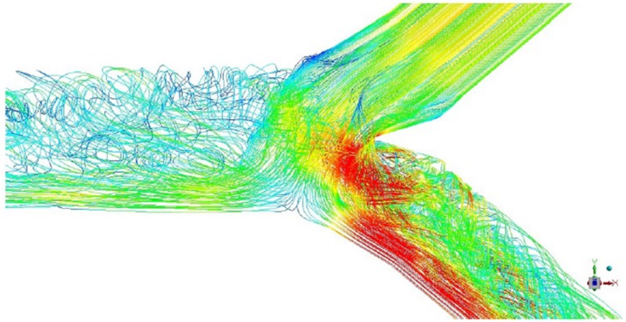
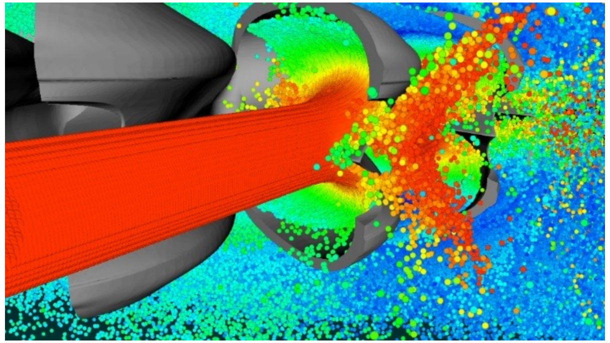
Shaping the Future of Hydropower with Numerical Simulations
Hydraulic short circuit and Erosion Challenges

Prof. C. Münch-Alligné

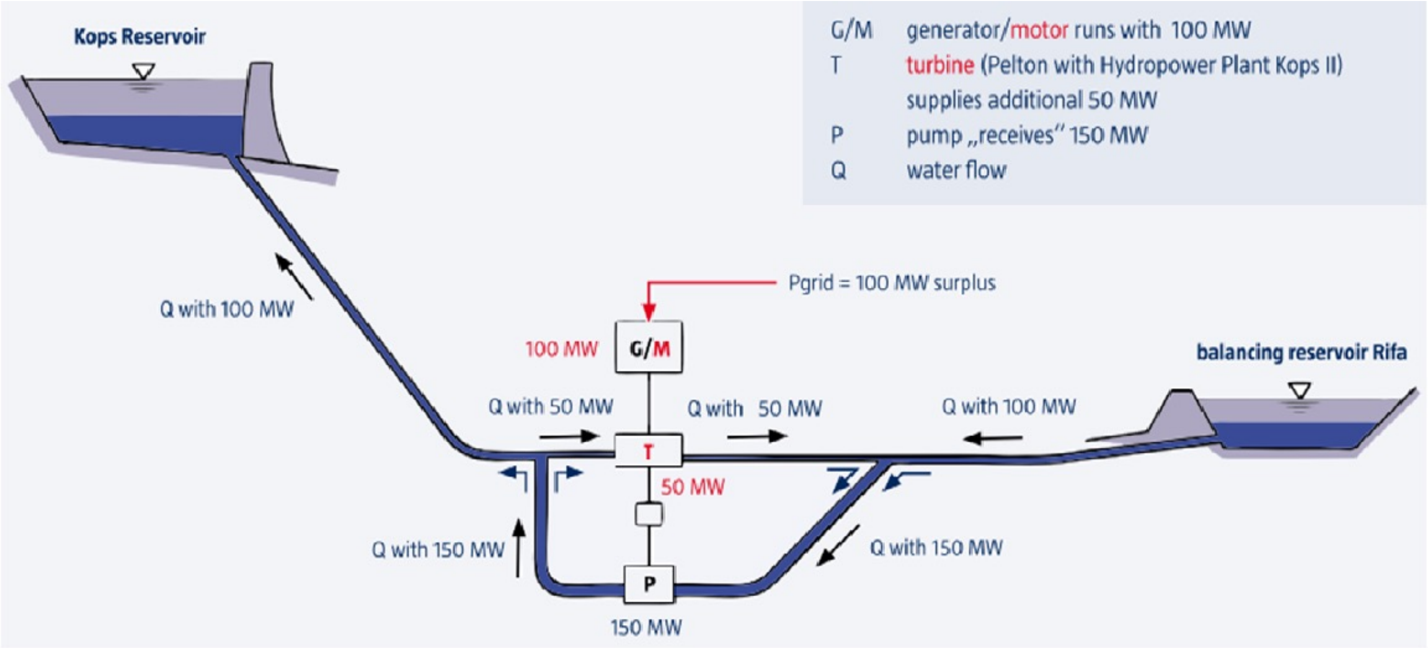
Harnessing Hydropower's Energy Storage and Flexibility for the Energy Transition

October 2nd 2025





Hydraulic Short Circuit ?



Jover, Chazarra and M. S. J. Joaquin. "Optimal joint day-ahead energy and secondary regulation reserve scheduling of pumped-storage power plants operating with variable speed or in hydraulic short-circuit mode in the iberian electricity market." (2017).

Hydraulic short circuit is when pumped storage plants undertake pumping and generating modes at the same time for increased flexibility.

Fixed-speed pumping units are operated to ensure net power consumption from the grid, while in parallel a unit is run in generating mode to **regulate the load.**

Hydraulic short-circuit

1^{st} case study - Grand Maison(FR) – XFLEX Hydro

Main information

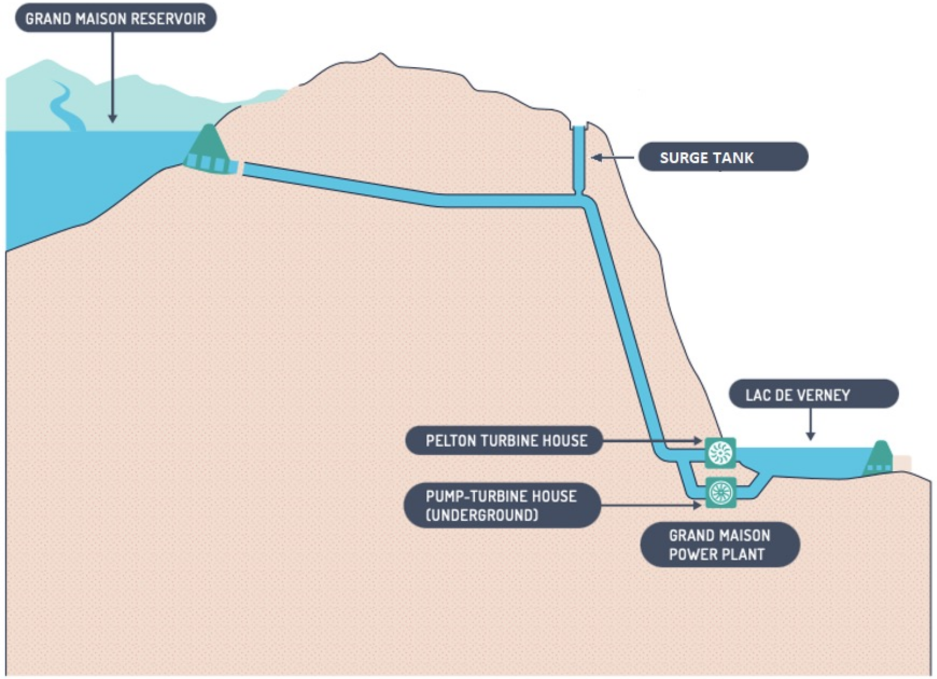
1986 | **PUMPED STORAGE**

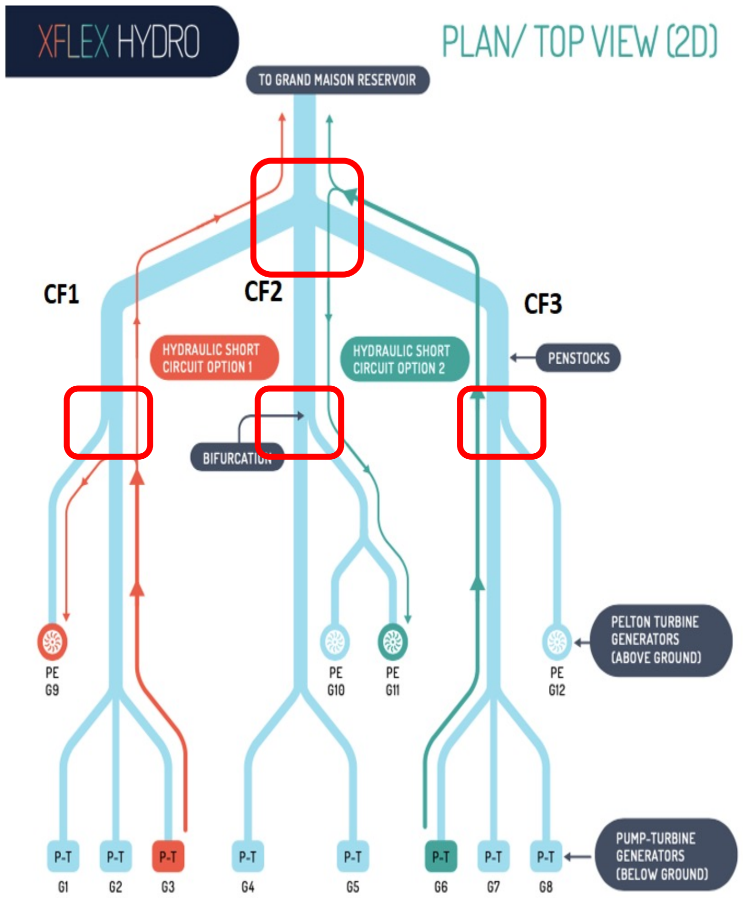
x8

x4

150MW

- Largest PSP in Europe
- 1800 MW
- Head : 900mCE
- 2 réservoirs : 150 Mio m^3 et 15 Mio m^3





The Hydropower Extending Power System Flexibility (XFLEX HYDRO) project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 857832.

