TURBOMACHINERY COMPUTATIONS WITH LAGRANGIAN PARTICLE TRACKING:
Developments and validation

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Code_Saturne user meeting

2nd of April 2014

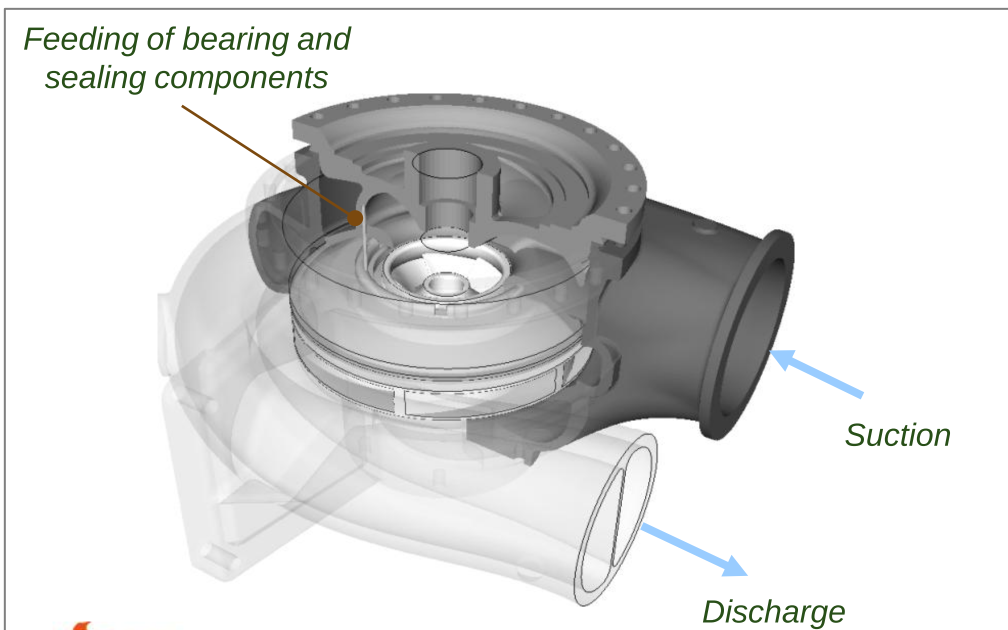
OUTLINE

1. **INTRODUCTION**
2. **CONSERVATIVE APPROACH FOR ROTOR/STATOR COUPLING**
3. **LAGRANGIAN PARTICLE TRACKING ON ROTATING GRIDS**
4. **CONCLUSION AND FUTUR PROSPECTS**

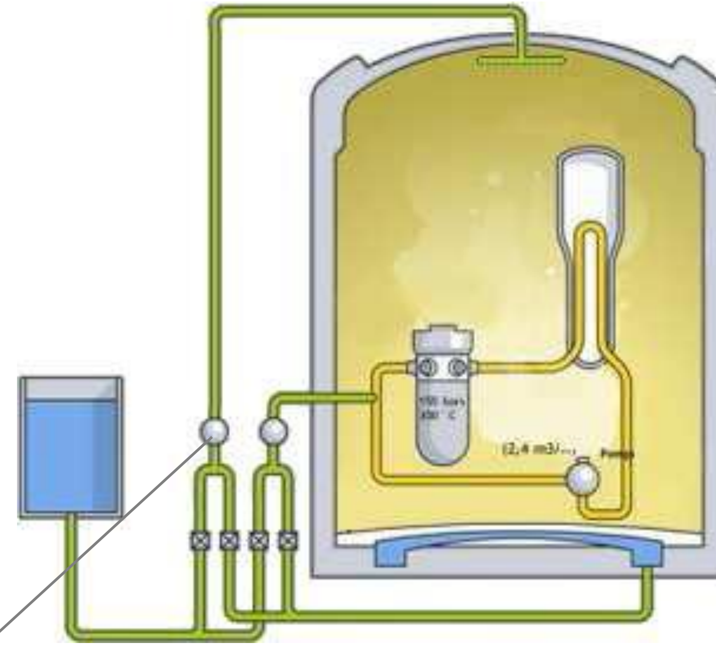
OUTLINE

CONTEXT

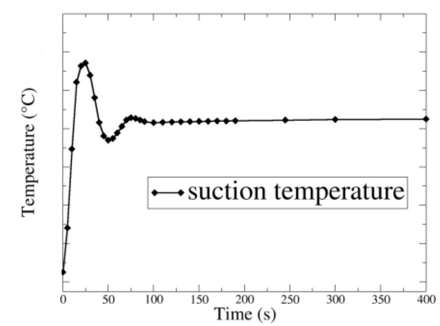
- **Emergency Core Cooling System (ECCS) and Containment Spray System (CSS) studies**
  - Pumps affected by the recirculation mode
    - Thermal shock ⇨ thermomechanical stress
    - Particle entrainment could damage the shaft bearing or sealing components



