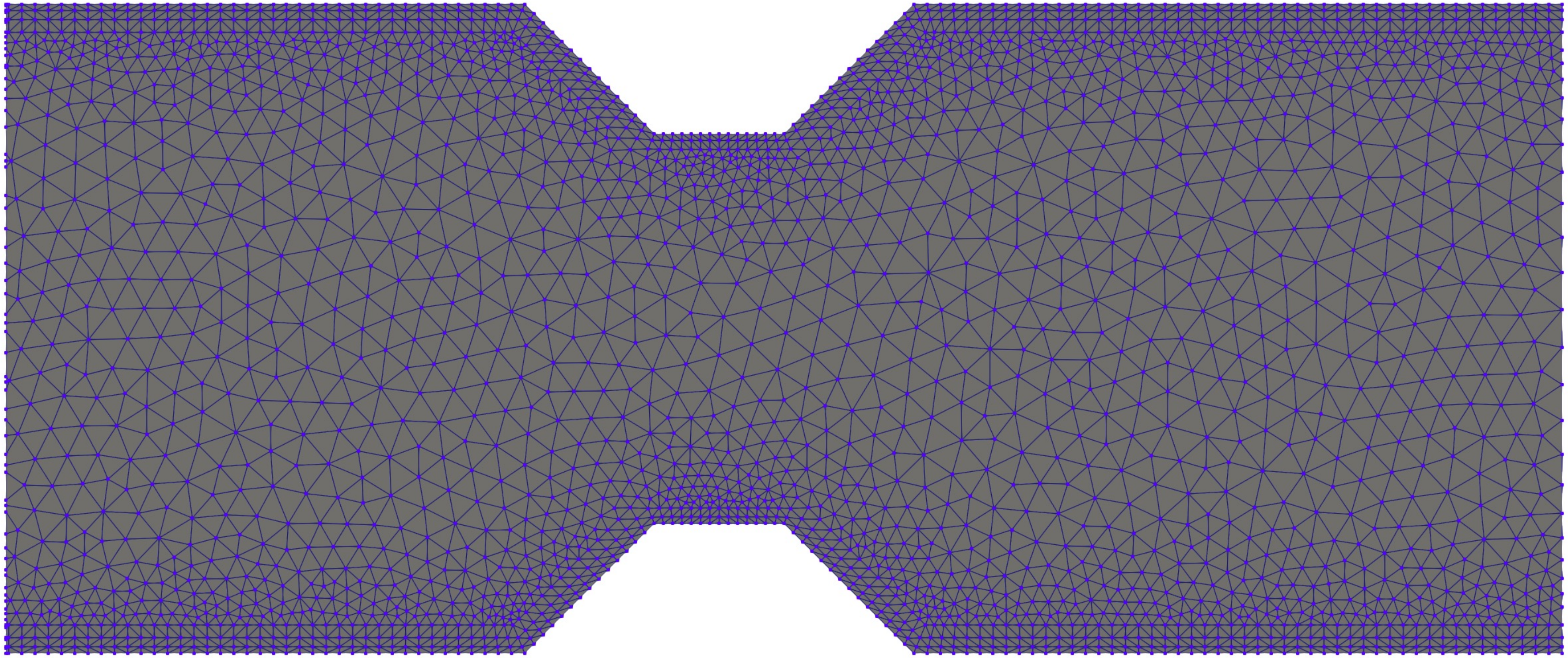
More complex problems

What if we need pressure distribution?



