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Milano, 18 Aprile 2018

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Experimental and Computational Fluid Dynamics applied to control valves

POLITECNICO
MILANO 1863

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Experimental and Computational Fluid Dynamics applied to control valves

fluid lab @Polimi

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fluid lab @Polimi

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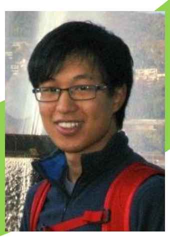
Phd Students

Ing. L. Fenini

Ing. G. Ferrarese



Ing. Y. Wang

Ing. MV Mastronardi

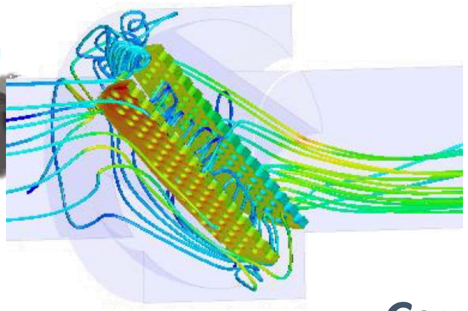
… Undergraduates (M.Sc. & B.Sc.)

- Industrial fluid dynamics
- Fluid structure interaction
- Energy Harvesting

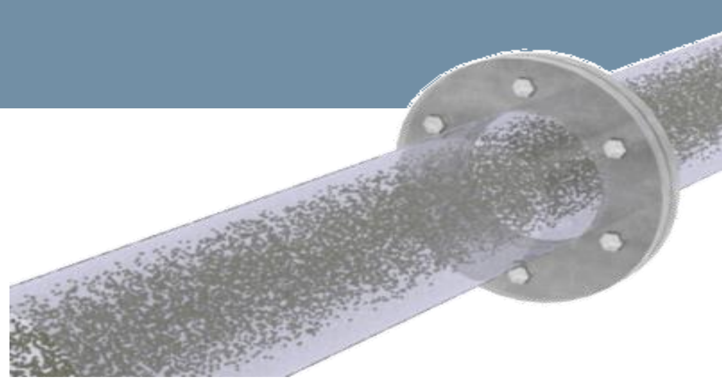
CIRCOR ENERGY | Pibiviesse | BREDA | Eni | SAIPEM | ANSALDO ENERGIA | premel | MIVAL | FEMA | Score Group plc | erreesse s.r.l. trunnion & floating ball valves | Téchne VALVE & WELLHEAD COMPONENTS | INOXRIVA | ATB RIVA CALZONI

• The research topics → connected to control valves

- Industrial fluid dynamics
- Fluid structure interaction
- Energy Harvesting

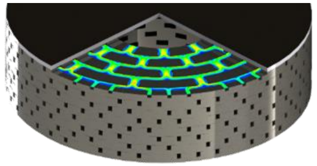


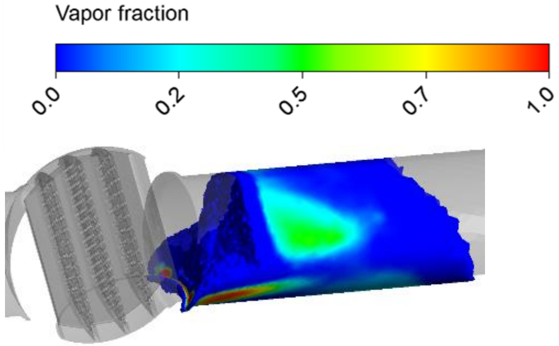
Control and regulation



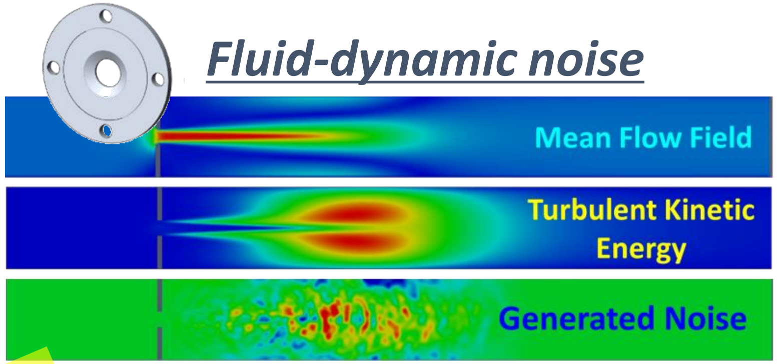
Multi-phase processes

Cavitation

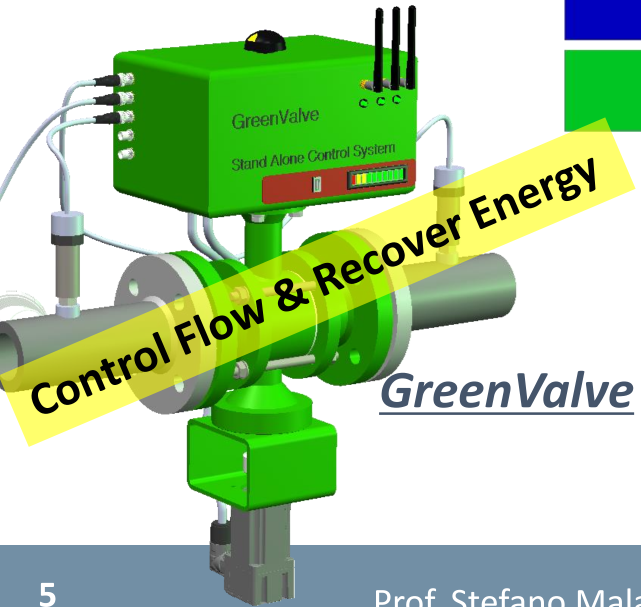




Fluid-dynamic noise



Energy Harvesting



GreenValve

Impact erosion

LANO 1863

The study or the characterization of the fluid dynamic behavior of a control valve can be approached by experimental or numerical way .


Experimental

Which are the differences?

Numerical

$$\begin{cases} \frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=\nu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)-\frac{1}{\rho}\frac{\partial p}{\partial x}+F_x \\ \frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=\nu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)-\frac{1}{\rho}\frac{\partial p}{\partial y}+F_y \\ \frac{\partial u}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=\nu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)-\frac{1}{\rho}\frac{\partial p}{\partial z}+F_z \\ \frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \end{cases}$$

Navier-Stokes + Continuity

We measure a physical phenomenon

Issues to overcome
How to reproduce the phenomenon?
How to perform correct measurements?
How to analyze the experimental data?
How to make the results comparable?

We model a physical phenomenon by equations

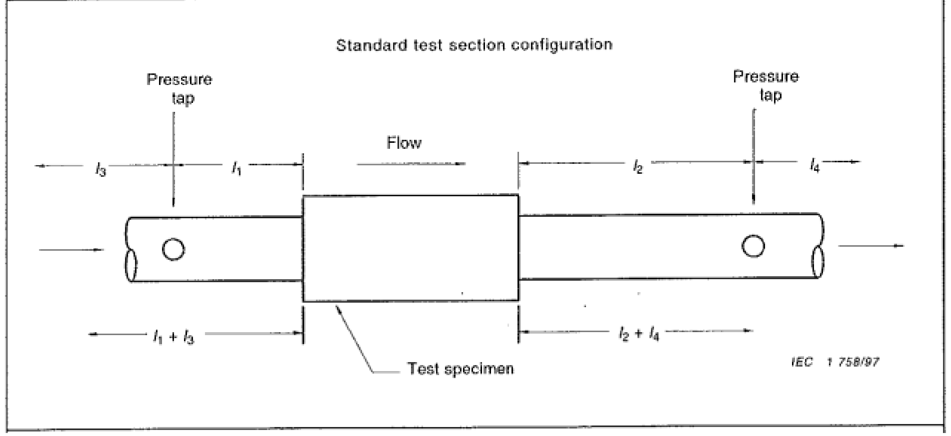
Issues to overcome
What is the set of equations to use?
What are the strategies to solve the set of equations?
What are the information to keep?
How can we judge the results?