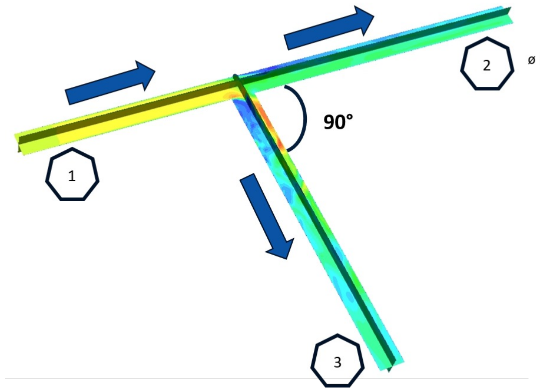
Hydraulic short-circuit

1st case study - Grand Maison – XFLEX Hydro

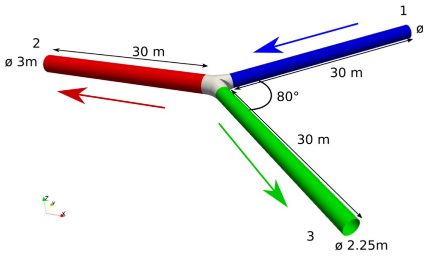
Methodology

GEOMETRY

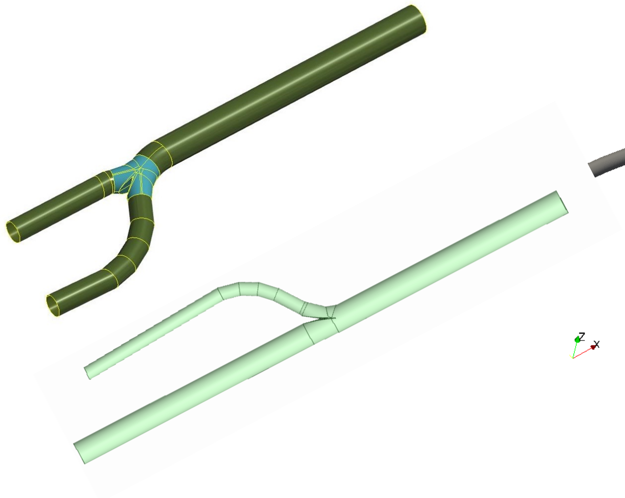
T - Jonction



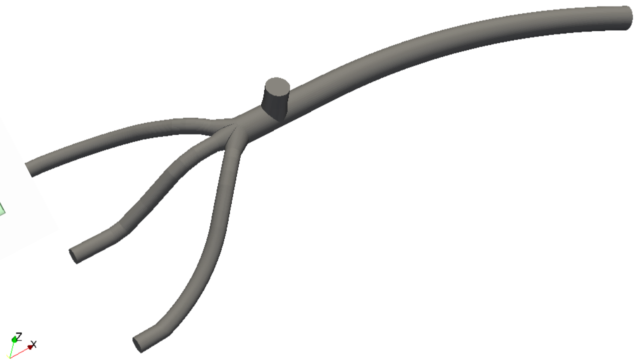
Y - Jonction



Bifurcation CF1 & CF2



Trifurcation



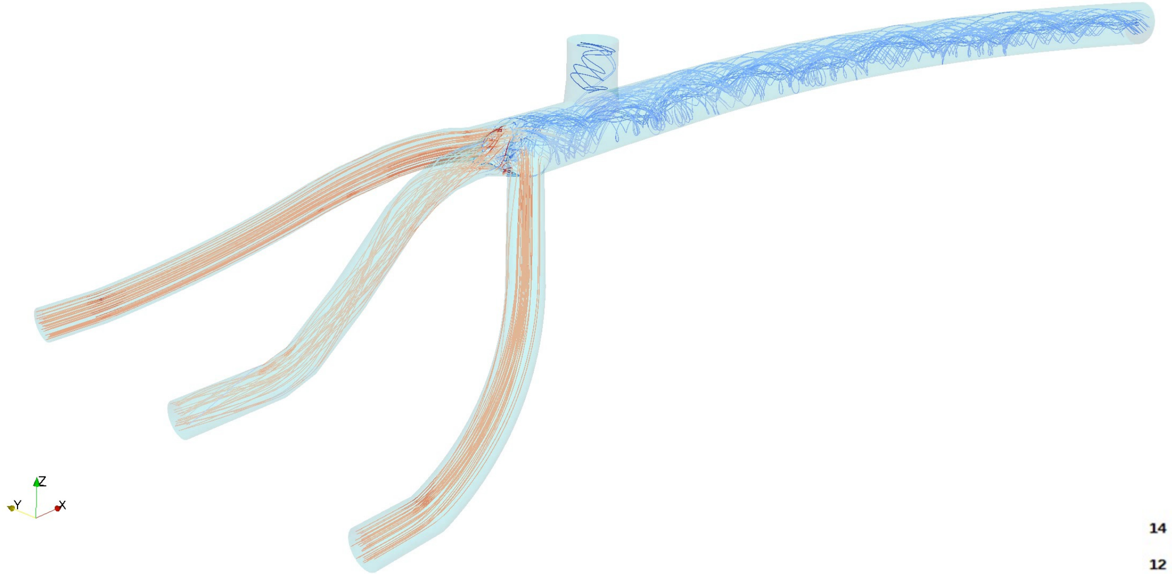
NUMERICAL SET UP

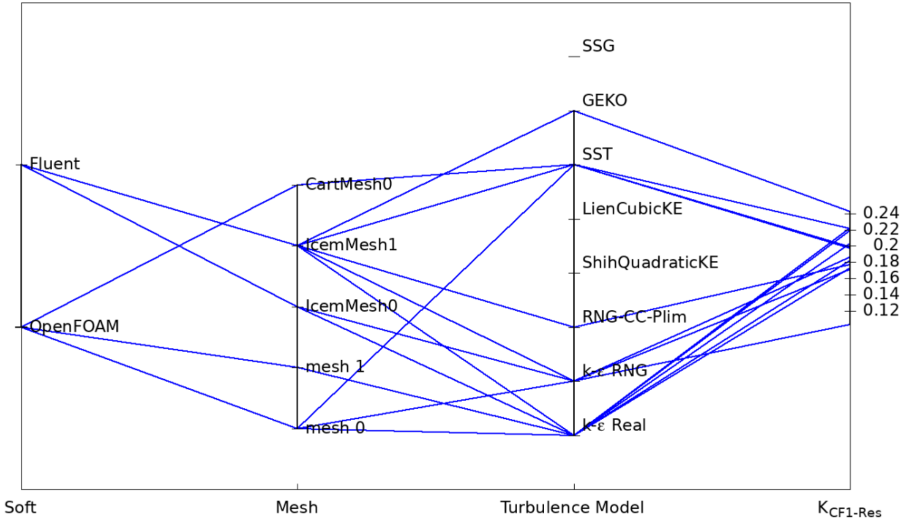
- RANS & URANS simulations
- 2 softwares : OpenFOAM & Fluent
- Several meshes: hexa vs Tetra + refinement
- 3 turbulence models : k-ε RNG, k-ε realizable, STT