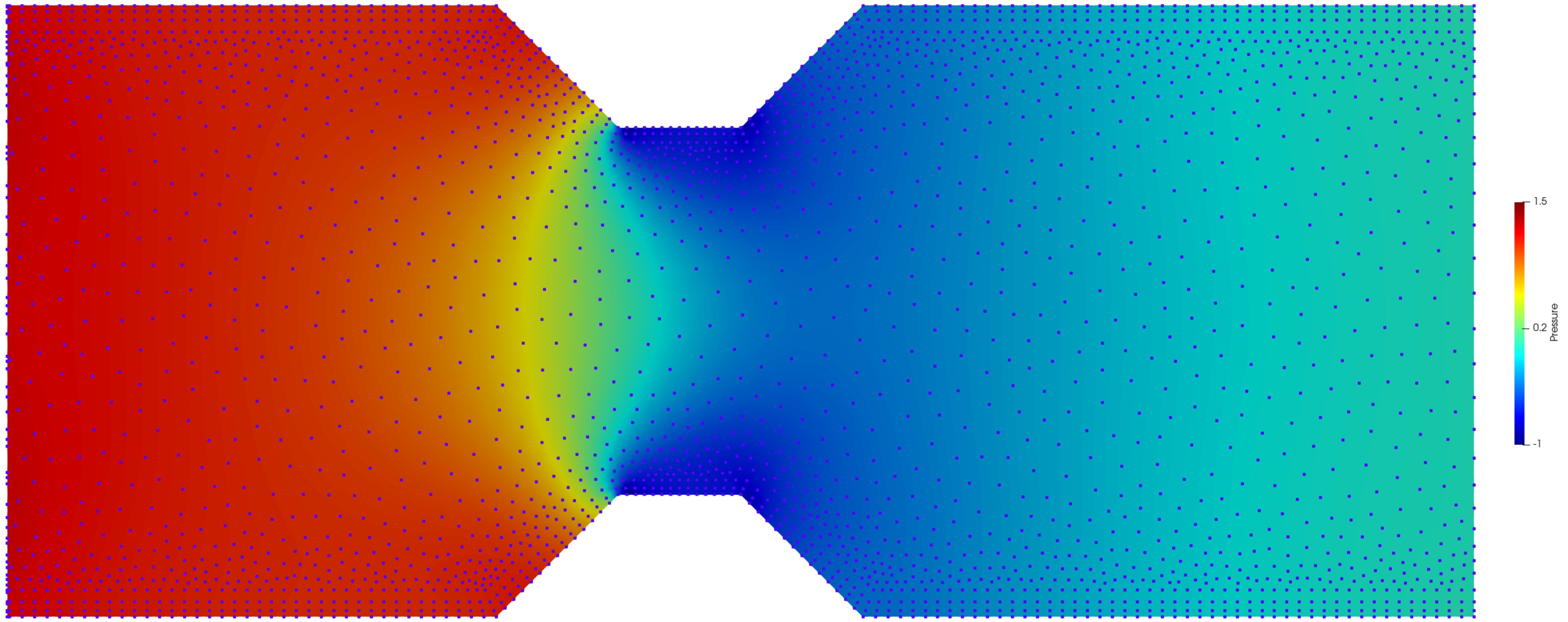
More complex problems

Need finite element discretization

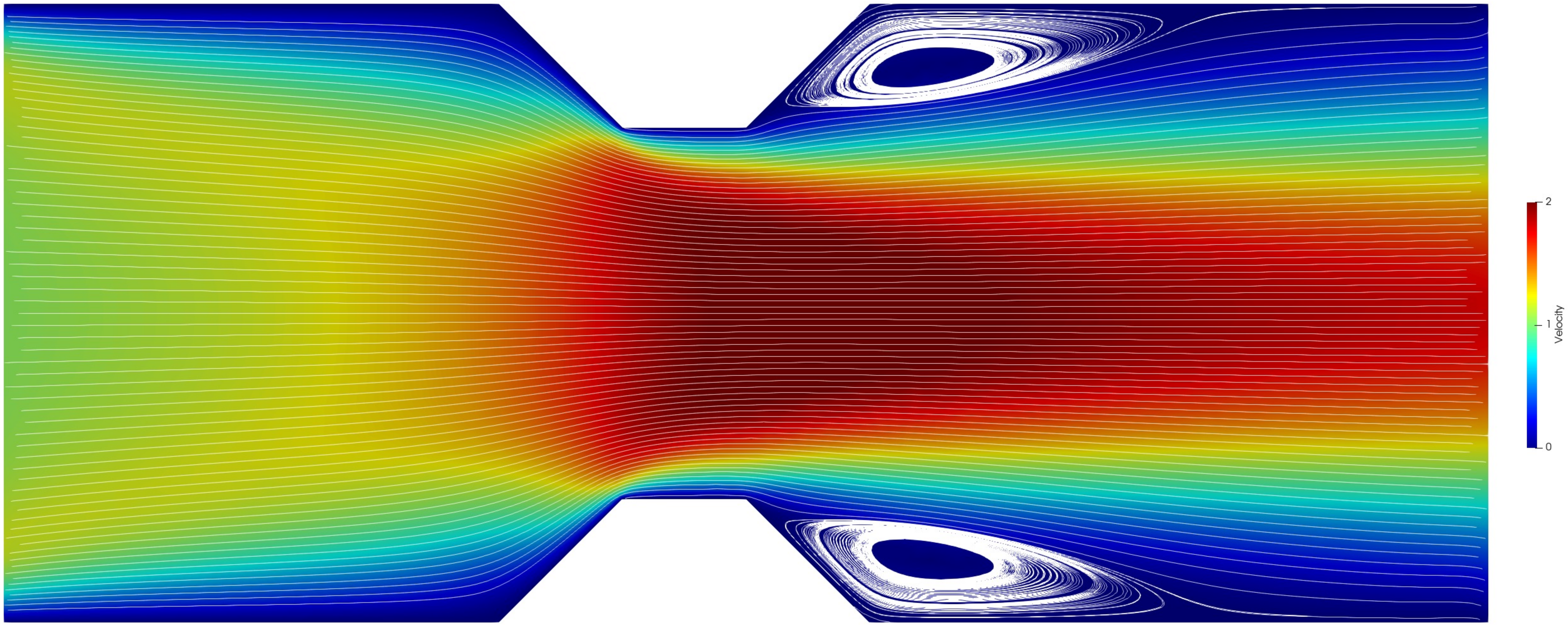


More complex problems

Pressure distribution

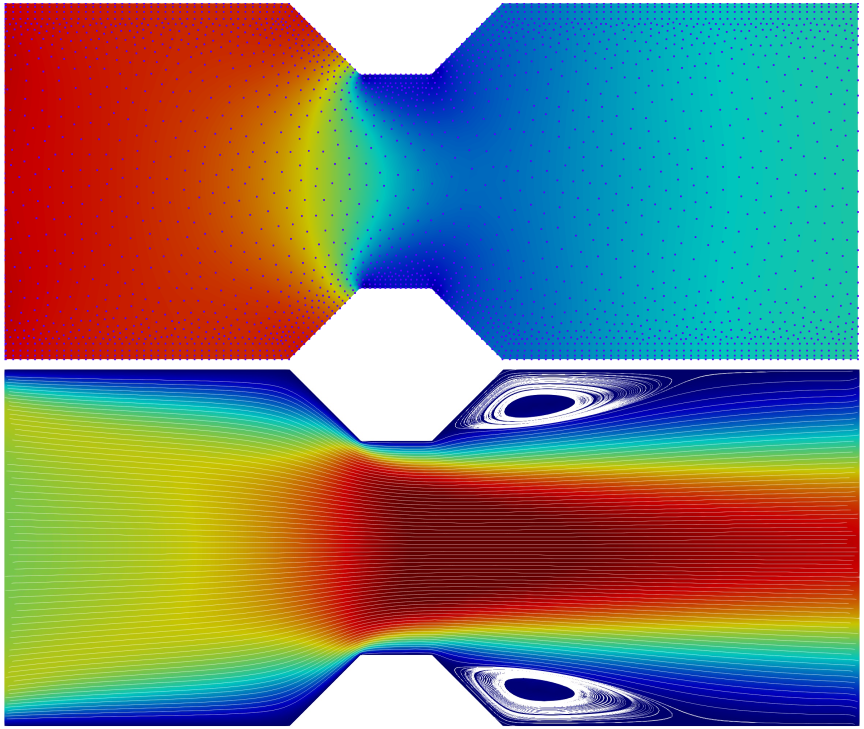


More complex problems
Velocity distribution & streamtraces



More complex problems

- The Navier-Stokes Equations
  - For incompressible fluid flow
  - Fluid mechanics governing equations
  - Momentum conservation
  - Continuity
  - Non-linear PDEs



$$\rho\left(\frac{\partial \mathbf{u}}{\partial t}+\boldsymbol{\nabla}\cdot(\mathbf{u}\mathbf{u})-\mathbf{f}\right)-\boldsymbol{\nabla}\cdot\boldsymbol{\sigma}=\mathbf{0}$$