Experimental characterization of control valves

Experimental

Table 1 – Test section piping requirements

l_1	l_2	l_3	l_4
Two times nominal pipe diameter	Six times nominal pipe diameter	Eighteen times nominal pipe diameter minimum	One times nominal pipe diameter minimum



We measure a physic phenomenon

Issues to overcome
How to reproduce the phenomenon?
How to perform correct measurements?
How to analyze the experimental data?
How to make the results comparable?

International STANDARDS
IEC / ISA / VDMA …..

- **IEC 60534**
- **ISA 72.01 01**
- **ISA 75.02**
- **VDMA 24422**
- **………..**

Definitions

Terminology

Parameters

Test procedures

Main parameters:

- **Flow coeffcient Cv or Kv**
- **Cavitation indexes $\sigma_i - \sigma_c - \sigma_{mv}$**
- **Liquid pressure recovery factor Fl**
- **Critical Pressure drop ratio factor Xt**
- Liquid critical pressure ratio factor F_F
- Piping geometry factor F_p
- Valve style modifier F_D
- Reynolds number factor F_R
- Valve Reynolds number Re_v
- Compressibility factor Z
- Expansion factor Y

The basic approach to the exp characterization of a valve requires following the standards !

Numerical characterization of control valves

$$
\begin{cases}
\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=\nu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)-\frac{1}{\rho}\frac{\partial p}{\partial x}+F_x \\
\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=\nu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)-\frac{1}{\rho}\frac{\partial p}{\partial y}+F_y \\
\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=\nu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)-\frac{1}{\rho}\frac{\partial p}{\partial z}+F_z \\
\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0
\end{cases}
$$

Navier-Stokes + Continuity

Numerical "CFD"

We model a physic phenomenon by equations

Questions to overcome

What is the set of <u>equations to use</u>?

What are the <u>strategies to solve</u> the set of equations?

What are the <u>information to keep</u>?

How can we <u>judge the results</u>?

Laminar / turbulent
Incompressible / Compressible / Newtonian /……
Single-phase / Multi-phase ….
Heat transfer / ….
………

Define the physics

Laminar / turbulent
Steady (RANS) / Unsteady (URANS / LES)
Closure equations (K-ε ; K-ω ; Low-Re; ….)
Exploitment of symmetries
………

Define the numerical scheme

V(x,y,z, "t") & **P**(x,y,z, "t") in each point of the computational volume.
Mimic the experimental Standards or provide more information?

Define the information

Strategies are needed to ensure the consistency of the numerical solution
Strategies are needed to ensure the consistency of the physical solution

Provide the reliability

The basic approach to the numerical characterization of a valve needs a deep knowledge about the phenomenon to model and about the numerical strategies / approaches / methods to use. → NO specific STANDARDS to follow

Experimental → Control Valve ← Numerical (CFD)

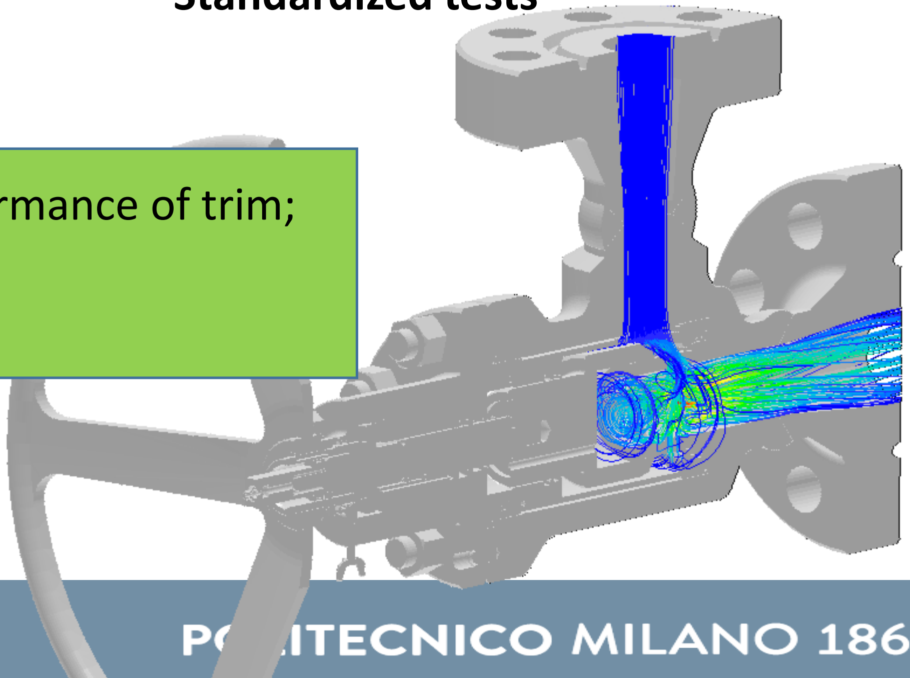
We can choose to use one or integrate them depending on our convenience

Example: **Flow Coefficient CV (or Kv)**

If only CV is required;
If the valve diameter is small;
If the flow characteristics are not limiting

The experimental characterization is convenient in terms of costs / knowhow / reliability of results

Standardized tests



The CFD characterization allows: Knowing the flow features inside the valve; simulating large size system; simulating limiting flow conditions (very high pressure jump / different fluids / ….)

If you want to know/to improve the performance of trim;
If the valve diameter is too big for testing;
If the flow characteristics are limiting

No standardized tests

Example: **Flow Coefficient CV (or Kv)**

Because no standards are available for CFD approach it is important to :