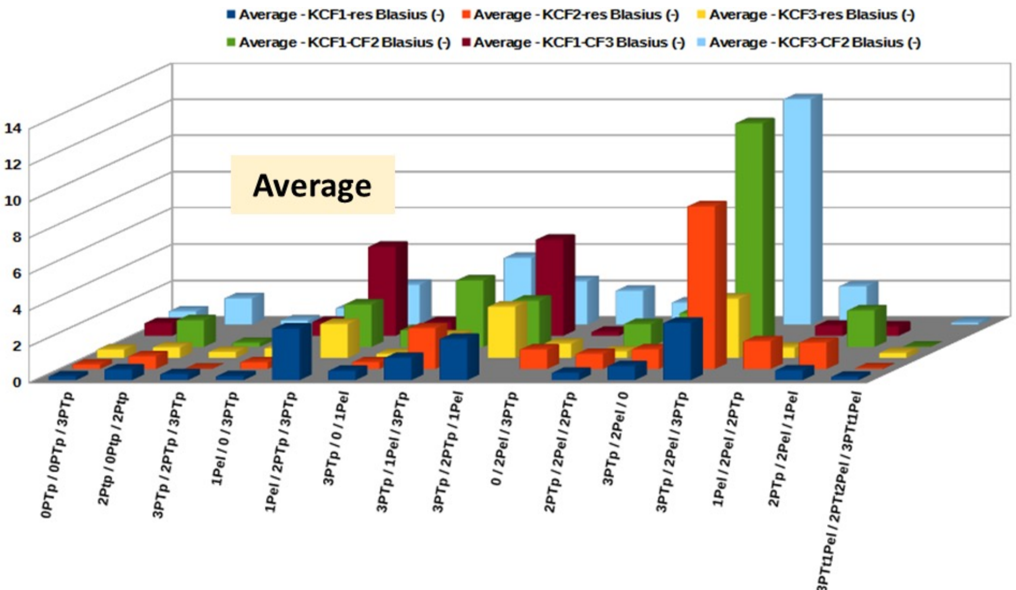
Hydraulic short-circuits

1st case study - Grand Maison – XFLEX Hydro

Main results – Trifurcation – Statistical approach







Decaix, J., Mettille, M., Drommi, J. L., Hugo, N., & Münch-Alligné, C. (2023). Computation fluid dynamics investigation of the flow in junctions: application to hydraulic short circuit operating mode. LHB, 109(1), 2290025.

Drommi, J. L., Joly, B., Aelbrecht, D., Nicolet, C., Landry, C., Münch, C., & Decaix, J. (2023). XFLEX Hydro: Extending operation flexibility at EDF-Hydro Grand Maison PSP. In Role of Dams and Reservoirs in a Successful Energy Transition (pp. 294-302). CRC Press.

Decaix, J., Drommi, J. L., Avellan, F., & Münch-Alligné, C. (2022, September). CFD simulations of hydraulic short-circuits in junctions, application to the Grand Maison power plant. In IOP Conference Series: Earth and Environmental Science (Vol. 1079, No. 1, p. 012106). IOP Publishing.

Hydraulic short-circuit

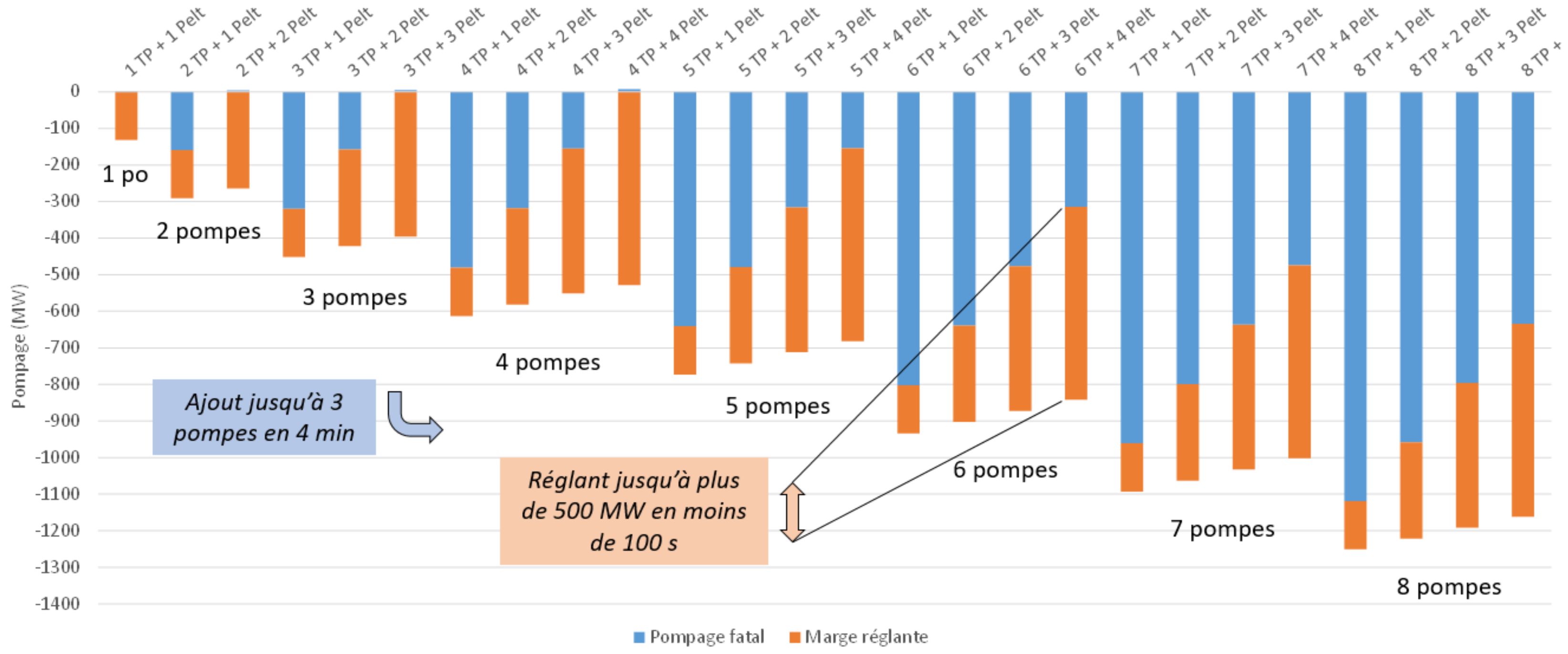
1st case study - Grand Maison – XFLEX Hydro

Implementation

Hydraulic Short Circuit in operation since September 2021

More than 50% of operations in HSC with 2h to 3h par cycle

During the first year :
509 start-ups in HSC
488 turbine start-ups
51% of operation in HSC
56% of pumping hours in HSC