$$\boldsymbol{\nabla}\cdot\mathbf{u}=0$$

where

$$\boldsymbol{\sigma}=-p\mathbf{I}+2\mu\boldsymbol{\varepsilon}(\mathbf{u})$$

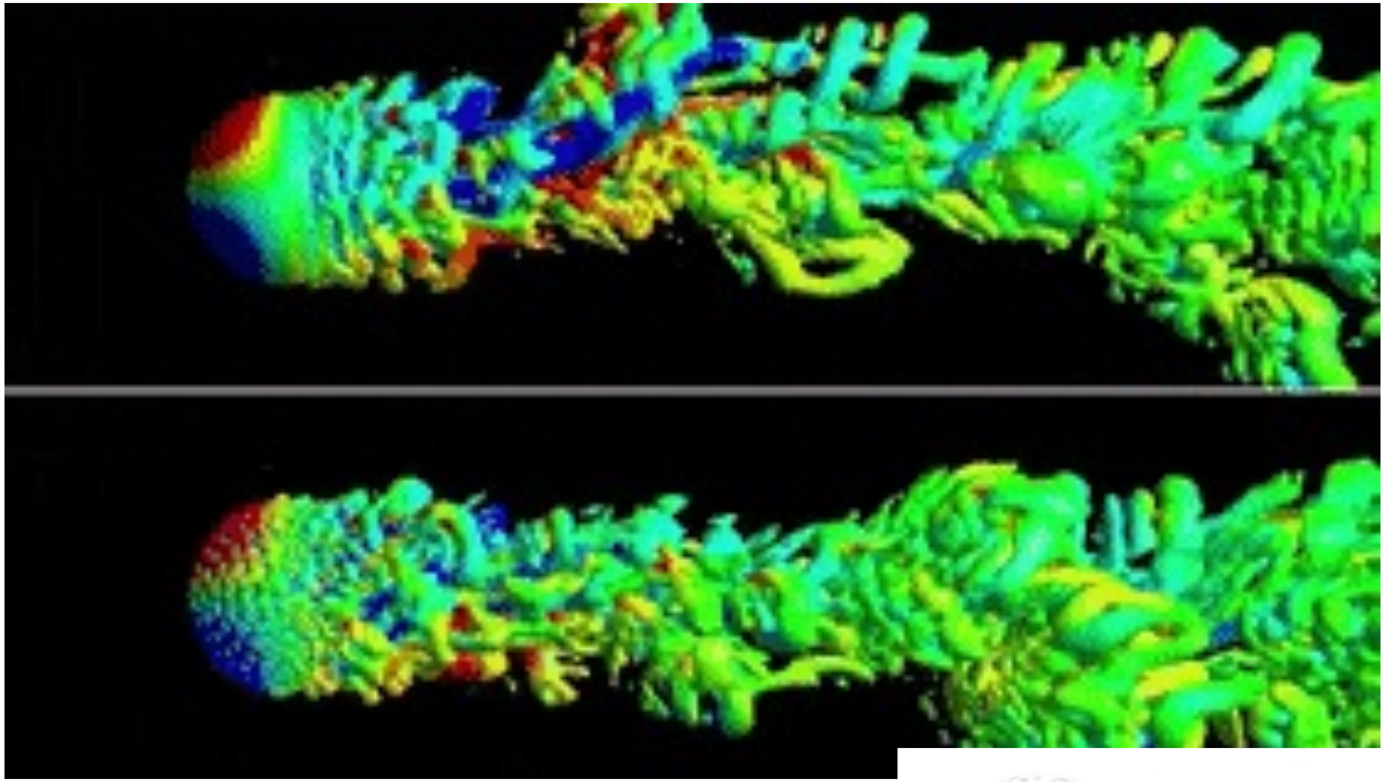
and

$$\boldsymbol{\varepsilon}(\mathbf{u})=\frac{1}{2}\left(\boldsymbol{\nabla}\mathbf{u}+(\boldsymbol{\nabla}\mathbf{u})^{\mathsf{T}}\right)$$

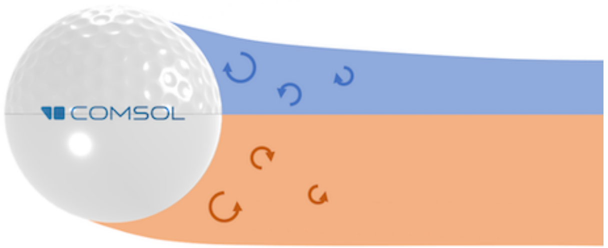
ρ, $\mathbf{u}$, $\mathbf{f}$, $\boldsymbol{\sigma}$, μ, $\mathbf{I}$, p, fluid density, velocity, external force, stress tensor, dynamic viscosity, identity tensor, and pressure