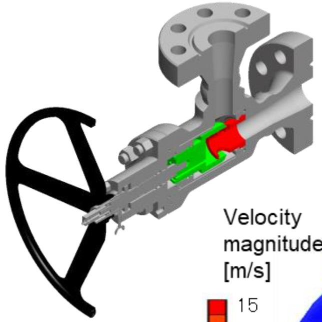
Define the physics

Define the numerical scheme

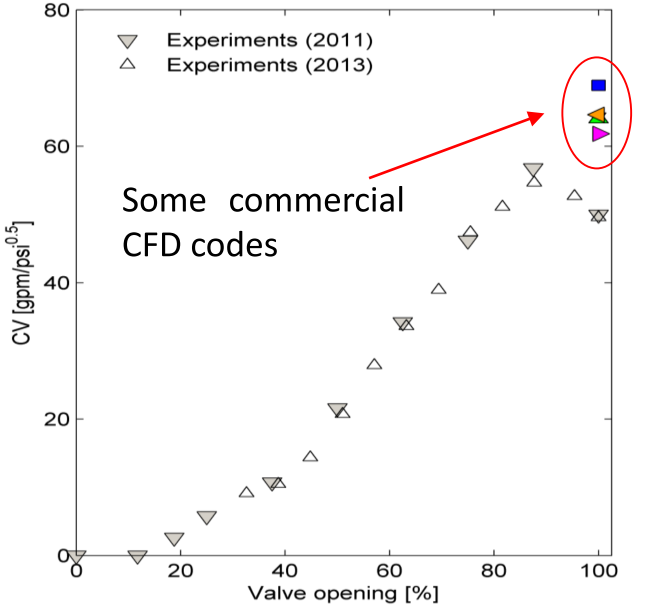
Define the information

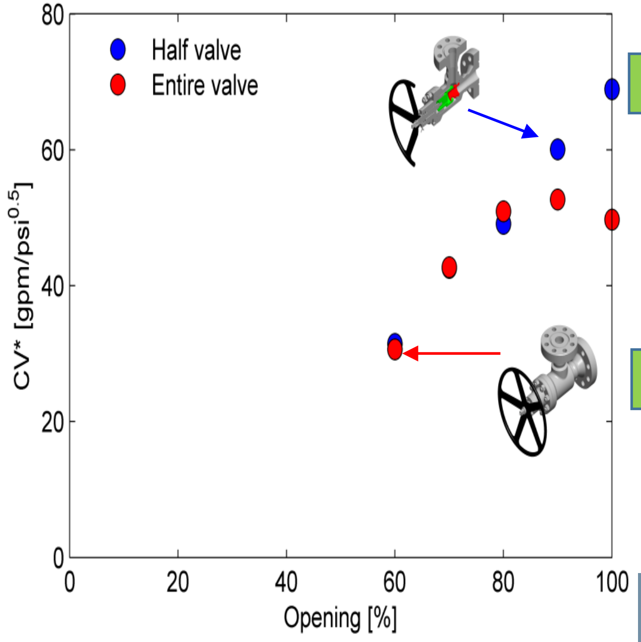
Provide the reliability

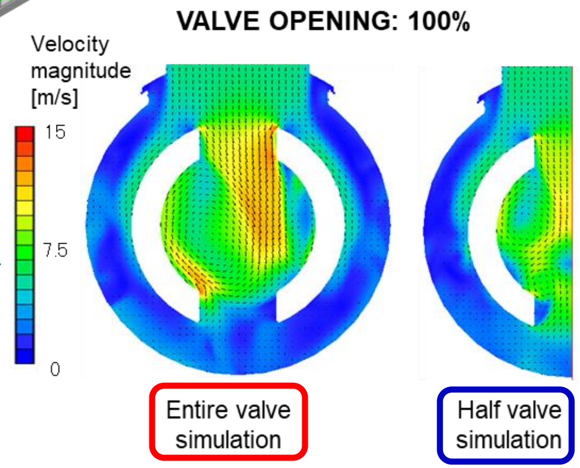
CFD MODELLING OF A CHOKE VALVE UNDER CRITICAL WORKING CONDITIONS
ASME 2014 Pressure Vessels & Piping Conference, PVP2014.



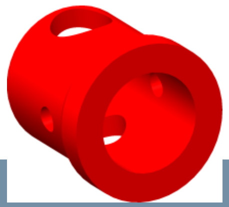
Possible problem due to use of symmetry

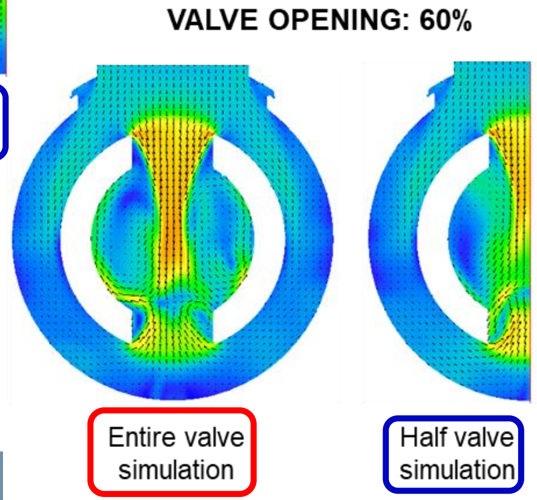






Velocity distribution inside the trim

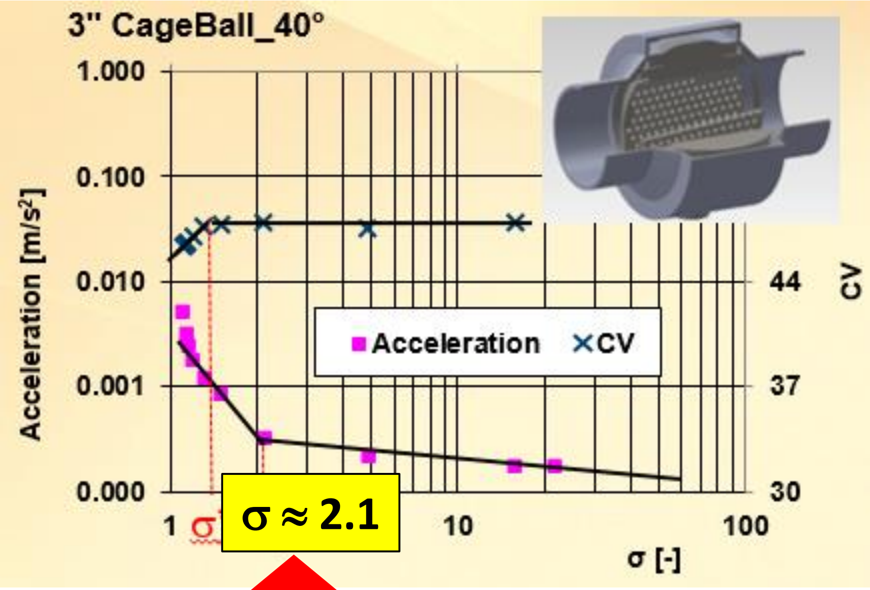




Experimental → Control Valve ← Numerical (CFD)

We can choose to use one or integrate them depending on our convenience

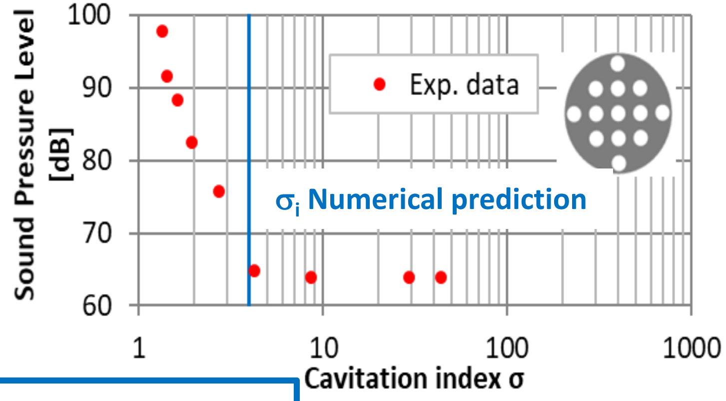
Example: **Cavitation Index σ**



Here you measure the bubble implosion effects on the structure

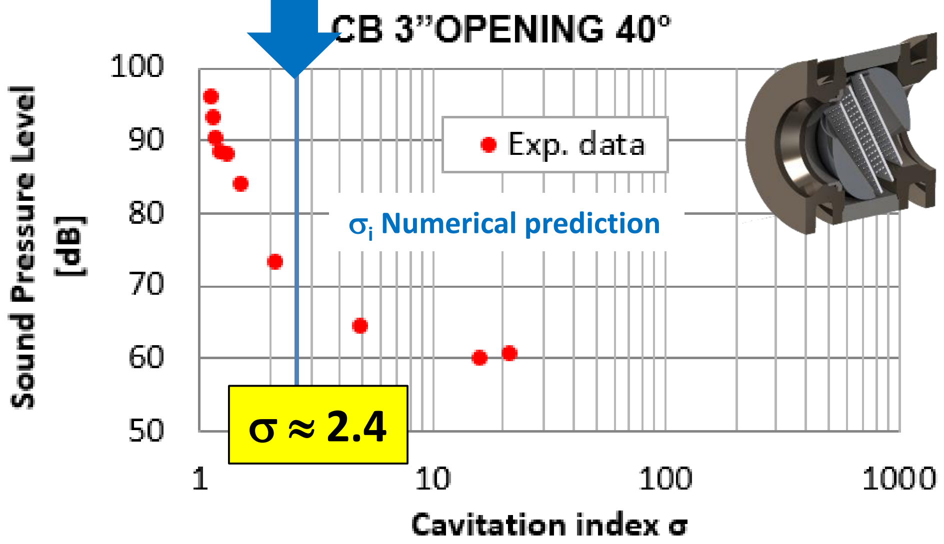
Prediction and handling of cavitation in rotary control ball valves.
Valve Word Conference 2012

Improvements and validation of the numerical prediction of the incipient cavitation index.
Pressure Vessels & Piping Conference, PVP2015,