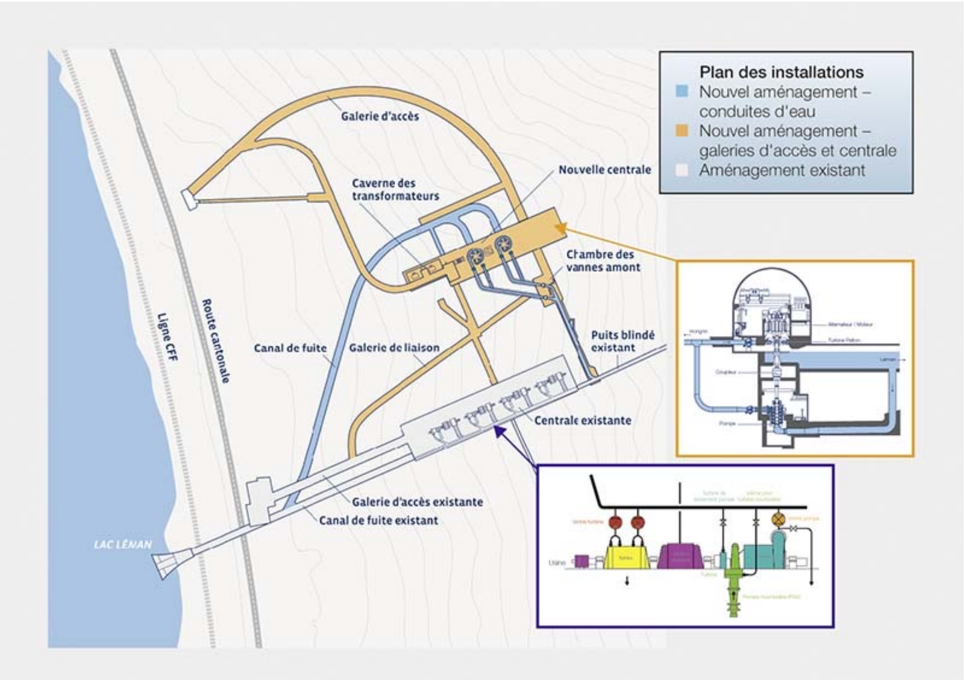
Hydraulic short-circuit

2nd case study – FMHL/FMHL+

Main information

Original Veytaux I Power House: 4 x 60 MW Ternary Unit (Units 1 to 4) - FMHL

New Veytaux II Power House: 2 x 120 MW Ternary Unit (Units 5 & 6) – FMHL+

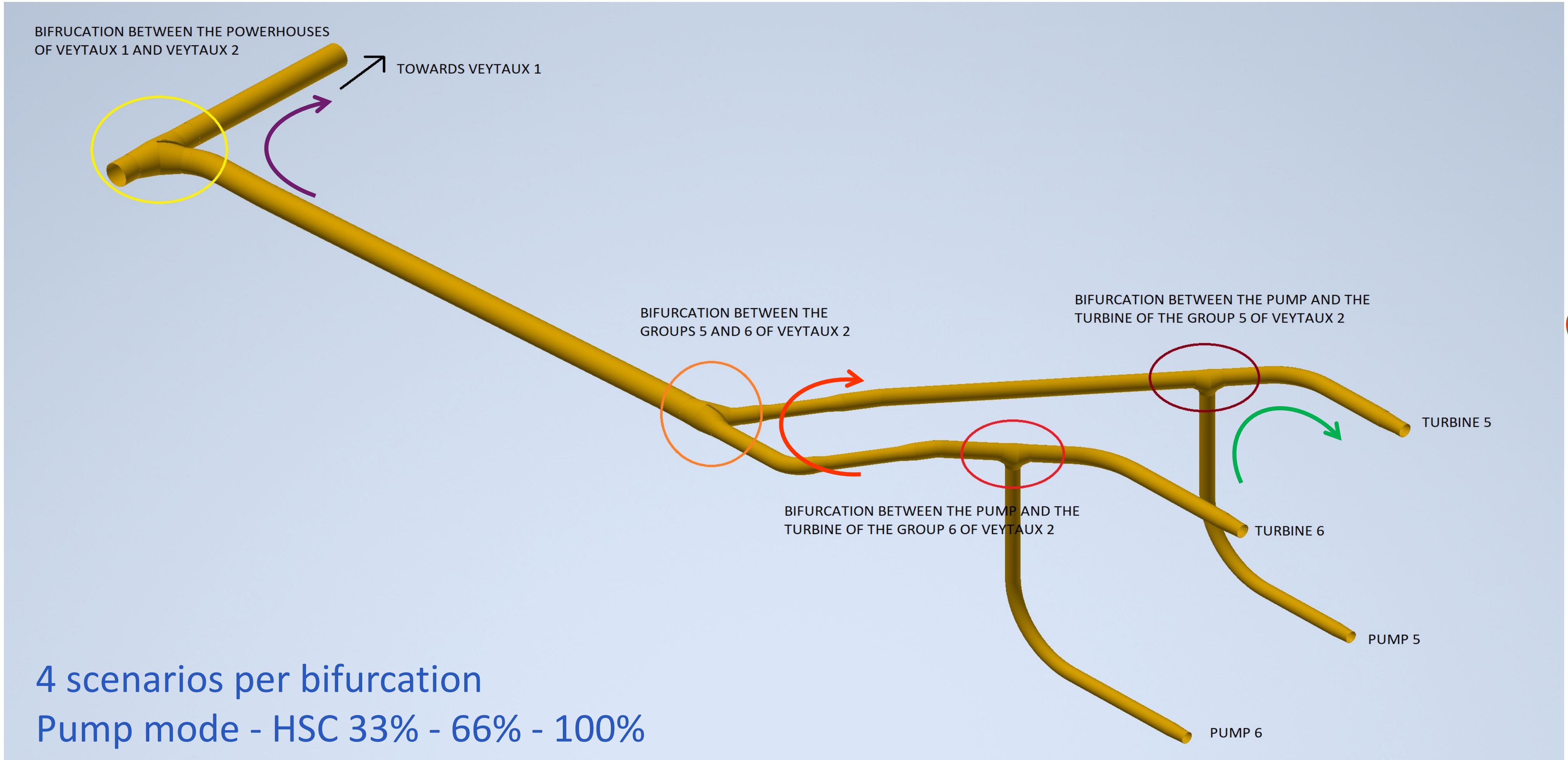


Source N. Rouge, «FMHL+ : de l'idée à la mise en service», Bulletin Electro Suisse, 11 / 2016

Hydraulic short-circuit

2nd case study – FMHL/FMHL+

Geometries & Scenarios



4 scenarios per bifurcation

Pump mode - HSC 33% - 66% - 100%

Intragroup HSC mode
Limited to the range -35 MW to -114 MW

Intergroups HSC mode
Not allowed

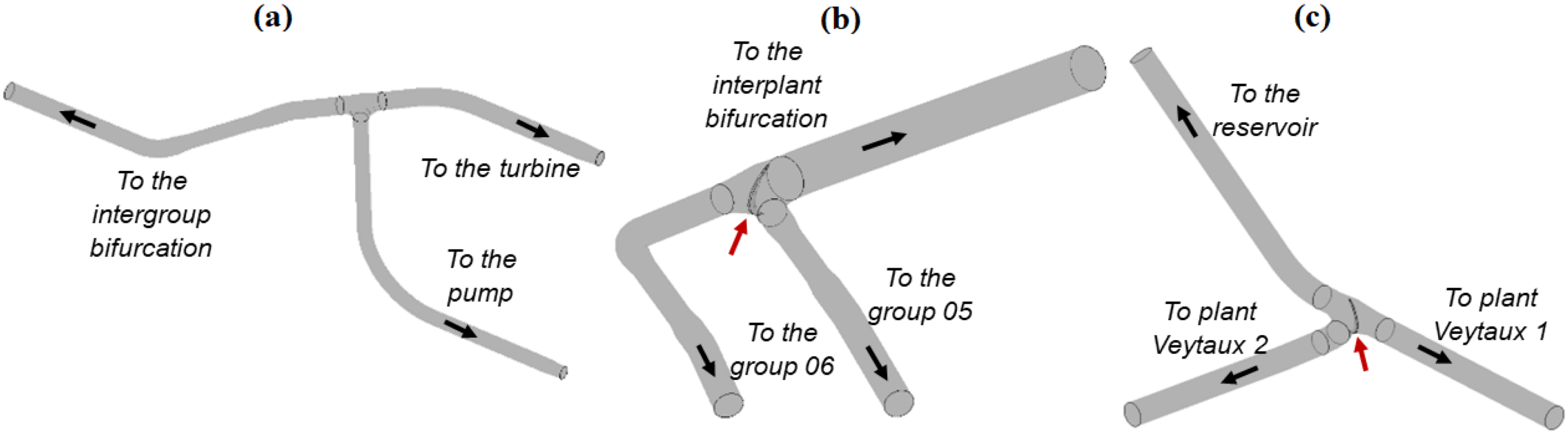
Interplants HSC mode between FMHL and FMHL+
Not allowed

Hydraulic short-circuit

2nd case study – FMHL/FMHL+

Geometries & Scenarios

«Intragroup» FMHL+ G5	«Intergroup» FMHL+ G5 & G6	«Interplant» FMHL+ G5-G6 & FMHL G1-G2-G3-G4



(**a**) the intragroup HSC mode, (**b**) the intergroup HSC mode and (**c**) the interplant HSC mode.

Hydraulic short-circuit

2nd case study – FMHL/FMHL+

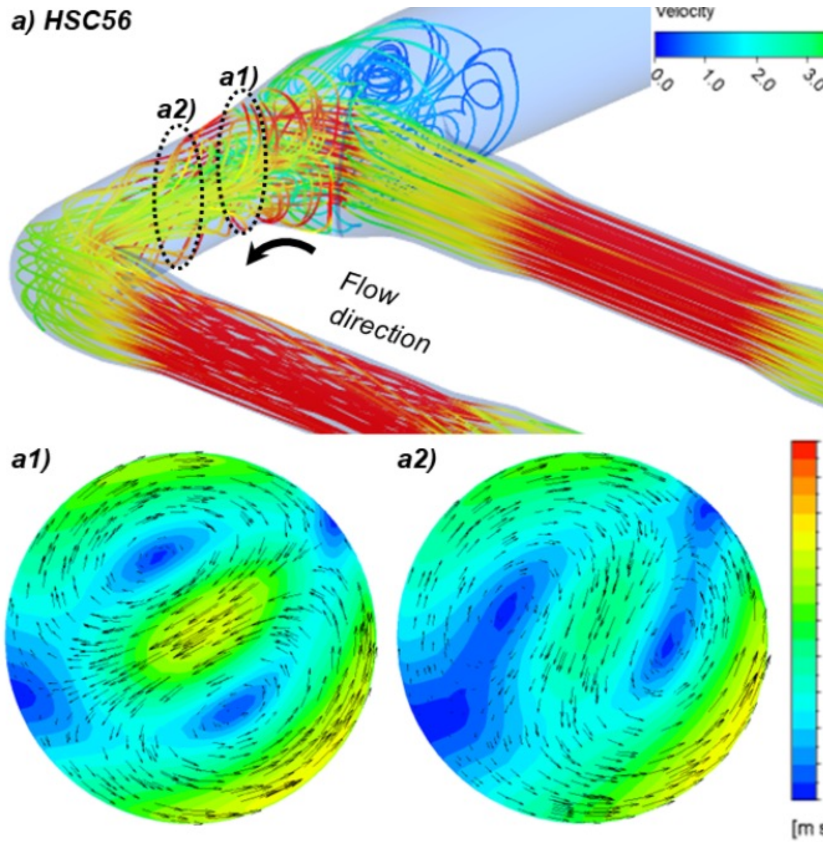
Synthesis – Comparison of the scenarios

Losses between pump and turbine compared to the reference case HSC 66%

	Intragroup	Intergroup 56	Intergroup 65	Interplant Single Flowrate V1V2
HSC 33%	105%	53%	47%	46%
HSC 66%	100%	74%	50%	45%
HSC 100%	118%	95%	77%	70%

Helicity between pump and turbine compared to the reference case HSC 66%

	Intragroup	Intergroup 56	Intergroup 65	Interplant Single Flowrate V1V2
HSC 33%	33%	4%	14%	3%
HSC 66%	100%	17%	23%	6%
HSC 100%	214%	45%	82%	12%



Decaix, J., Mettille, M., Hugo, N., Valluy, B., & Münch-Allігné, C. (2024). CFD investigation of the hydraulic short-circuit mode in the FMHL/FMHL+ pumped storage power plant. *Energies*, *17*(2), 473.