CSS pump



Safeguard systems of PWR



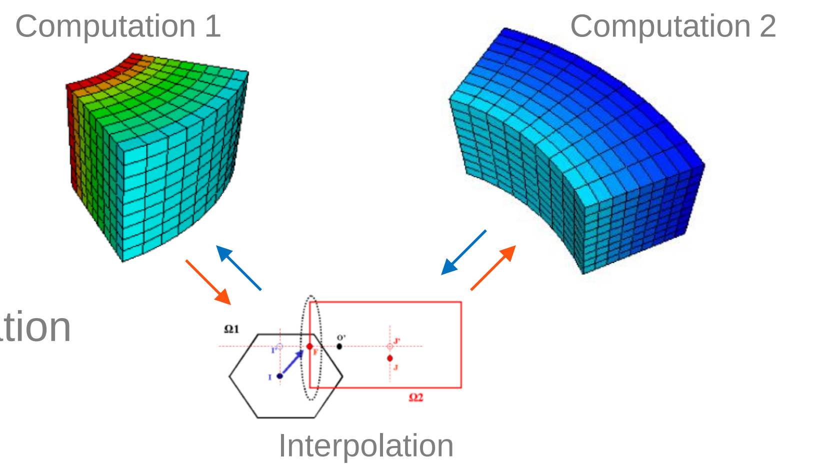
Suction temperature of CSS pump

METHODOLOGY

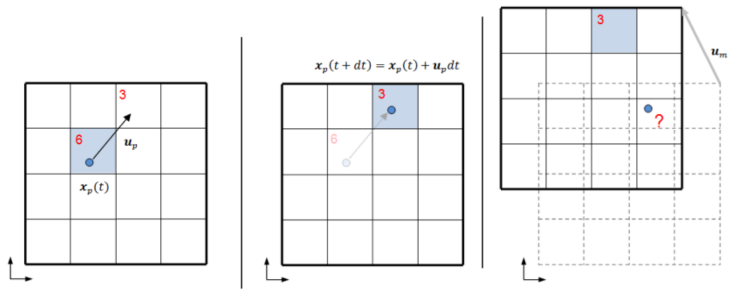
- **Computational approach for safeguard pumps studies ⇨ upgrade *Code_Saturne***

- **Rotor/stator interactions methods**
  - Previous implementation based on code-code coupling
  - Suffers deficiencies:
    - × Lack of conservativity during transient
    - × Cumbersome user data management
    - × **Lagrangian module: how to manage the particle tracking across the interface (boundaries) ?**

  ⇨ Full review of the rotor/stator coupling implementation



- **Lagrangian**
  - Existing algorithm has to be extended for rotating grids



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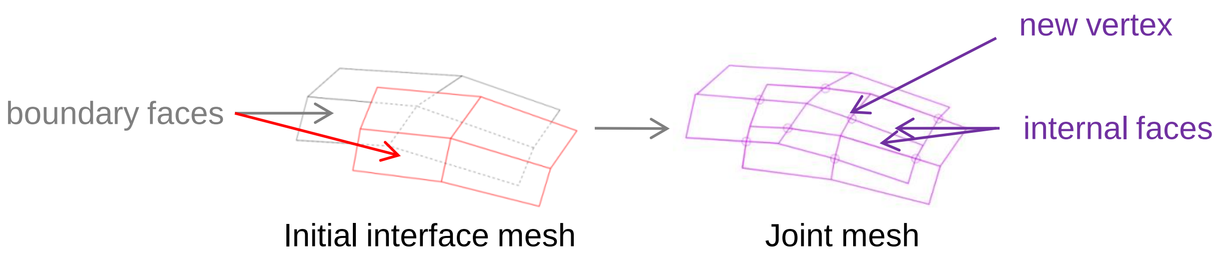
CONSERVATIVE APPROACH FOR ROTOR/STATOR COUPLING: description

- **Basic principle: rotor/stator interface treated as internal faces thanks to mesh joining**

✓ Conservative
✓ User friendly
✓ Portable



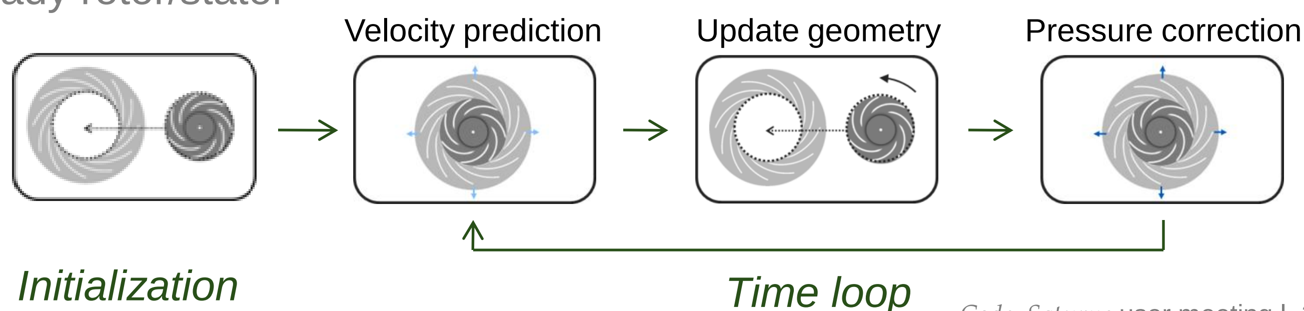
- Frozen rotor (steady)
  - One joining at the beginning or single mesh
  - Unknown variables of the system must be continuous across the interface ⇨ absolute velocity

$$\frac{\partial u_A}{\partial t} + \nabla\cdot(u_A \otimes u_R) + \mathbf{\Omega} \wedge u_A = -\frac{1}{\rho}\nabla p + \nabla\cdot(\nu \nabla u_A),$$