Here you estimate the pressure that allows bubble formation

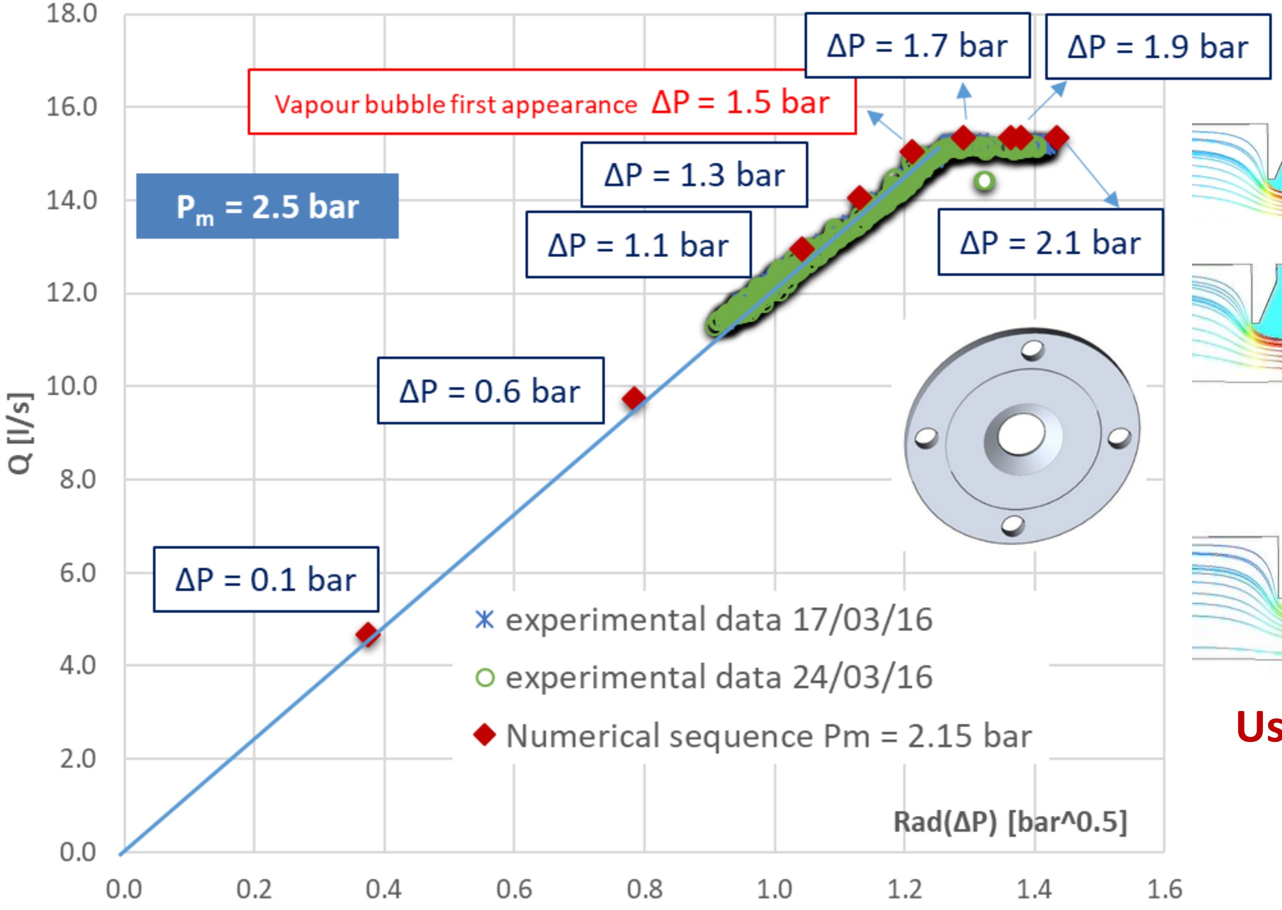
What do we measure and simulate ?

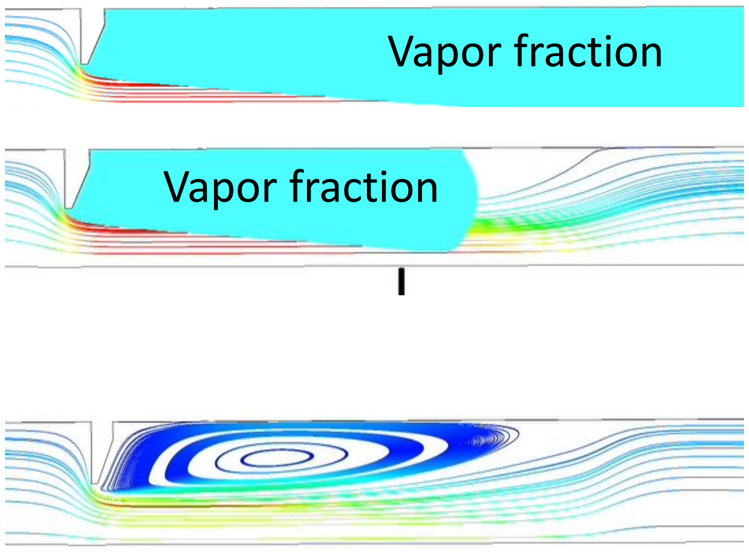


We can choose to use one or integrate them depending on our convenience

Example: **Recovery Factor FL** → **Calibration of numerical model using the standard orifice**

Exp. Test loop

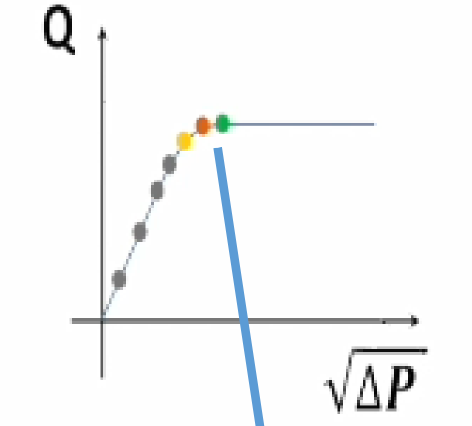




Usteady & multiphase CFD model

We can choose to use one or integrate them depending on our convenience

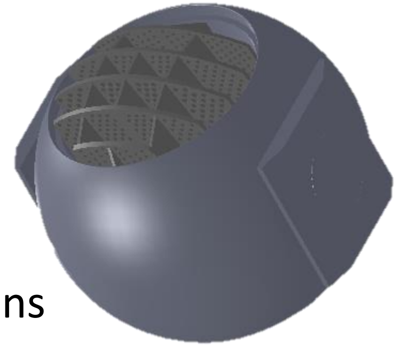
Example: **Recovery Factor FL** → Use of calibrated model on valves

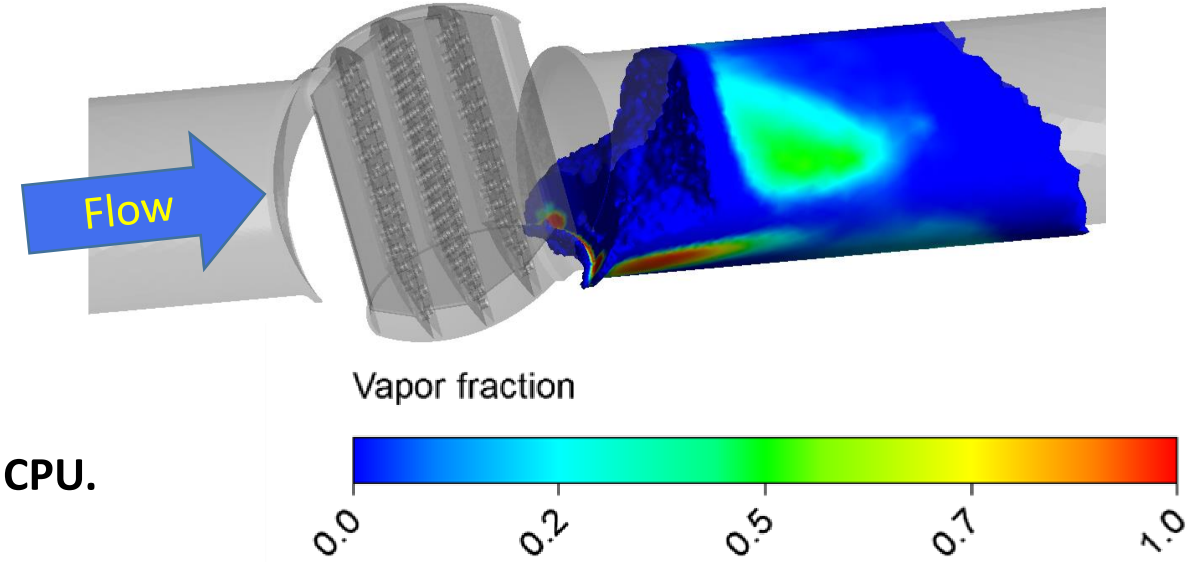


What does it take to numerically evaluate Fl on a valve's trim?