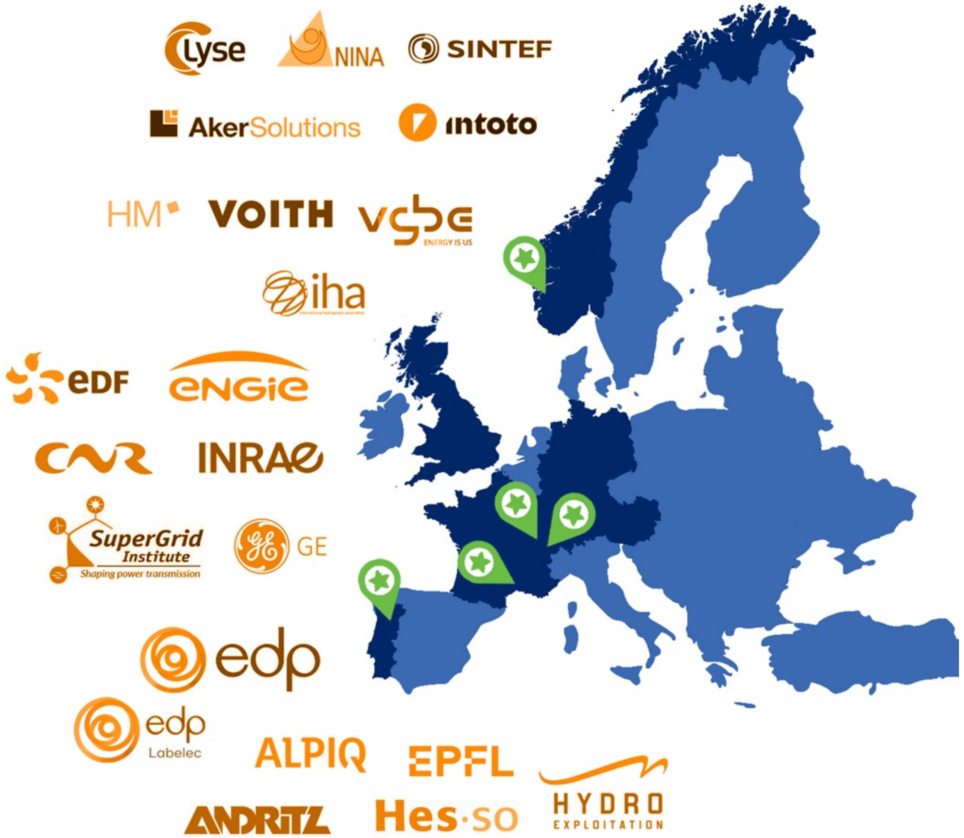
Turbine erosion due to sediments

- Global warming accelerates glacier retreat and melting increasing sediment inflows to rivers and reservoirs.
- Hard mineral particles can induce erosion of hydraulic machines and other mechanical equiment.
- Eroded surfaces lead to efficiency drops, lifetime reduction and an increase of maintenance needs.
- Numerical simulation and continuous sediment monitoring is essential to anticipate and mitigate damage.

Key objective

The main objective of ReHydro is to demonstrate how European hydropower can be **refurbished and modernized** to be fit for the future energy system respecting **sustainability requirements and societal needs** in a climate change context.

- 22 Partners from 7 countries
- 6 Operators
- 4 Manufacturers
- 3 Suppliers
- 7 Research Organisations
- 2 Associations



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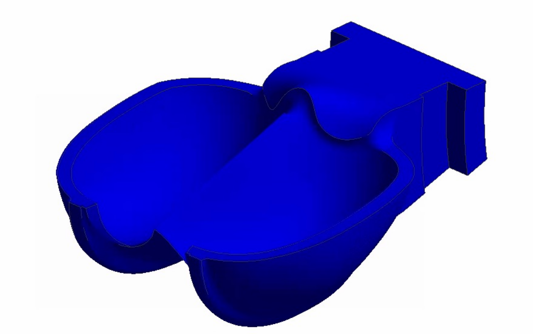
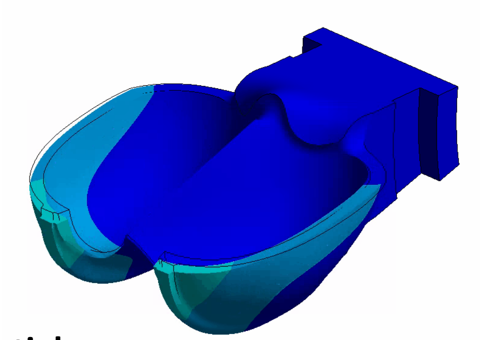
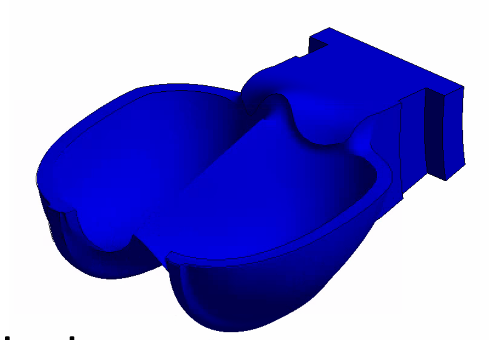
Dynamic behaviour of Pelton bucket



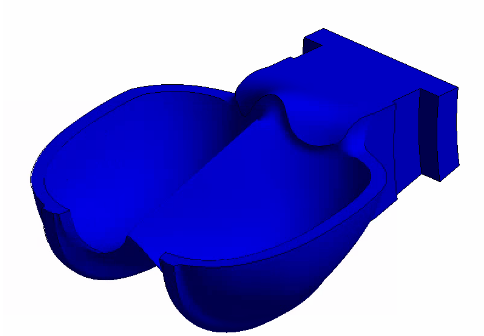
Axial



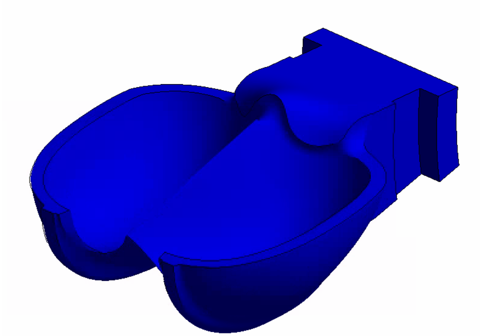
Tangential



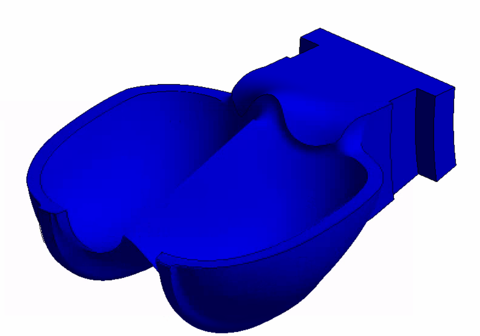
Tangential c-ph.



Axial c-ph.



Radial

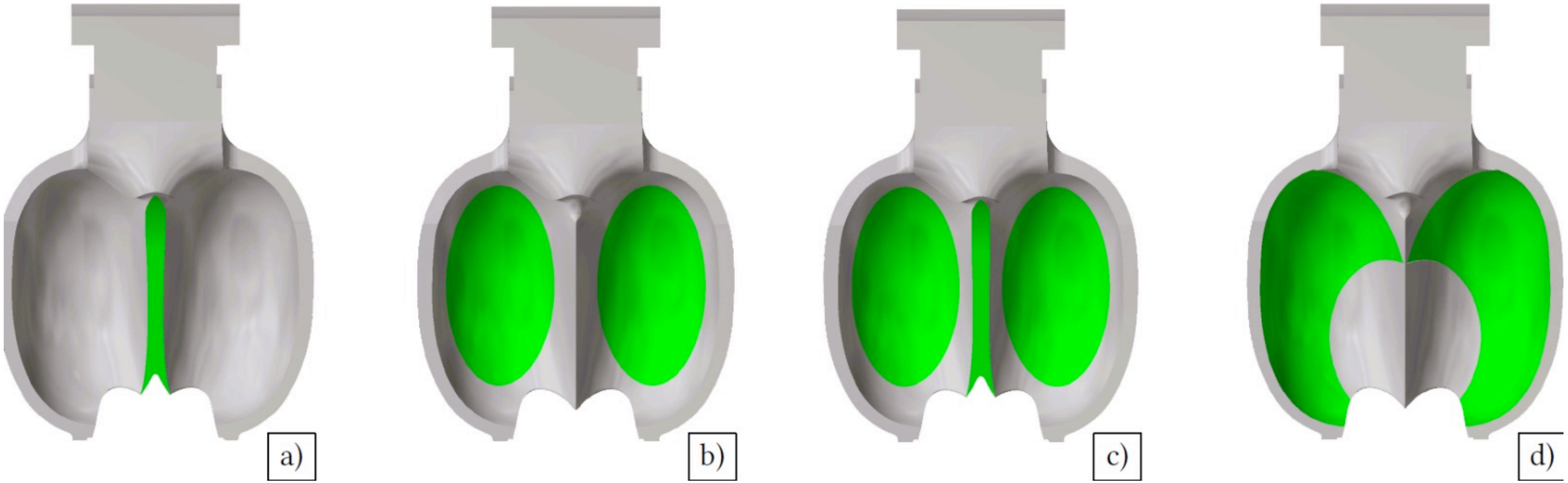


Radial c-ph.