CFD application examples

Fluid mechanics

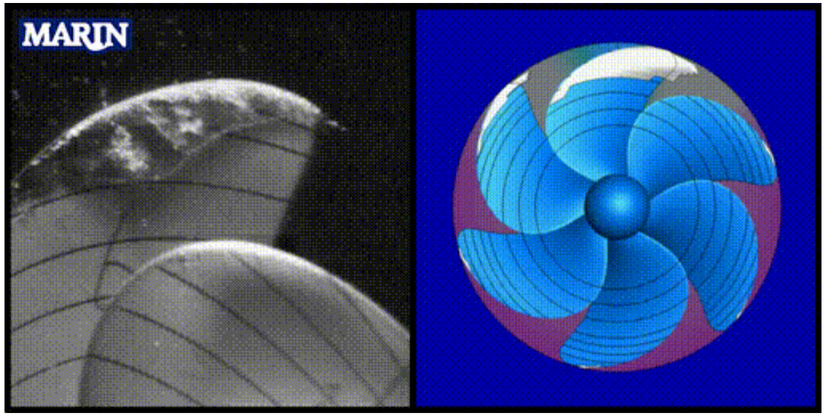


Source: https://gfycat.com/exhaustedickyjackrabbit-q-criterion-turbulence



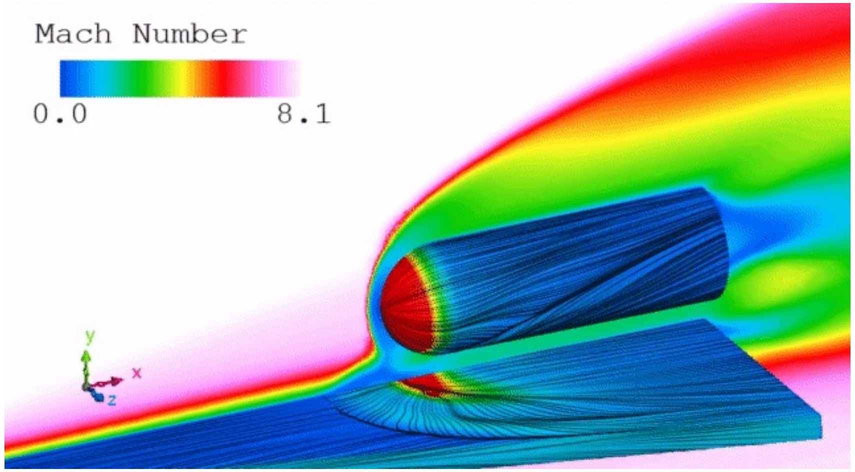
Source: https://www.comsol.com

CFD application examples
Fluid mechanics

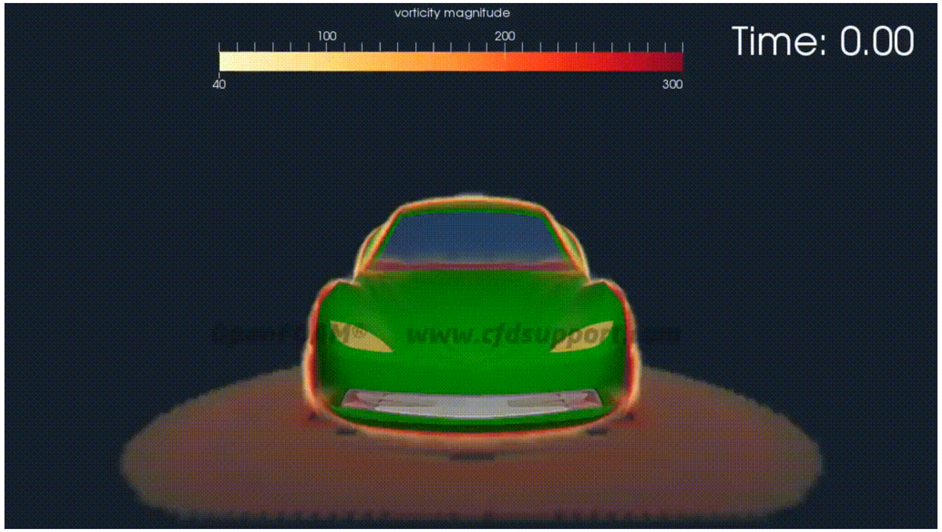


Source: https://blog.gridpro.com/meshing-aspects-for-open-water-marine-propeller-cfd/