Vapor fraction downstream the valve

- Multiphase / Unsteady model
- Very small time-step
- Variation of convergence coefficients
- Multiple changes of boundary conditions

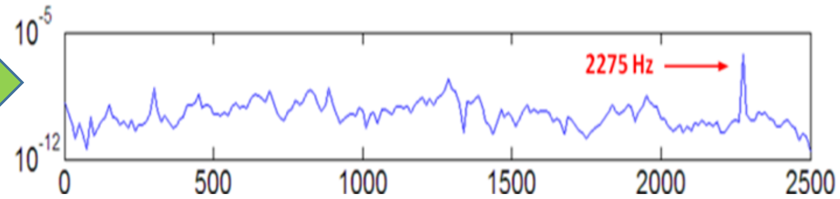


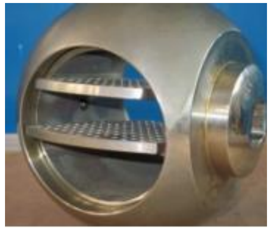


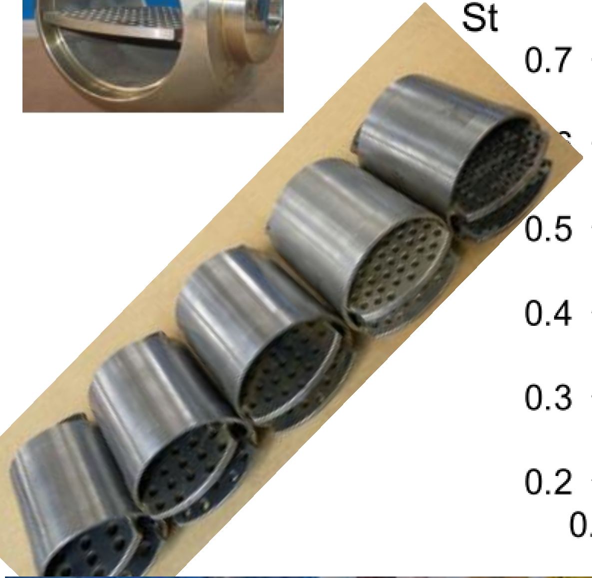
For a 8'' control ball valve, the calculation of Fl for one opening requires approximately 2800 core/hour, or 10 days with a 12 cores CPU.

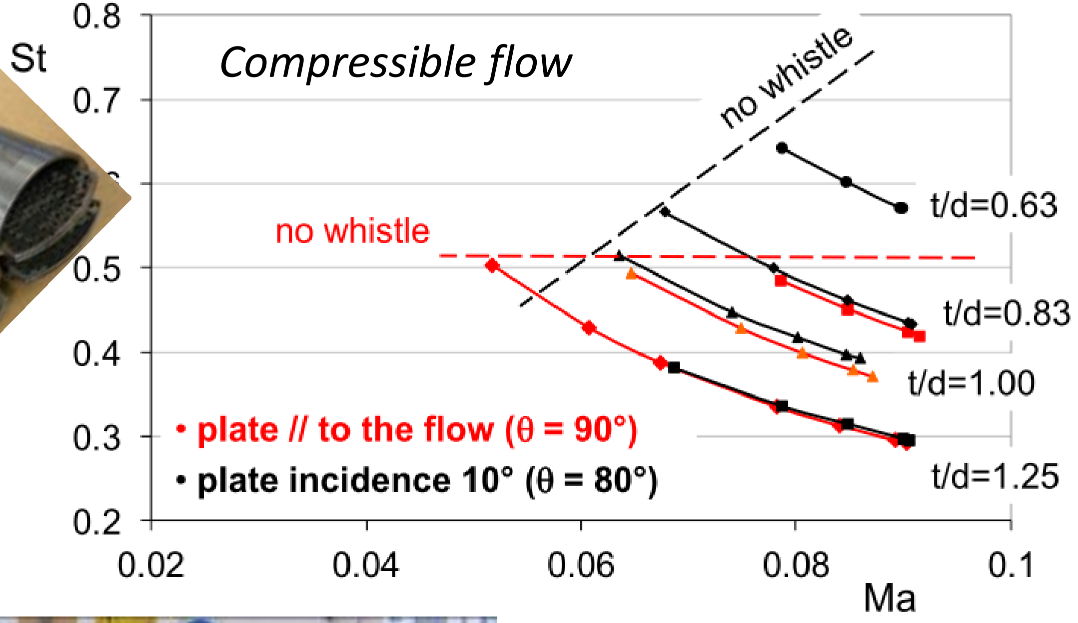
Experimental → Control Valve ← Numerical (CFD)

Example: **Tonal Noise**









fiv DUBLIN IRELAND 2012

TRINITY COLLEGE DUBLIN

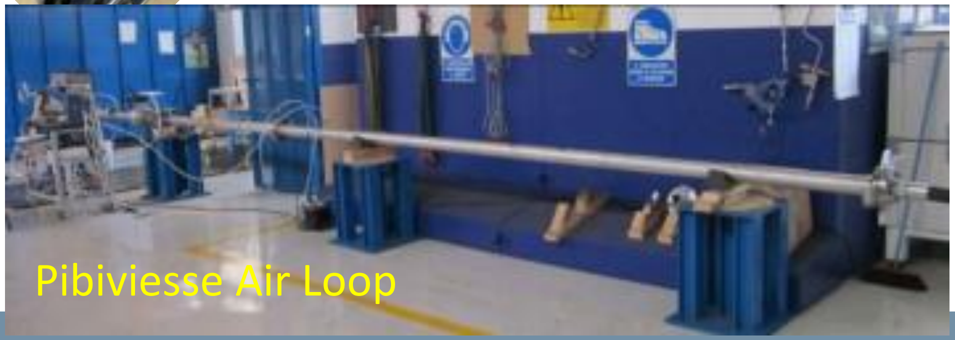
10th International Conference on Flow-Induced Vibration (& Flow-Induced Noise)

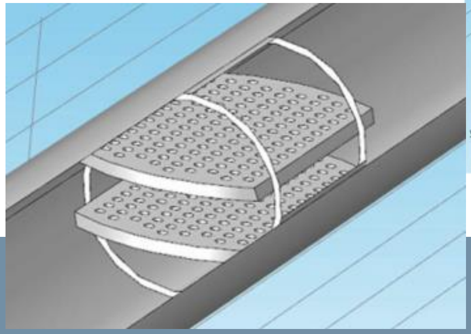
Experimental analysis of aerodynamic noise generation in a rotary control valve. FIV 2012

ASME 2014 JULY 20–24, 2014 · ANAHEIM, CALIFORNIA

PRESSURE VESSELS & PIPING DIVISION CONFERENCE

Acoustic analysis of a rotary control valve.
ASME 2014 Pressure Vessels & Piping Conference, PVP2014