Chiarelli, M., Vetsch, D. F., Boes, R. M., & Münch-Allигné, C. (2025, March). Investigation of the natural modes of a Pelton runner prototype. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1483, No. 1, p. 012015). IOP Publishing.

Effect of sediment erosion on the dynamic behaviour of Pelton runners

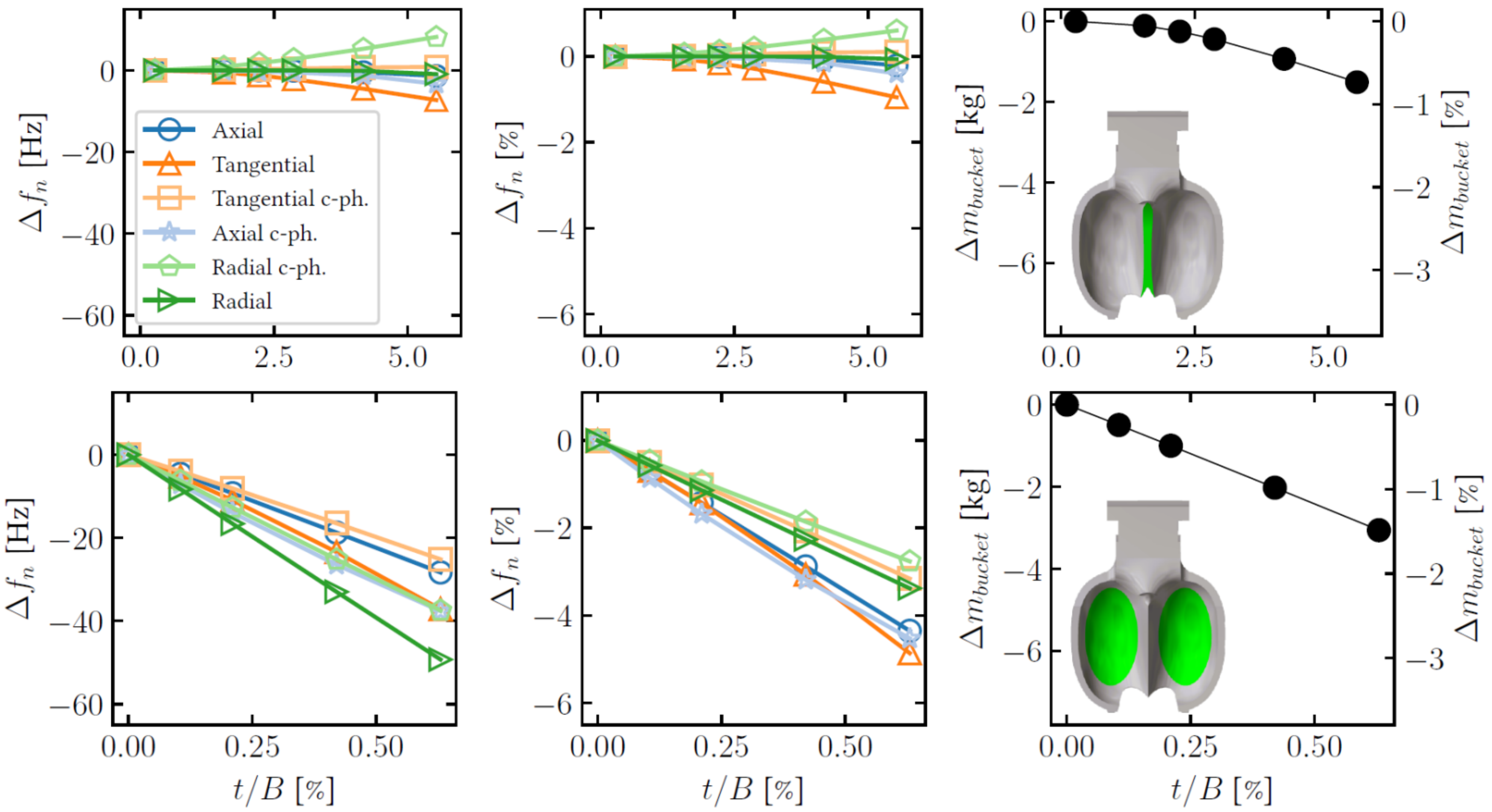
Simplified erosion scenarios



Source : M. Chiarelli, PhD thesis, ETHZ to be submitted

Effect of sediment erosion on the dynamic behaviour of Pelton runners

FEM of simplified erosion scenarios



Start-up monitoring may reveal eigenmode frequency shifts caused by sediment erosion in Pelton turbines

Chiarelli, M., Vetsch, D. F., Boes, R. M., Andolfatto, L., & Münch-Alligné, C. (2025). On the influence of geometrical parameters and erosive wear on the dynamic behaviour of Pelton turbine runners. *Results in Engineering*, 105638.

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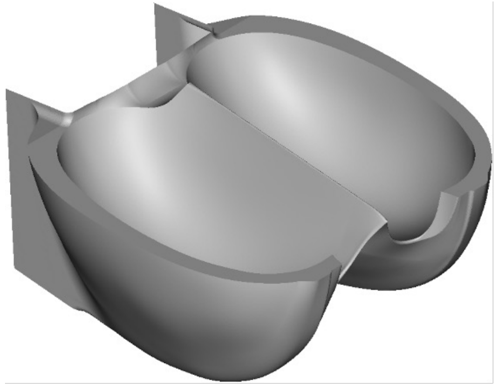
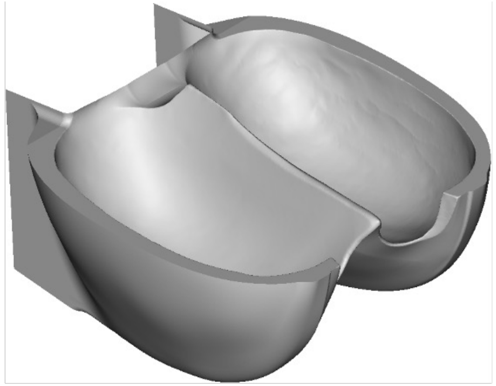
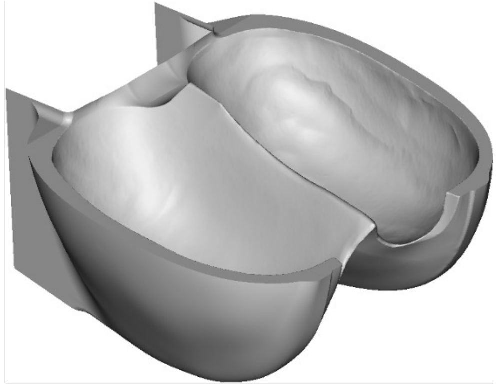
Effect of sediment erosion on Pelton runners



R1



R2



R3

	Runner 1	Runner 2	Runner 3
3D-scan of the geometry	✗	✓(3 buckets)	✓(25 buckets)
FEM modal simulation	✓	✗	✗
EMA	✓	✓	✓
Mass measurement	✓	✓	✓