u_A : absolute velocity

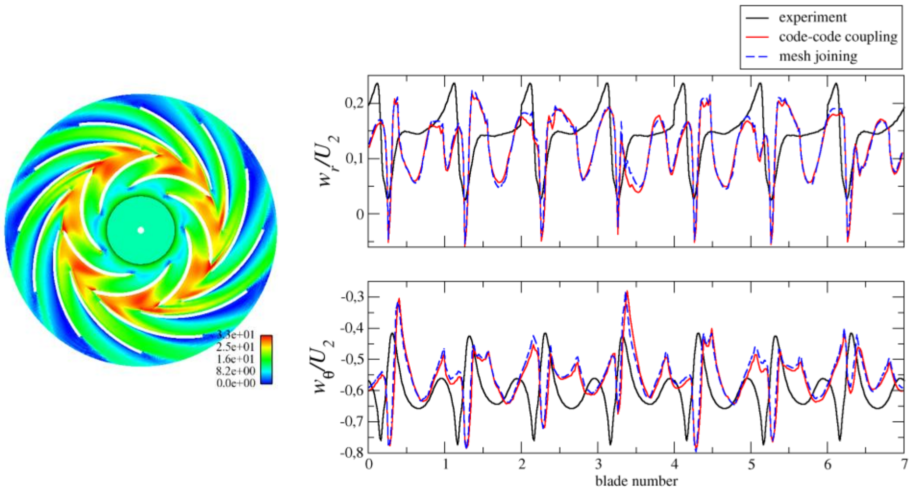
$u_R = u_A - \Omega \wedge x$: relative velocity

- Unsteady rotor/stator

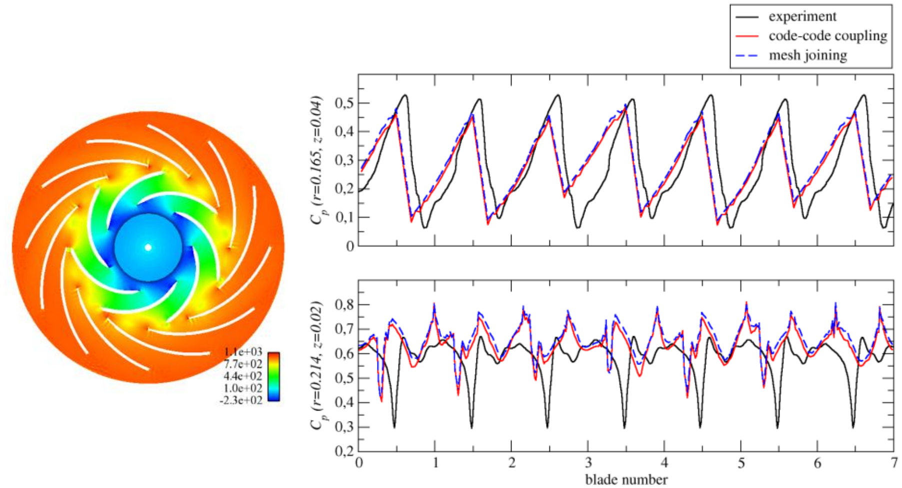


CONSERVATIVE APPROACH FOR ROTOR/STATOR COUPLING: validation test case

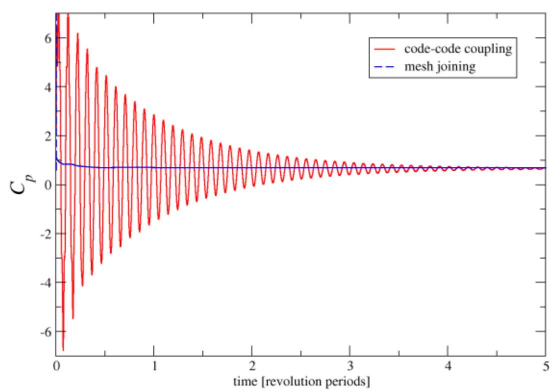
- **Genova's pump: frozen rotor**



Velocity: visualization of the field and profiles in the vaneless gap



Pressure: visualization of the field and profiles at mid-channel (top) and in the vaneless gap (bottom)