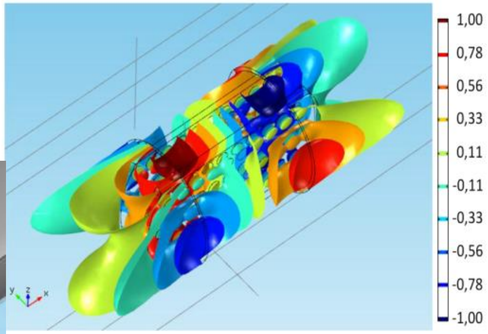


FIGURE 8: SHAPE OF THE $f_{2,2}$ MODE

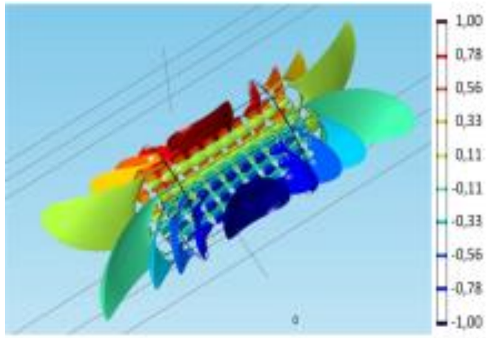
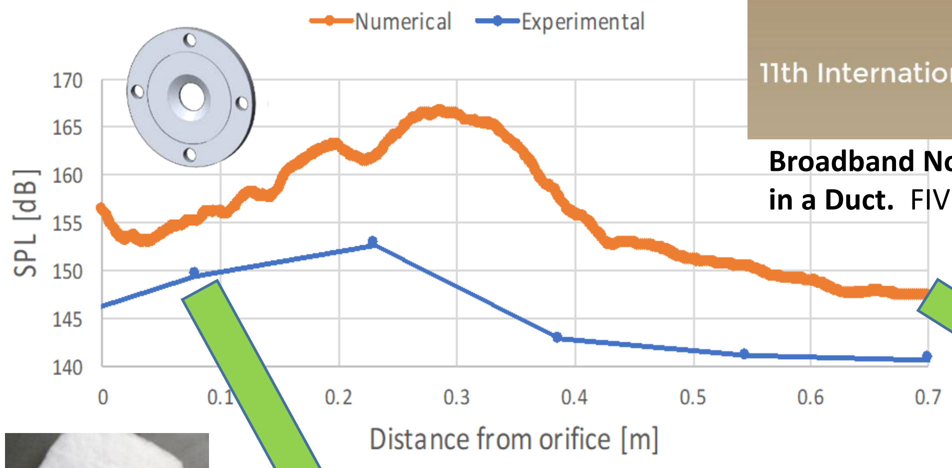


FIGURE 5: SHAPE OF THE $f_{1,1}$ MODE

Experimental → Control Valve ← Numerical (CFD)

Example: **Broad Band Noise**

Calibration of numerical model using the standard orifice



11th International Conference on Flow-Induced Vibration

4th - 6th July 2016 Hosted by TNO

Broadband Noise Generated Downstream of a Resistor in a Duct. FIV 2016

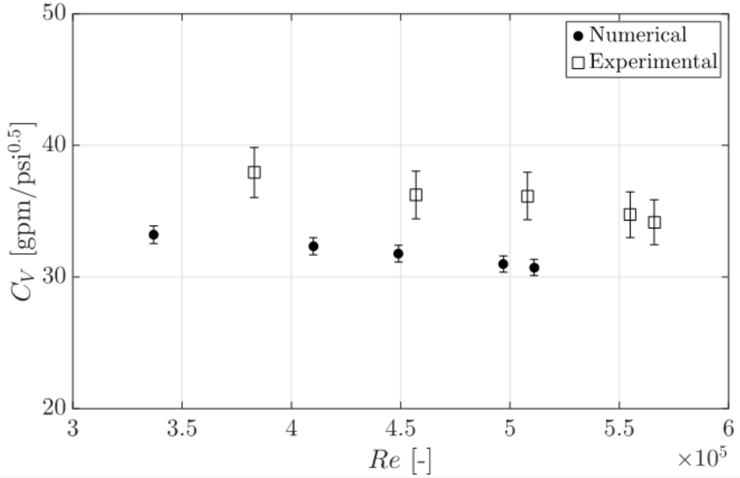
FIV2018: FSI2 & FIV+N. July 8-11, 2018, Toronto

9th International Symposium on Fluid-Structure Interactions, Flow-Sound Interactions, Flow-Induced Vibration & Noise

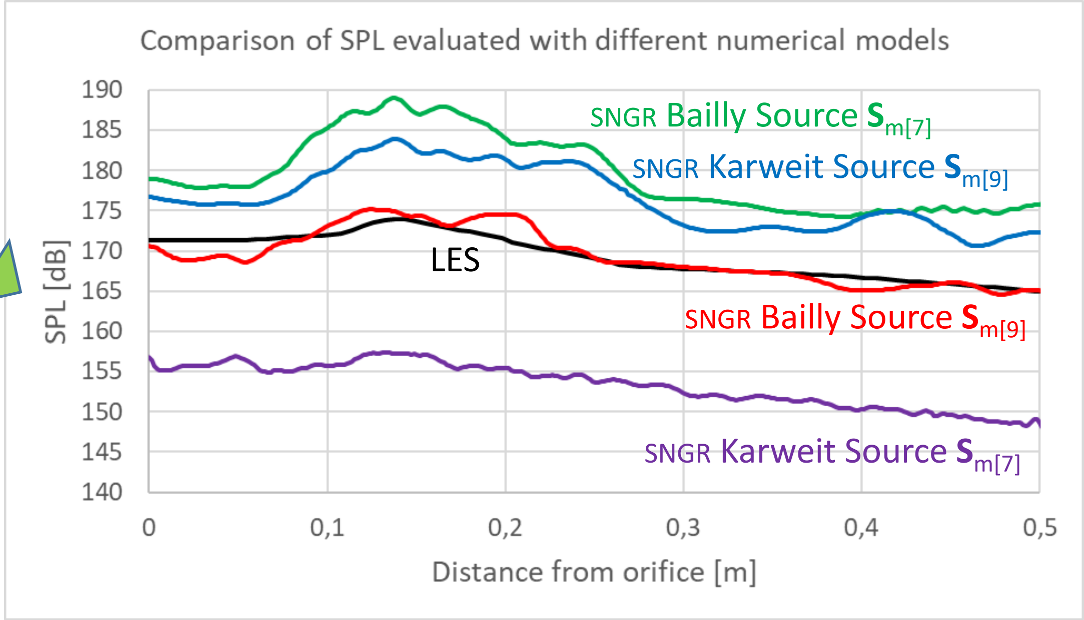
Numerical models for internal sound pressure level prediction. FIV2018

Main exp. uncertainty source

→ Air quality (no dry air)



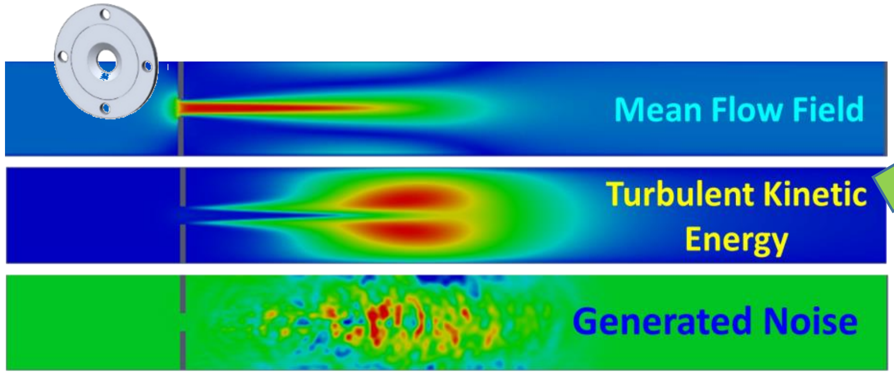
even CV is also affected by the air quality

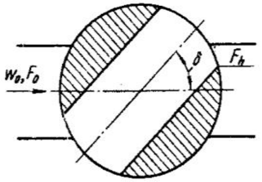


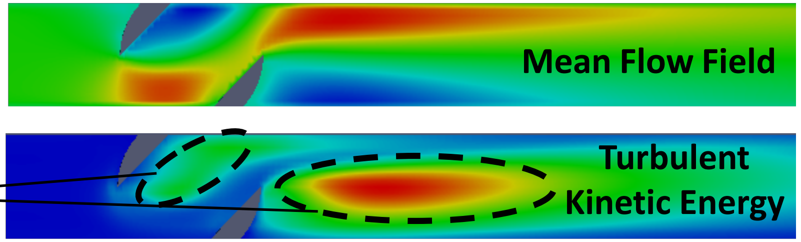
Main num. uncertainty source → num. model

Example: **Broad Band Noise**

Use of calibrated model to define IEC valve's parameters







Location of possible source regions

Aη

Identification of IEC parameters for noise prediction

Valve or fitting	Flow direction	A_η	St_p
Globe, parabolic plug	Either	-4,2	0,19
Globe, V-port plug	Either	-4,2	0,19
Globe, ported cage design	Either	-3,8	0,2
Globe, multihole drilled plug or cage	To open	-4,8	0,2
Globe, multihole drilled plug or cage	To close	-4,4	0,2
Butterfly, eccentric	Either	-4,2	0,3
Butterfly, swing-through (centered shaft), to 70°	Either	-4,2	0,3
Butterfly, fluted vane, to 70°	Either	-4,2	0,3
Butterfly, 60° flat disk	Either	-4,2	0,3
Eccentric rotary plug	Either	-3,6	0,3
Segmented ball 90°	Either	-3,6	0,3
Drilled hole plate fixed resistance	Either	-4,8	0,2
Expander	Either	-3,0	0,2

NOTE 1 These values are typical only. Actual values are stated by the manufacturer.