Source: www.cfdsupport.com



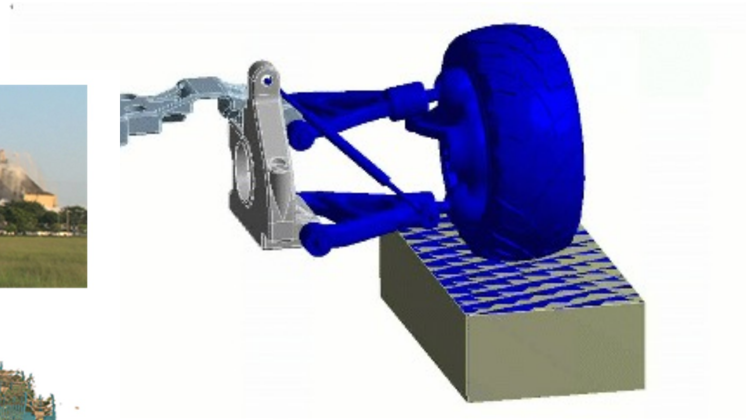
Source: https://mantiumcae.com/cradle-cfd-germany/

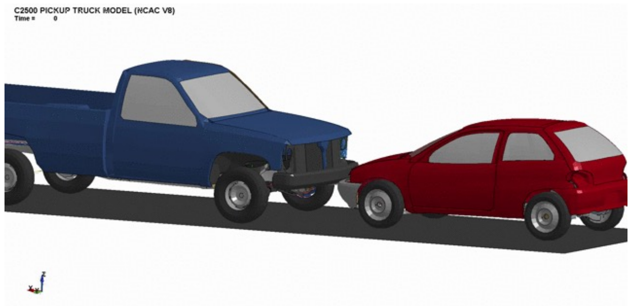


Source: www.cfdsupport.com

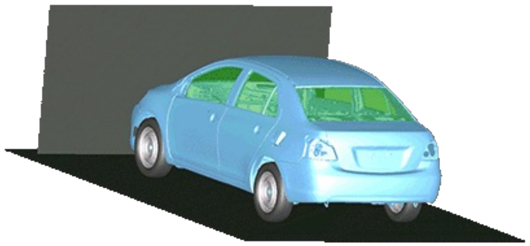
CM application examples
Solid mechanics

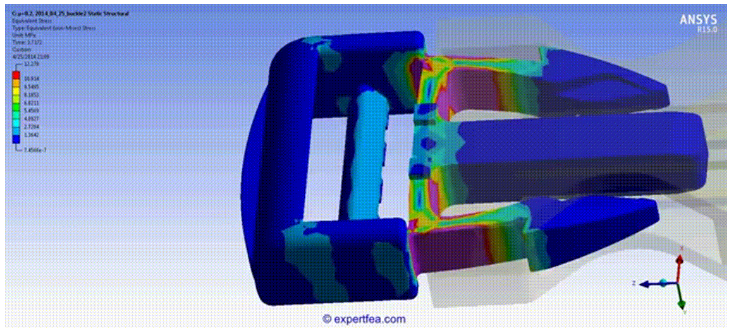
Source: www.extremeloading.com





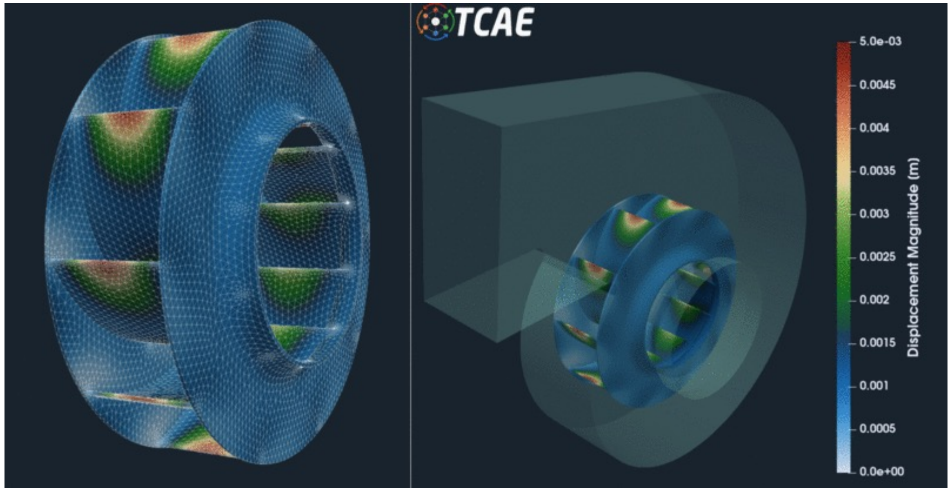
Source: https://www.xceed-eng.com/crash-test-tuesday-geo-vs-chevy-c2500/