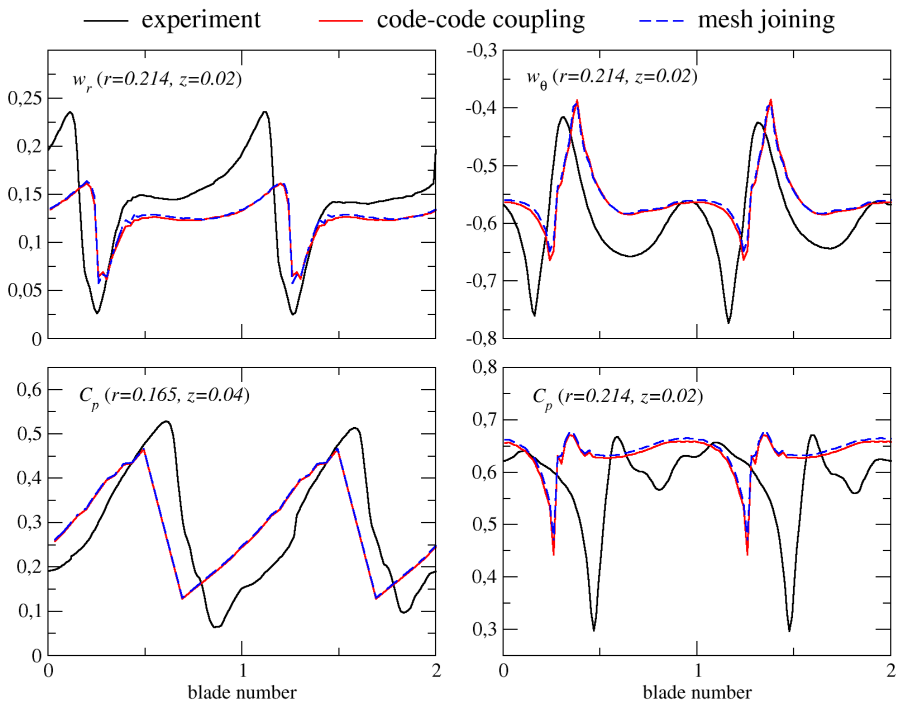


Time evolution of pressure close to the vaneless gap

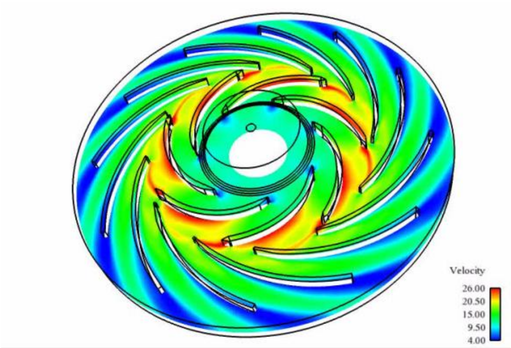
- Results almost identical with code-code coupling and mesh joining at convergence
- No more unphysical pressure fluctuations during the transient

CONSERVATIVE APPROACH FOR ROTOR/STATOR COUPLING: validation test case

- **Genova's pump: unsteady rotor/stator**



Relative velocity and pressure profiles at mid-channel and in the vaneless gap



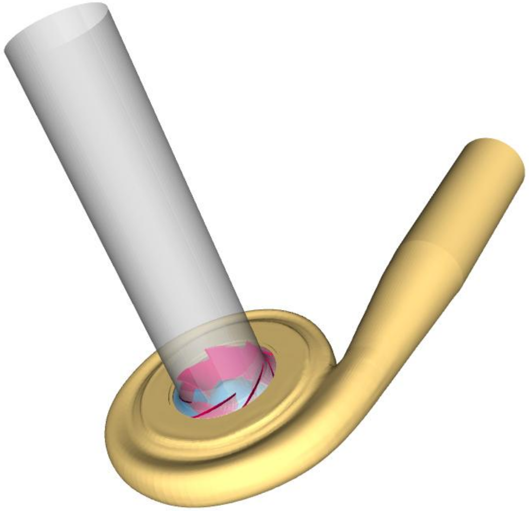
- Results almost identical with code-code coupling and mesh joining at convergence
- Slight computation savings with the mesh joining algorithm

CPU time mesh regeneration operations / total CPU time of the simulation	**14.7 %**
total CPU time with the mesh joining algorithm / total CPU time with the code-code coupling algorithm	**92.6 %**

Overview of computations performance

CONSERVATIVE APPROACH FOR ROTOR/STATOR COUPLING: industrial test case

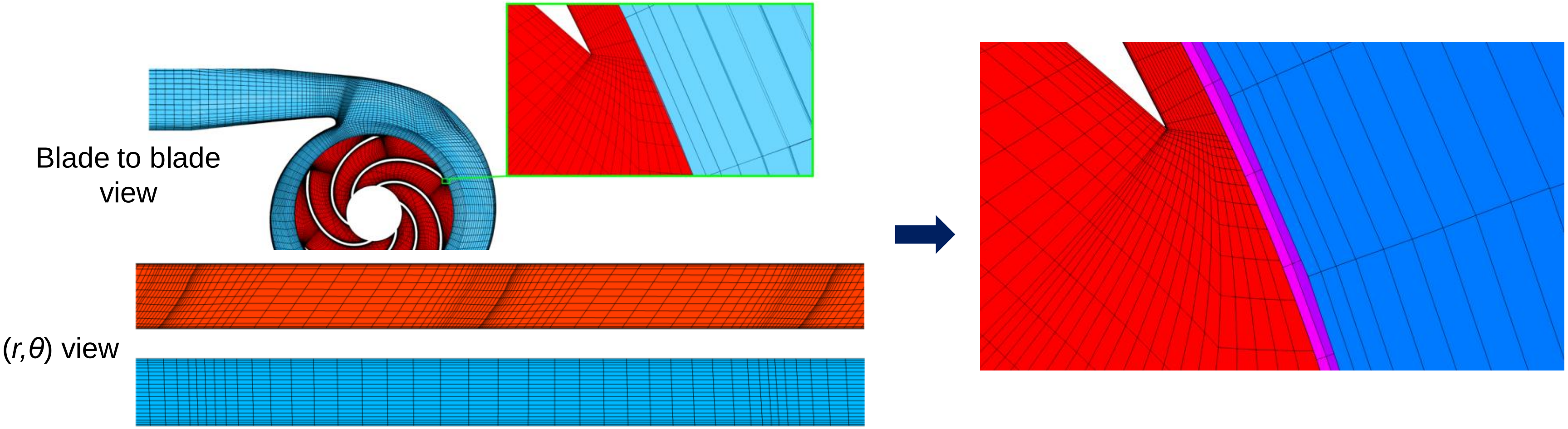
- **Gourdin's pump**
  - Centrifugal pump quite similar to safeguard pumps
  - Pump characteristics (total head, efficiency, …) at several flowrates measured at EDF Lab Chatou (EPOCA)
  - Previous numerical study with CFX TASCflow (CETIM, 2005)
    - ⇨ Existing CAD and mesh files