NOTE 2 Section 8 should be used, for those multihole trims, where the hole size and spacing i controlled to minimize noise.

Stp

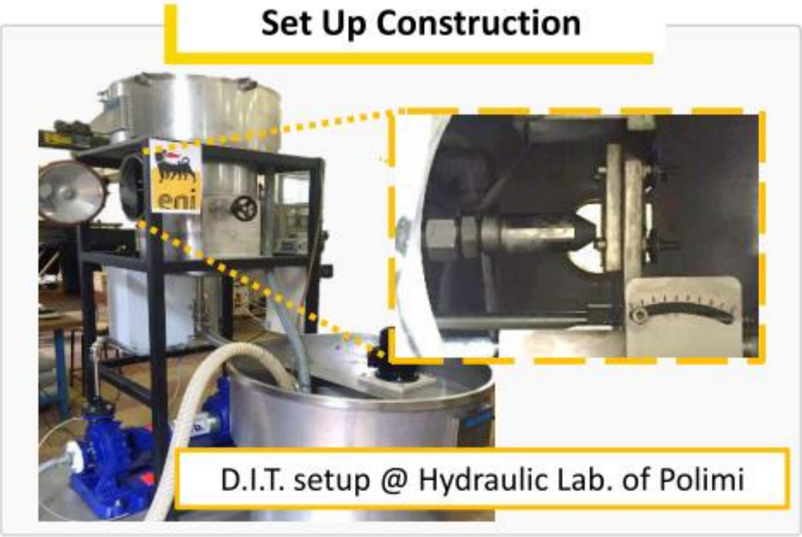
Results will be presented at Valve World Conference 2018

Integration of numerical methods with IEC standard for aerodynamic noise prediction in control devices

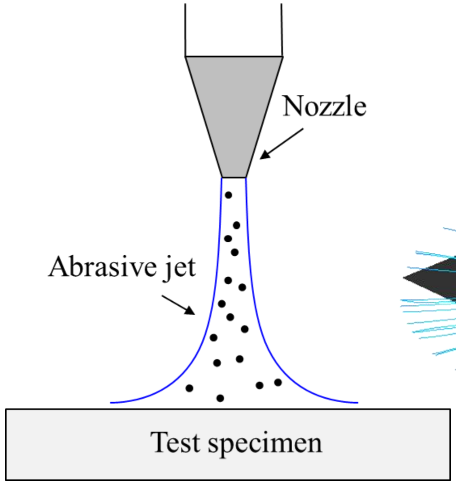
Experimental → Control Valve ← Numerical (CFD)

Experiments are difficult and costly, but CFD requires calibration

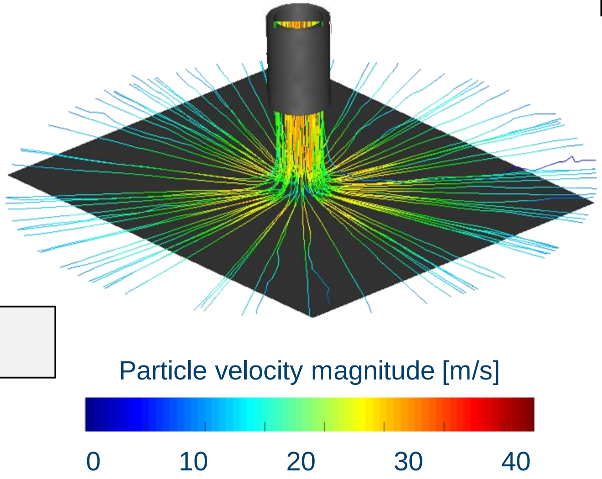
Example: **Erosive wear in a valve** → **Calibration of numerical model using the direct impact test**



Abrasive jet (water-sand)

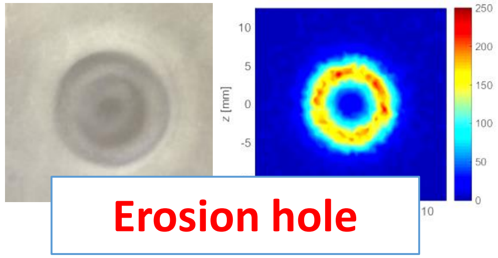


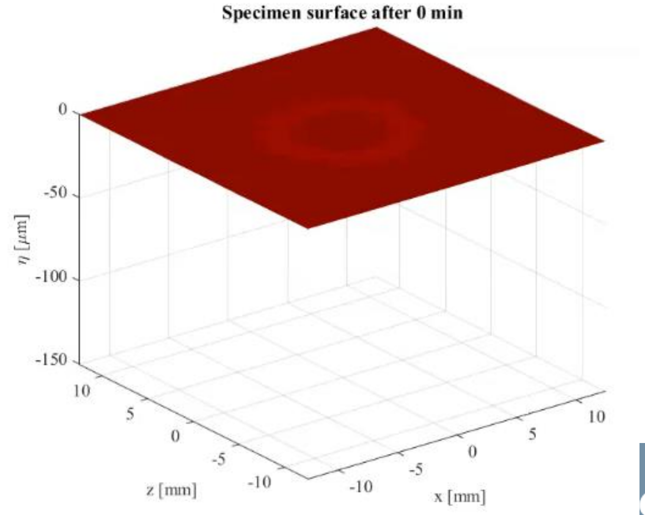
DPM particle tracking



OMC 2017 OFFSHORE MEDITERRANEAN CONFERENCE & EXHIBITION

Enhanced erosion prediction for Xtree valves' lifetime estimation





Erosion experiments are difficult …

- Hard to keep the desired test conditions
- Hard to assess the test conditions (e.g. concentration)
- Hard to measure small mass losses in a valve
- Destructive tests

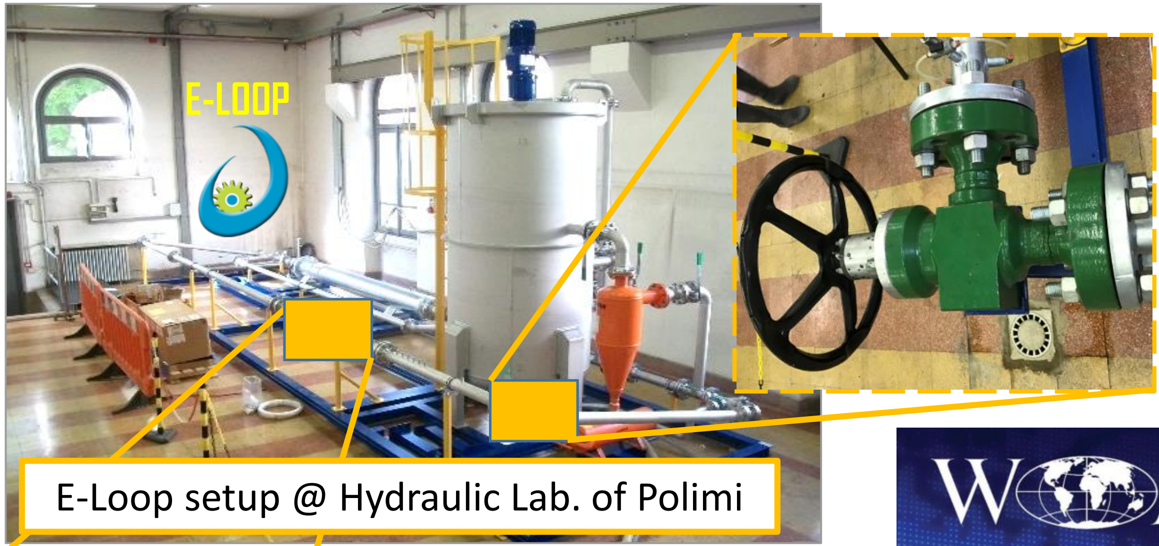
… but CFD prediction is not "EASY"!!!