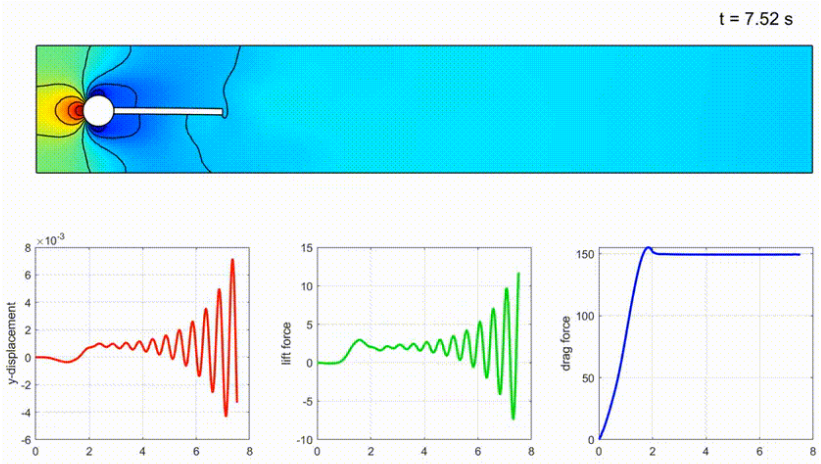


CM application examples

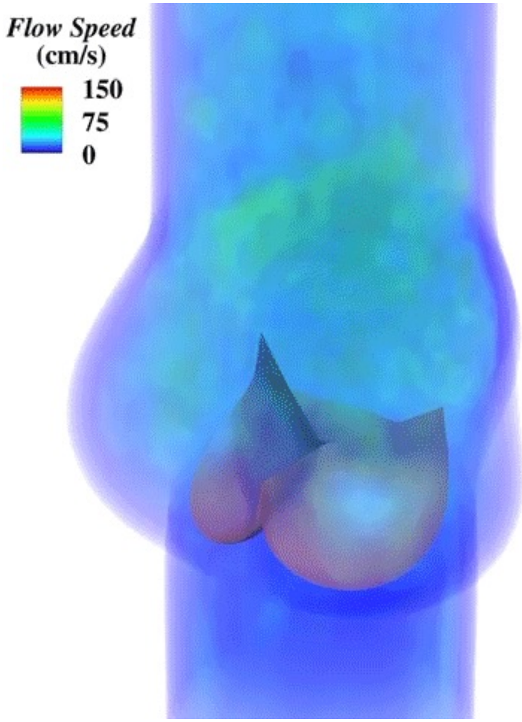
Fluid–structure interaction (coupled)