Fotograph of the pump (left) and computational model (right)

CONSERVATIVE APPROACH FOR ROTOR/STATOR COUPLING: industrial test case

- **Computation methodology**
  - Mesh ~ 1.2 M cells (hexaedral): 70000 (inlet) + 650000 (blade channels) + 500000 (casing)
  - Large grid refinement gap between rotor and casing
    - ✗ Joining failure or system inversion divergence
    - ✓ Introduce a buffer cells layer between rotating and fixed grid in order to « smooth » de refinement gap

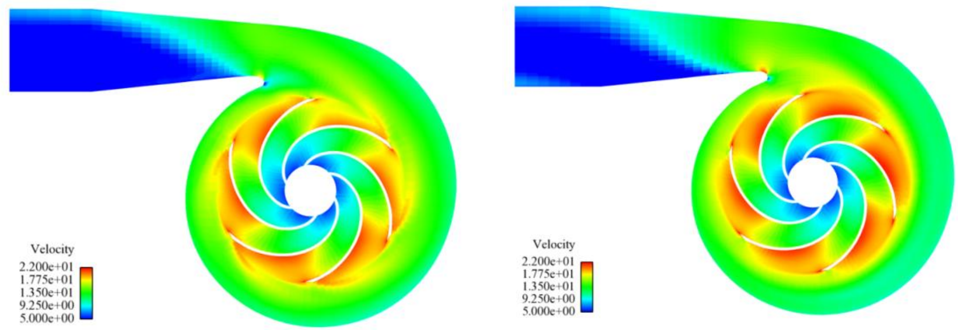


Grid refinement at interface: inital (left) and introduction of a buffer layer (right)

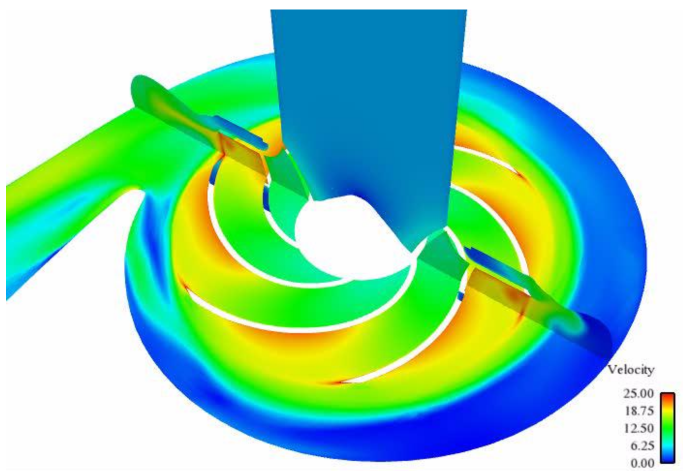
  - Solver options
    - Non-orthogonalities at rotor/stator interface ⇨ Bi-CgStab for all variables except pressure and relaxation of pressure sub-incerment
  - Turbulence: *k-ε + scalable wall function*

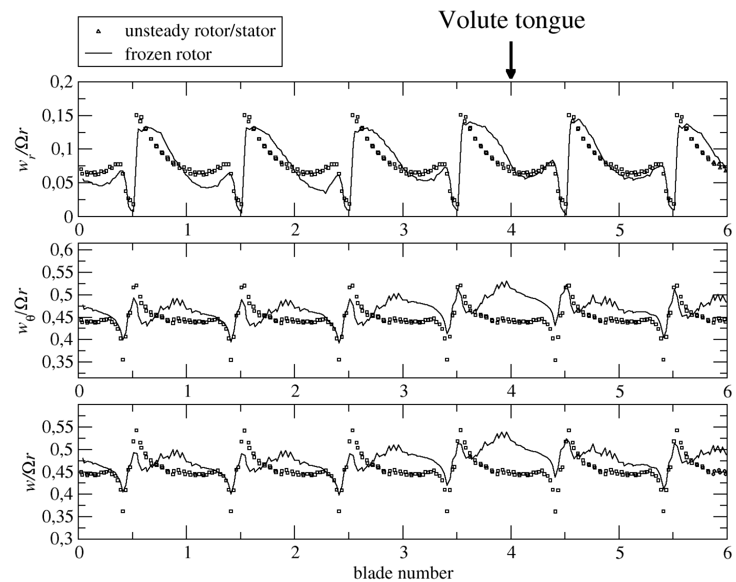
CONSERVATIVE APPROACH FOR ROTOR/STATOR COUPLING: industrial test case

- **Nominal flowrate**
  - Partial consistency between frozen rotor and unsteady computation
  - Limited rotor/stator interactions: only the volute tongue effects



Velocity magnitude : frozen rotor (left) and unsteady rotor/stator (right)