- Two-phase model
- Tracking of particles trajectories
- Fluid-particle-particle coupling?
- (empirical) erosion model

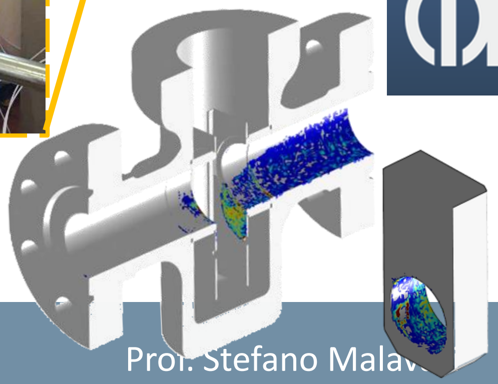
Experimental → Control Valve ← Numerical (CFD)

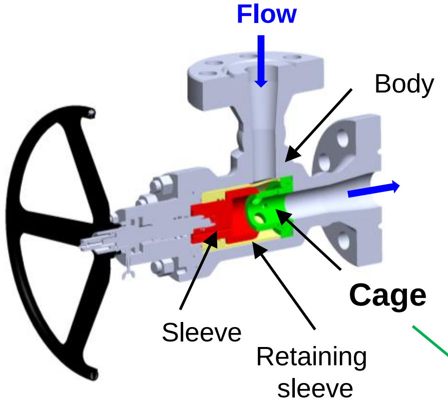
Experiments are difficult and costly, but CFD requires calibration

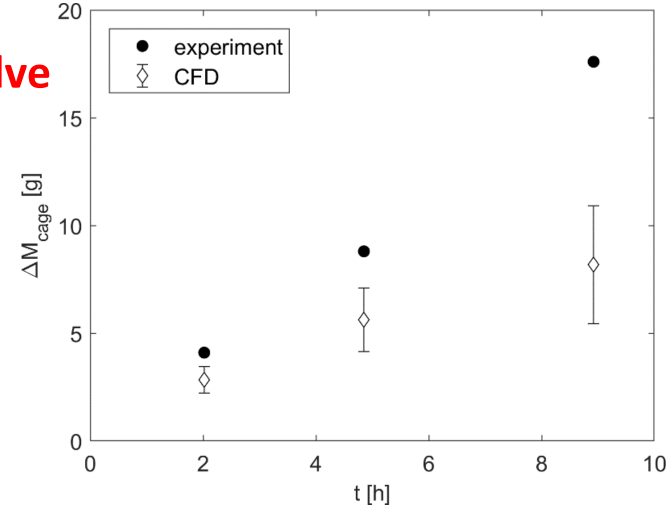
Example: **Erosive wear in valve** → Application of calibrated model to a valve



E-Loop setup @ Hydraulic Lab. of Polimi





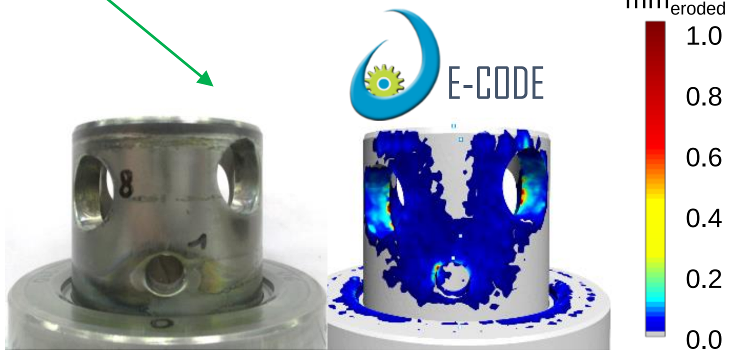


WOM 21st International Conference on Wear of Materials
Long Beach, California, USA // 26-30 March 2017

Lifetime prediction of valves subjected to impact erosion

AIMETA 2017 XXIII Congresso Associazione Italiana di Meccanica Teorica e Applicata

Estimation of the useful lifetime of a gate valve subjected to impact erosion



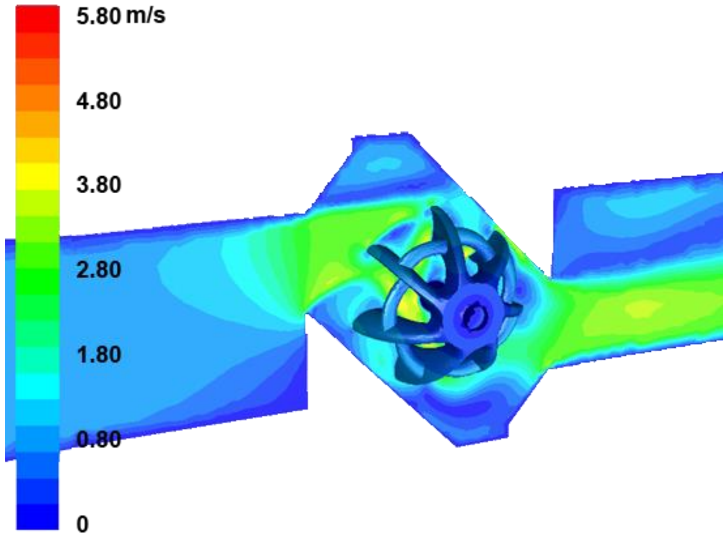
PVP Pressure Vessels & Piping Conference
Prague, Czech Republic
CONFERENCE July 15-20, 2018
EXHIBITION July 16-18, 2018

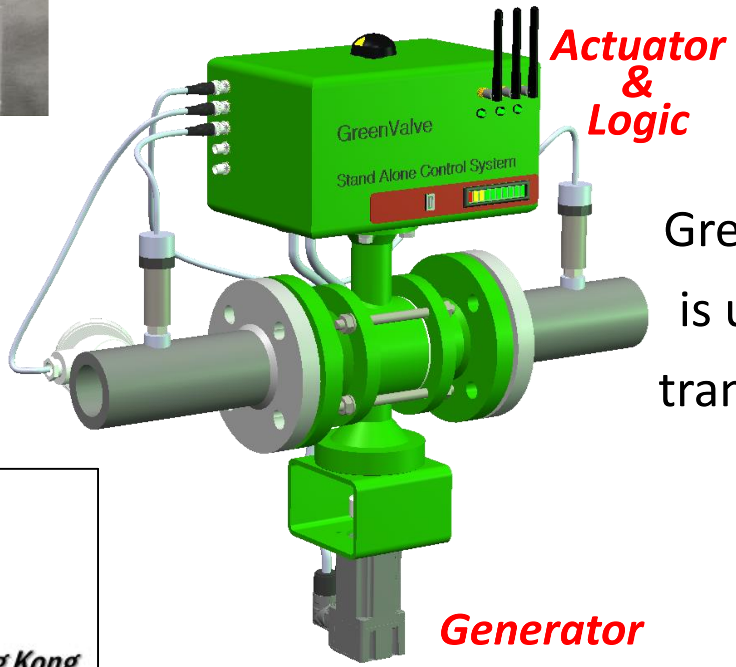
Prediction of erosion damage in a choke valve working in severe slurry condition (to be presented soon)

Example: **Energy Harvesting in control process**

GreenValve system

Flow Control
Remote Monitoring
Automatic - regulation





GreenValve system **recovers the energy** that is usually dissipated for regulation, thereby transforming a control valve in a **stand-alone** system for **IOT and smart-system** applications

WDSA 2014
Water distribution system analysis
14-17 July 2014, Bari, Italy

APAC Innovation Summit
HKSTP 香港科技園
Sept. 2016 Hong Kong

Thank you for your attention

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