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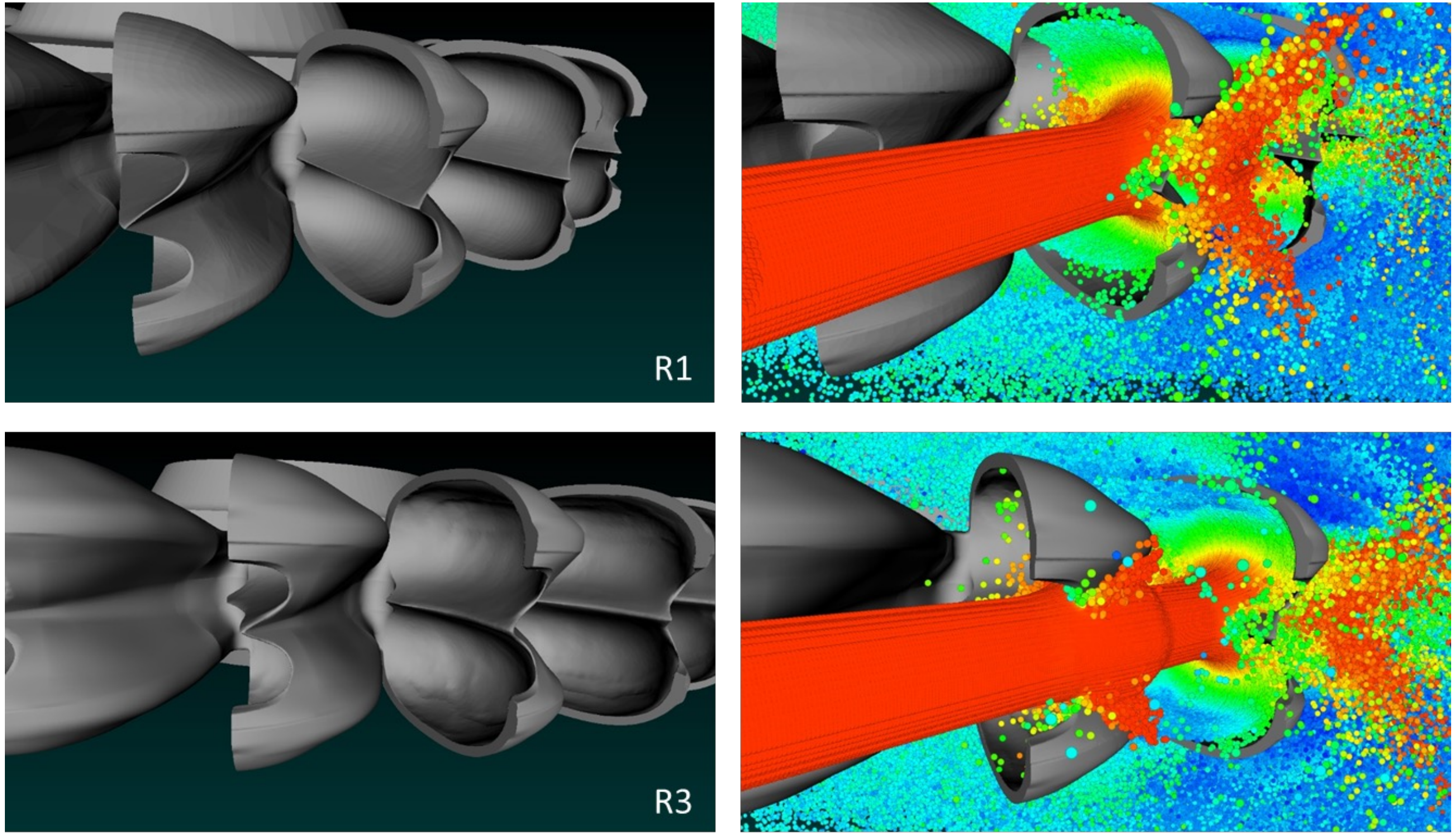
Influence of erosion on Pelton turbine flow and efficiency



Particleworks™
Particle-based simulation software for CAE

Particle works :
Meshless Lagrangian approach
&
moving particle semi-implicit method

Decaix, J., Mettille, M., & Münch-Alligné, C. (2024). Simulation of a Pelton turbine using the moving particle simulation method: application to two challenging situations. *Journal of Hydraulic Research*, *62*(4), 365-369.

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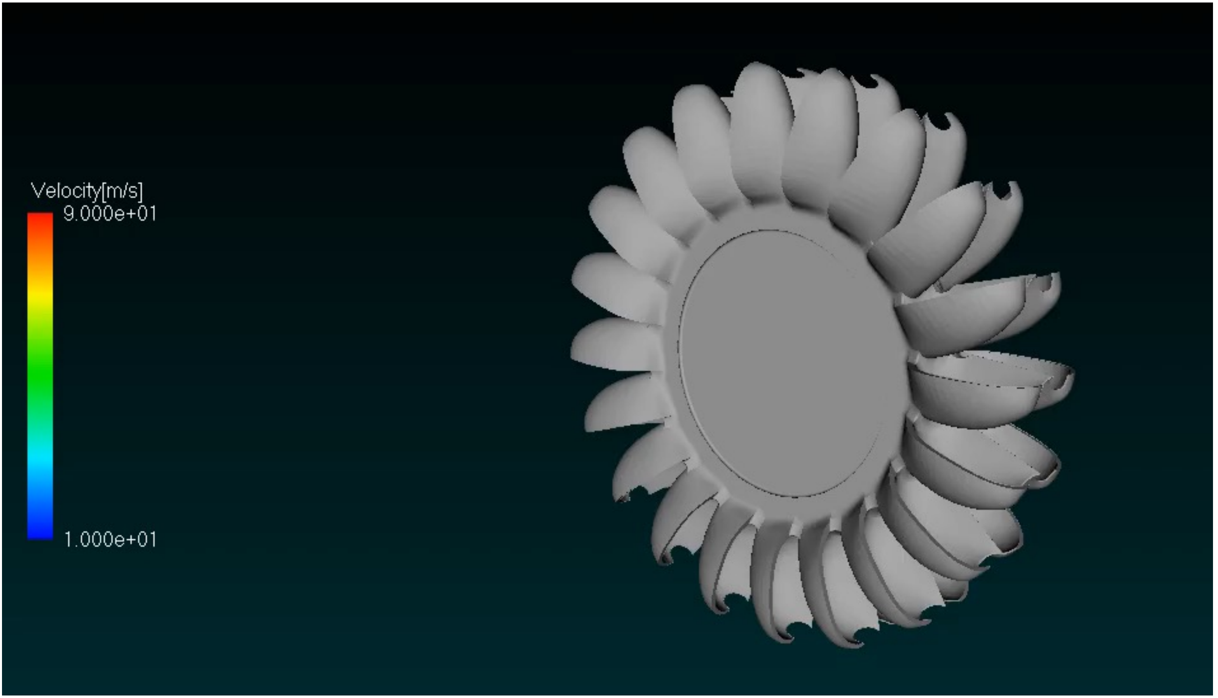
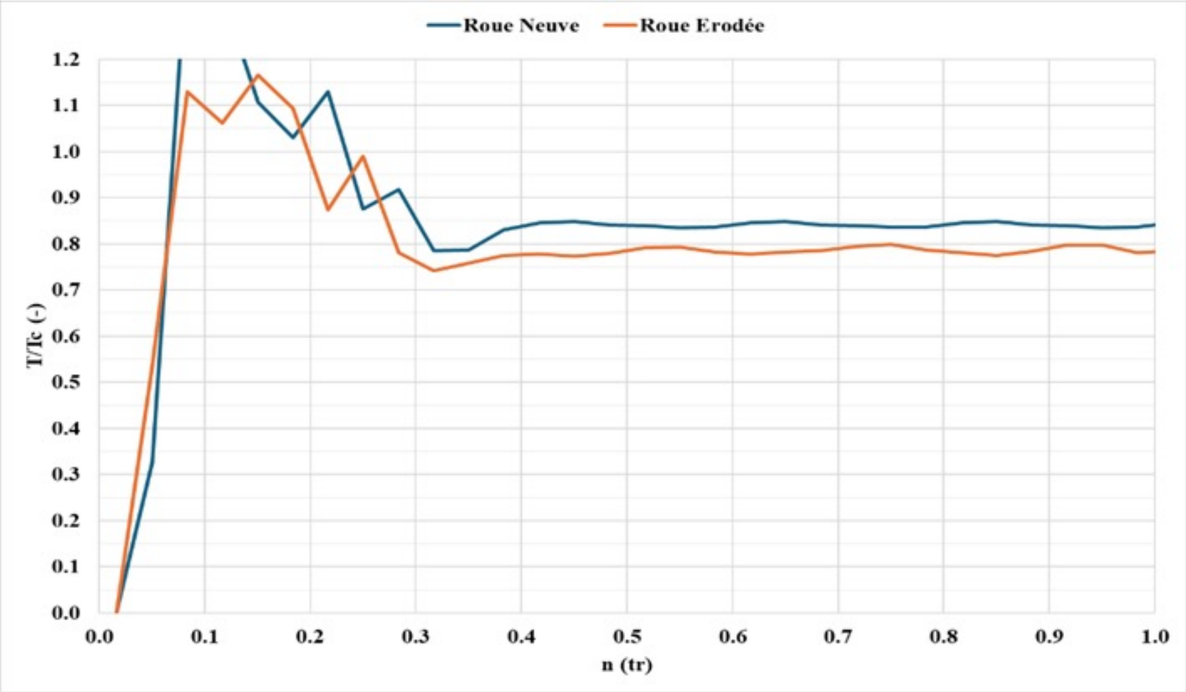
Influence of erosion on Pelton turbine flow and efficiency





Decaix, J. Chiarelli M, Munch-Allligné C, Boden. M, Numerical simulation as a support to develop digital twin. Hydro ES, September 2025, Grenoble
Boden, M., Chiarelli, M., Tsingos, V., Allaban, N., Decaix, J., Stojanovic-Roth, S & Münch-Alligné, C. (2025). Digital Twin for Vibration Monitoring of Pelton Units. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1442, No. 1, p. 012008). IOP Publishing.