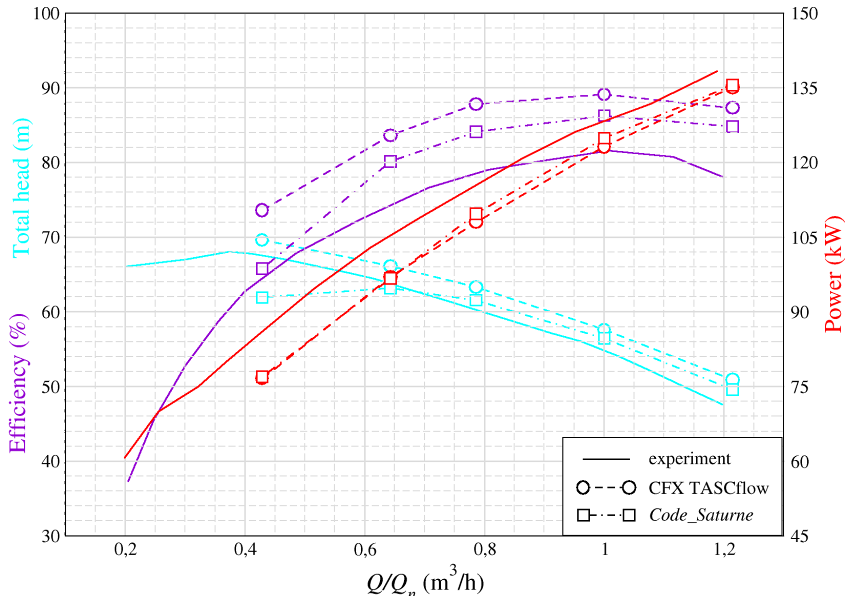




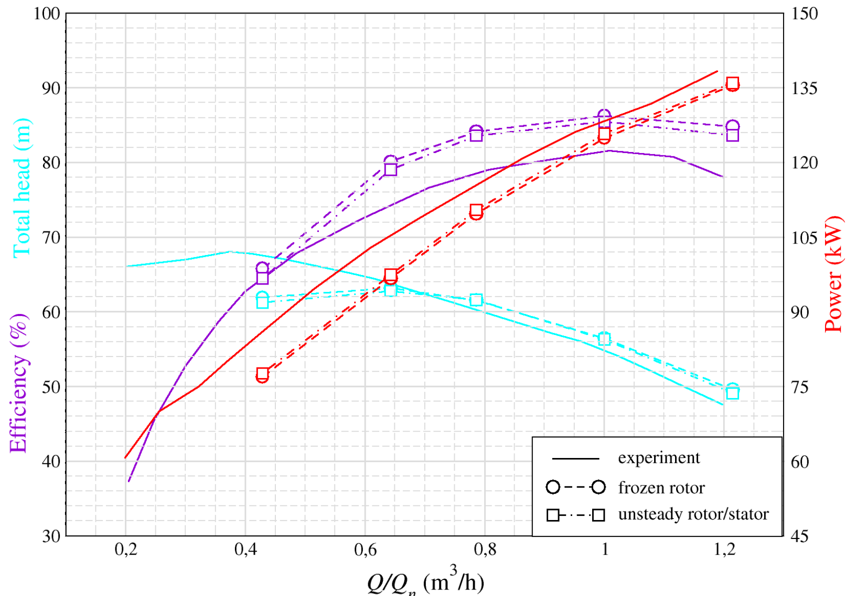
Relative velocity profiles in the vaneless gap

CONSERVATIVE APPROACH FOR ROTOR/STATOR COUPLING: industrial test case

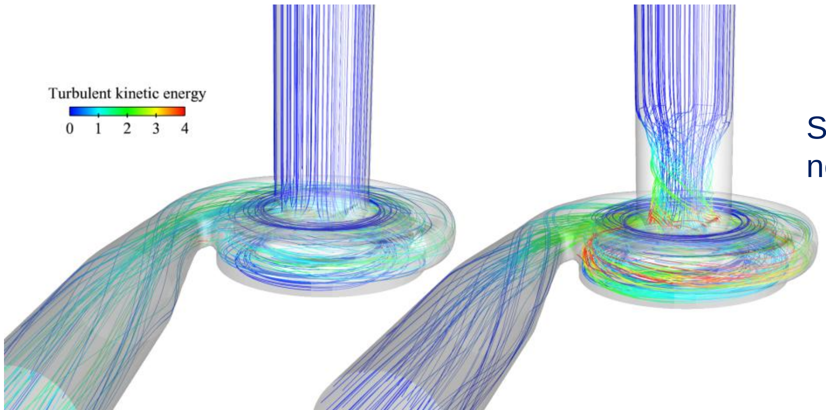
- **Partial and over flowrates**



Frozen rotor: comparison between CFX and *Code_Saturne*



Code_Saturne: comparison between frozen rotor and unsteady rotor/stator



Streamlines colored by turbulent kinetic energy at nominal (left) and partial flowrate (rate)