Source: www.cfdsupport.com

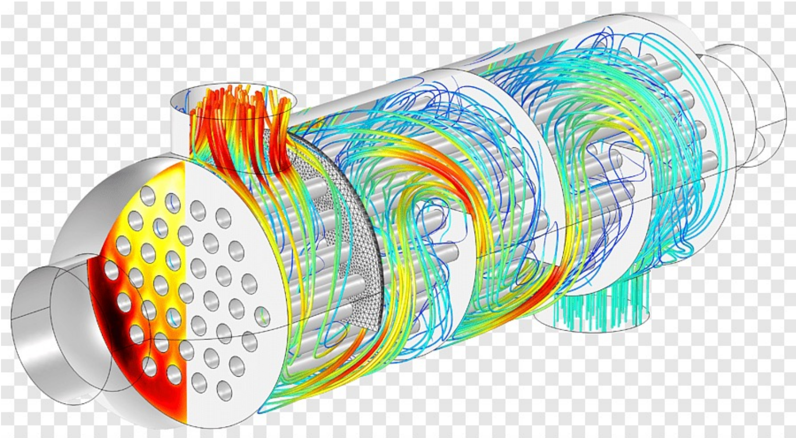


Source: www.featool.com

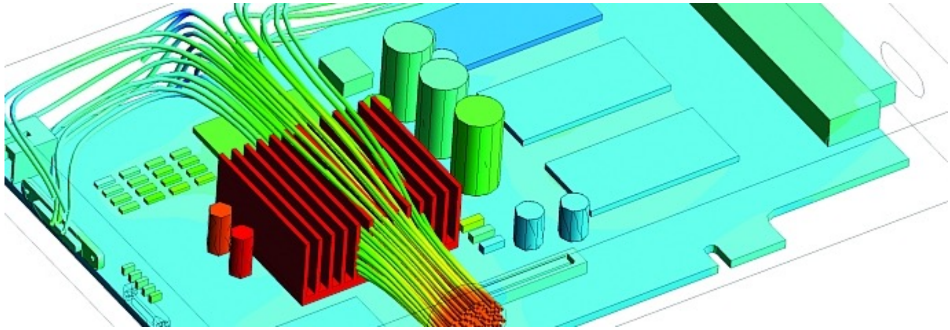


https://www.tacc.utexas.edu/-/supercomputers-listen-to-the-heart

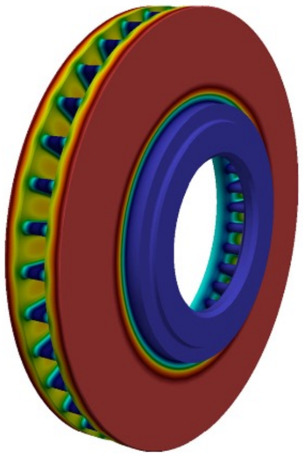
CM application examples
Thermo-fluid problems (coupled)



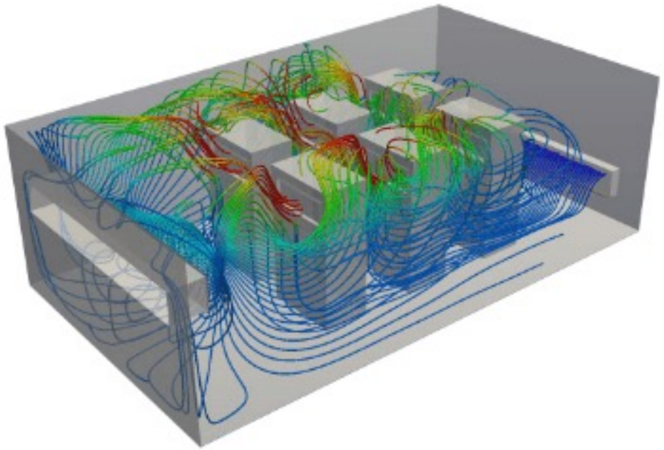
Source: https://www.pngegg.com/en/png-pmzjy



Source: https://www.computationalfluiddynamics.com.au/conjugate-heat-transfer/



Source: DOI 10.1007/s00466-016-1272-4



Source: https://www.simscale.com/blog/2014/06/server-room-cooling-hvac-simulation/

About this course

- Expectations
  - Calculus (integration, differentiation…)
  - Differential equations
  - Linear algebra (vectors, matrices…)

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- Tentative plan

25.02	1.	Introduction to the course
04.03	2.	Introduction to CFD
11.03	3.	Introduction to OpenFOAM (Lid-driven cavity)
18.03	4.	CAD generation by Salome (Cyclone)
25.03	5.	Post-processing using ParaView (Cyclone)
29.03-04.04		Ramazan Bayrami
08.04	6.	Meshing strategies (OpenFOAM)
15.04	7.	Meshing strategies (Salome)
22.04	8.	Advanced look at OpenFOAM options
29.04	9.	CFD for Automotive Flows
03.05-11.05		Midterm Exams
13.05	10.	CFD for Turbomachinery Flows
20.05	11.	CFD for Thermo-fluid Applications
27.05	12.	CFD for Multiphase Flows
02.06-09.06		Kurban Bayrami
10.06	13.	CFD for Aerospace Applications
17.06	14.	Final Presentations

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- Midterm Project 20%
  - Team (of 2 people) work
  - Only presentation
- Homework 20%
  - 2 homeworks 10+10%
- Final Project 60%
  - Individual work
  - You will choose what to work on
    - Final presentation 14th week 20% (10mins)
    - Final report due by final exam date 40%

- Tentative plan

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