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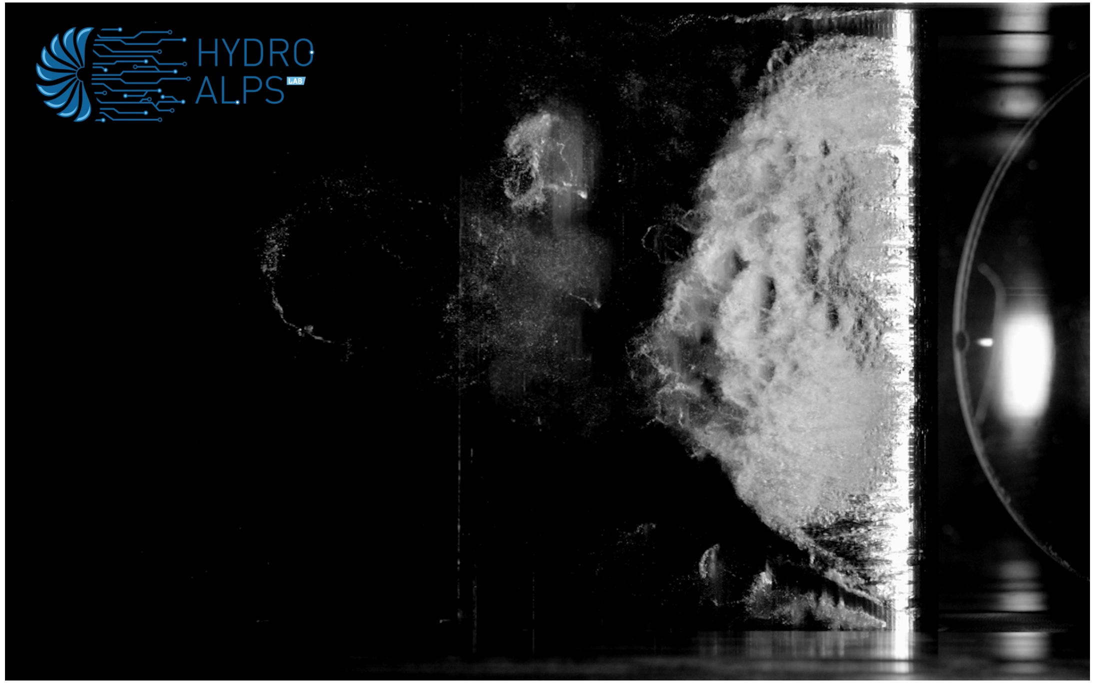
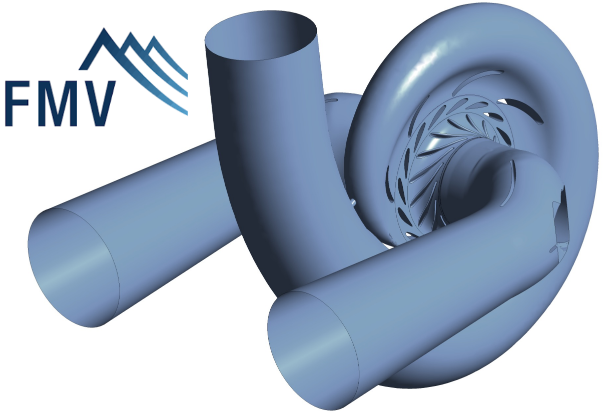
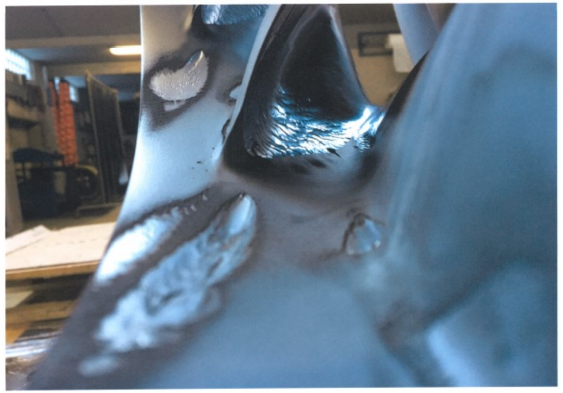
Turbine erosion due to cavitation

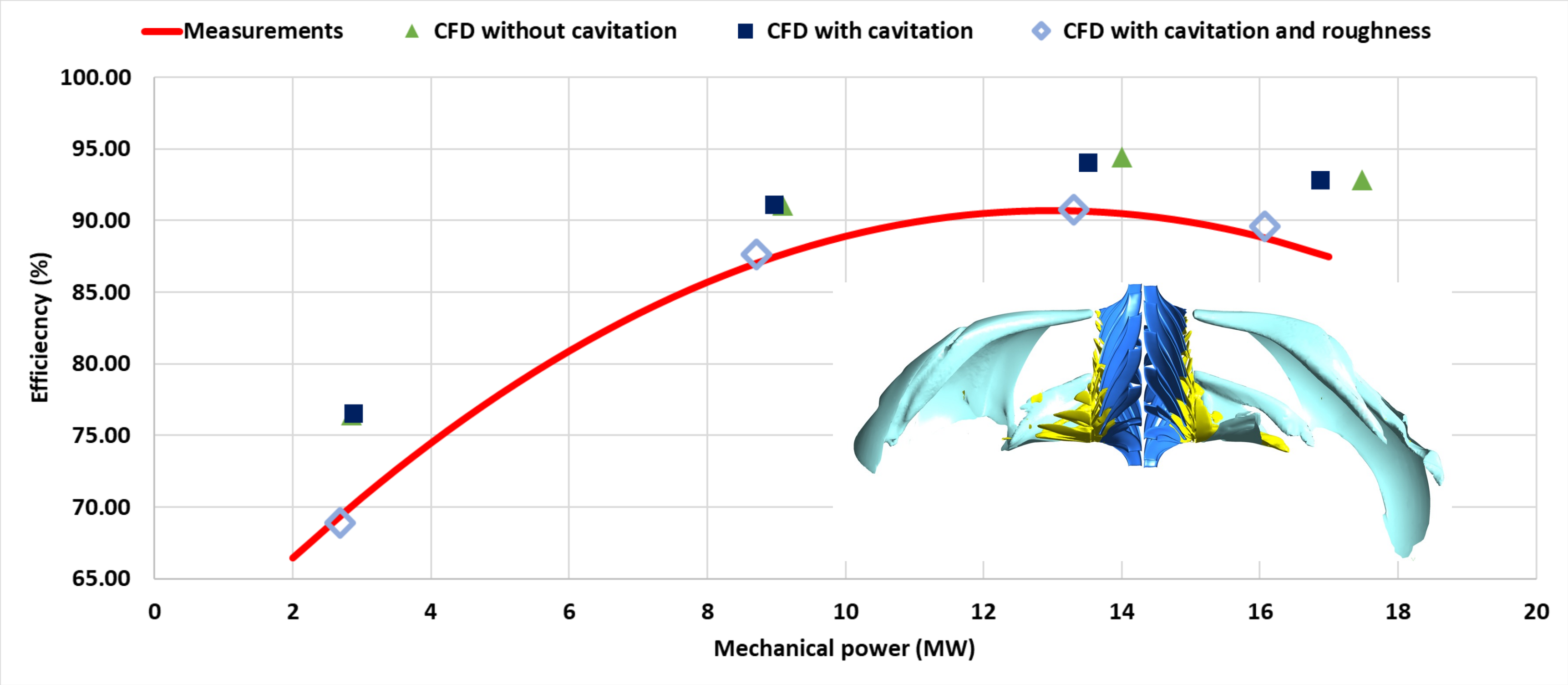
- With the growing need for flexibility in hydropower plants, turbines are increasingly operated over a wider operating range, which raises the risk and severity of cavitation.
- Cavitation occurs when local pressure in the fluid drops below vapor pressure.
- Collapse of vapor bubbles near solid surfaces produces micro-jets and shock waves.
- This leads to noise and vibration, affecting performance and mechanical stability.



Effect of erosion in Francis turbine due to cavitation







Decaix,, J. Mettille M, Pacot, O. Münch-Alligné C. Cavitation simulation of a prototype double Francis turbine at off design operating points. IAHR 2025 Brno, October 2025

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Bundesamt für Energie BFE
Office fédéral de l'énergie OFEN

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Shaping the Future of Hydropower with Numerical Simulations Hydraulic short circuit and Erosion Challenges

Take-away message

- **Numerical simulations enable safe and efficient implementation of hydraulic short-circuit operation**, predicting complex flow interactions and optimizing flexibility strategies.
- **Advanced modelling is essential to predict the effect of sediment or cavitation erosion**, allowing us to anticipate efficiency losses, extend turbine lifetime, and reduce maintenance costs.
- **Simulations drive modernization** – Digital tools are key to adapting hydropower for the energy transition.