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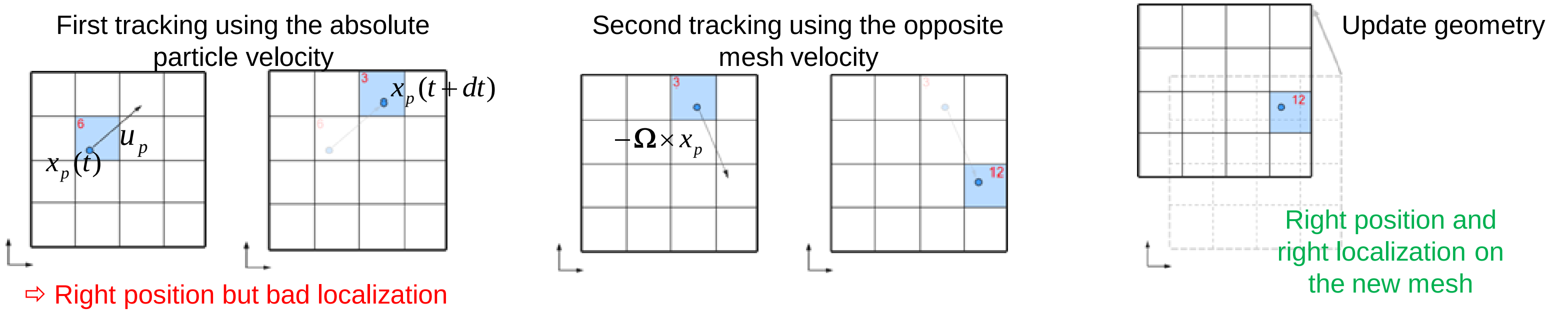
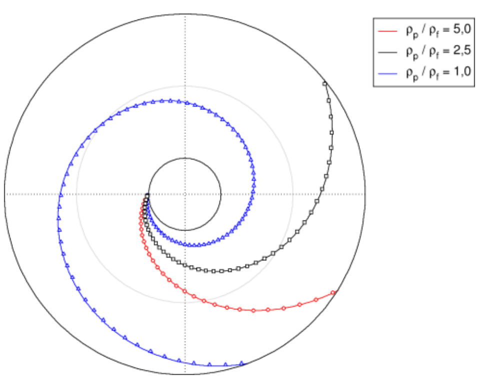
PARTICLE TRACKING ON ROTATING GRID

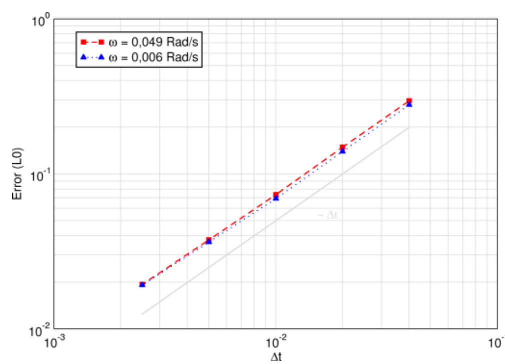
- **Trivial extension of the Lagrangian module in order to take into account the mesh displacement**



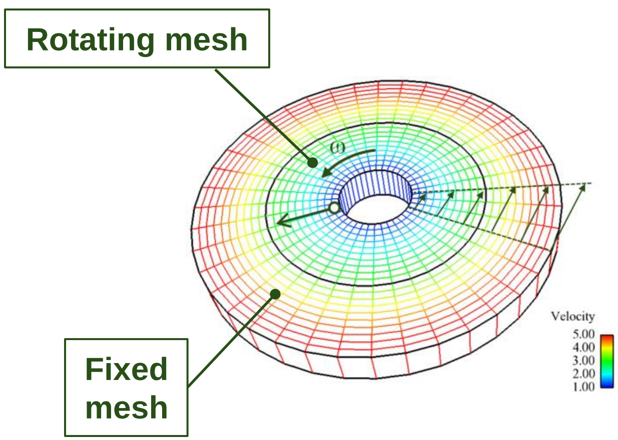
- **Verification test case:**
  - Radial injection of a particle in a solid body rotation flow (laminar)
  - Particle subjected to the drag force only
  - Inner part of the mesh is rotating



Particle trajectories (various density ratio)

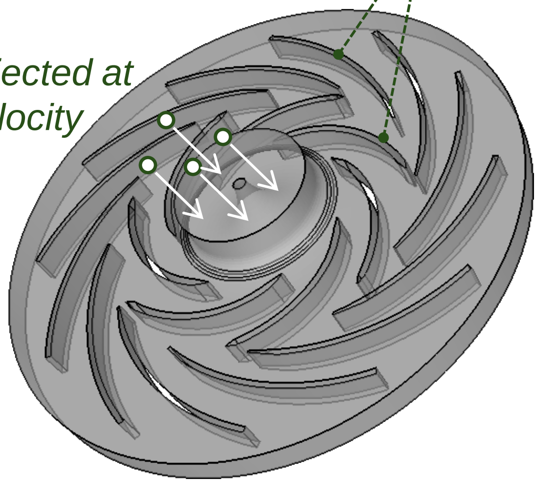


Time convergence of the error



PARTICLE TRACKING ON ROTATING GRID

- **Qualitative test case**
  - Particle density effect in the Genova's centrifugal pump



- **Model description**
  - Particle properties
    - Density ratio: 1 and 100
    - Spherical particles of 50μm diameters
    - Particles subjected to drag force and pressure gradient
  - Numerical parameters
    - CFL max ~ 0,3
    - One way coupling
    - Integration of stochastic differential equations: second order scheme
    - Turbulent diffusion: standard model

- **Observations**
    - Light particles: mainly follow the streamlines
    - Heavy particle: many rebounds, large particle velocity variations, depending on they are hit by the rotor blades or not

TOP VIEW SIDE VIEW

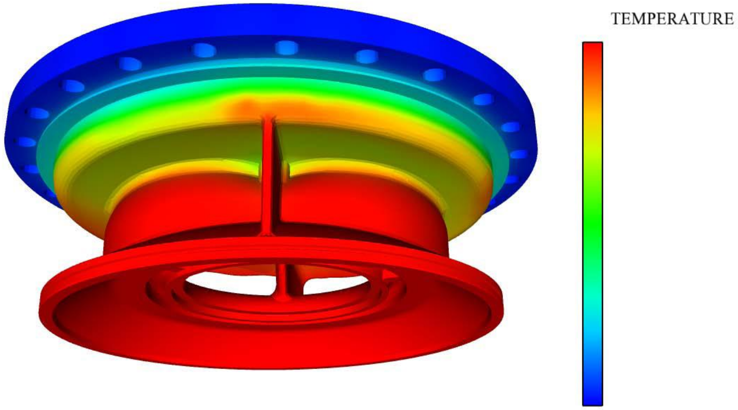
OUTLINE

CONCLUSION

- **Fully revised implementation of the rotor/stator interactions methods (available in v3.2)**
  - Conservative
  - Single user data management
- **Application to the prediction of a centrifugal pump characteristics at various flowrates**
  - Special attention to mesh strategy and appropriate numerical parameters
- **Extension of the Lagrangian module for rotating grids**
  - Analytical verification and qualitative comparisons in a centrifugal pump test case
- **Perspectives**
  - Multi-rotor management
  - Dedicated post-processing routines (machinery characteristics, etc…)
- **Present and future works**
  - Industrial studies on safeguard pumps
  - Cavitation modeling

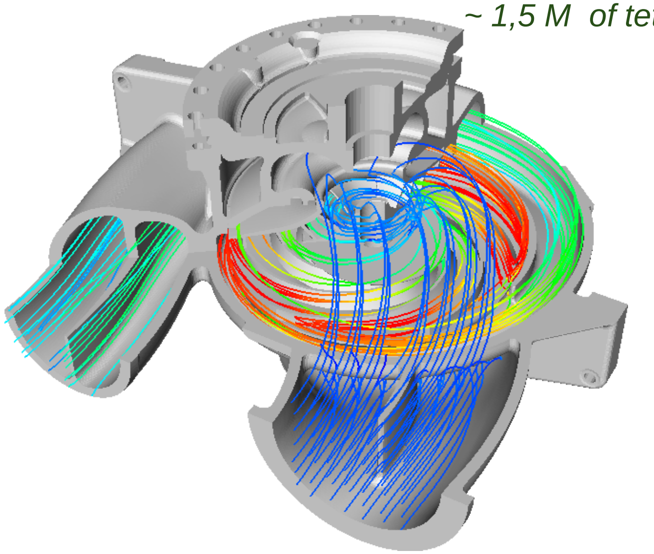
INDUSTRIAL APPLICATION TO CSS PUMP: OVERVIEW

- **Thermal shock**
  - Large temperature gradient in the upper part of the lid
  - Possible differential dilatation of the material
    - Thermomechanical study in progress…



Temperature field in the lid
(calculation of F. Jusserand)

~ 1,5 M of tetrahedrons



Streamlines colored by velocity

- **Particle nocivity**
  - Prediction of the particle distribution at the inlet of the lubrication system
  - Work in progress…

HYDRAULIC MACHINERY COMPUTATIONS: FUTURE CAVITATION MODULE OF *CODE_SATURNE*

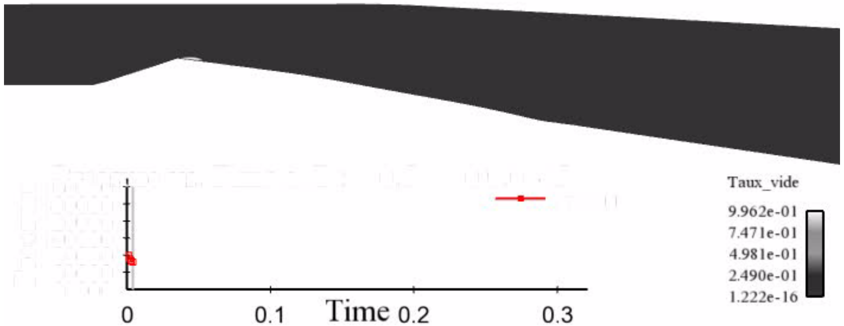
- **Homegeneous two-phase flow model (R. Chebli, B. Audebert)**
  - Mixture density: $\rho = \alpha\rho_V + (1-\alpha)\rho_L$ (ρ_V, ρ_L constant)

$$\frac{\partial \alpha}{\partial t} + \nabla \cdot (u\alpha) = \frac{\Gamma}{\rho_V}$$

Γ: vaporisation source term

- **Validated in a serie of cavitating flows**

Cavitation pockets on rotor blades



	L (mm)	*F* (s^{-1})	*St*
Experiment	**50**	**45**	**0.31**
k-ε	47.5	38.5	0.25
k-ε RNG	57	35	0.28
SST	49	45	0.30
SSG	62.5	33.5	0.29

Venturi 8°: preliminary results

- **Available in v3.3**

THANK YOU