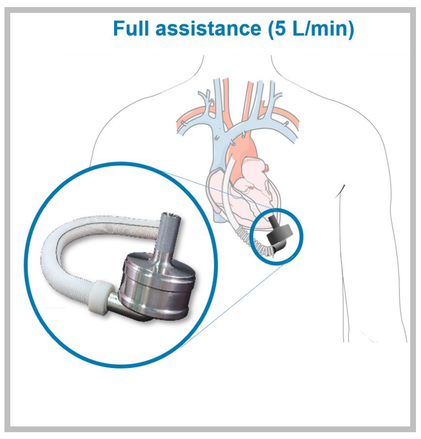
Fluid-Structure Interaction Simulations of Flexible Membrane-based LVAD

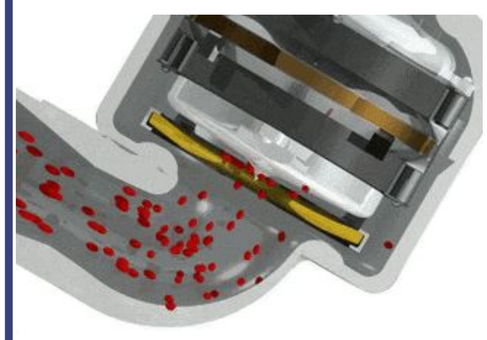
Martinolli M^*, Bernardo $C^\dagger$, Labouret $T^\dagger$, Polverelli $L^\dagger$, Cornat $F^\dagger$, Biasetti $J^\dagger$, Monticone $PP^\dagger$, Vergara C^*

* MOX, Dipartimento di Matematica, Politecnico di Milano, via Bonardi 9, 20133, Milan, Italy
† CorWave SA, 17 rue de Neuilly Impasse Passoir, 92110 Clichy, France

1. Membrane-based Blood Pumps

Left-Ventricular Assist Devices (LVADs) are blood pumps that support the activity of failed hearts by mechanically pumping blood into the ascending aorta.
LVADs have become a life-saving option for many patients, being a promising treatment as bridge to transplantation or destination therapy. However, their implantation might lead to severe side effects, like hemolysis, clotting and gastro-intestinal bleeding.





CorWave has developed new blood pumps where the interaction between blood and an elastic membrane results in an effective pulsatile pumping action.
Such pumps, named **membrane-based pumps,** are designed so that patterns of velocity and shear stress lead to a reduced risk of blood trauma.

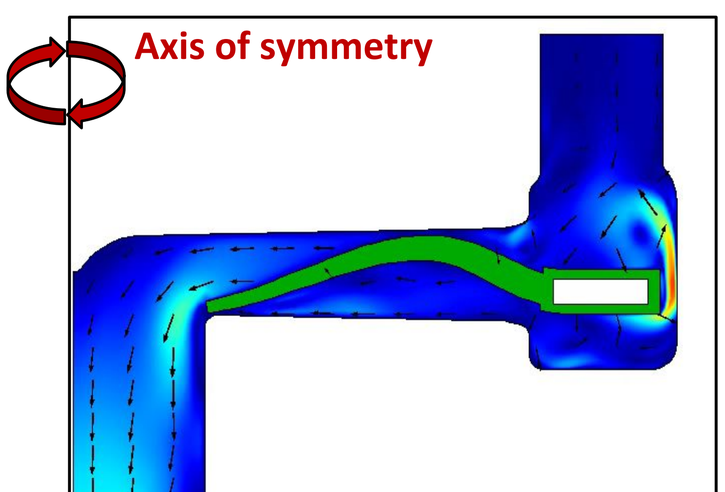
2. Final Objectives

- Implement a new efficient software for **full 3D time-dependent simulations** of the **Fluid-Structure Interaction (FSI)** problem that supports **multi-thread parallelization**
- Perform **model validation** using experimental data on membrane motion, fluid dynamic measurements and blood data acquired at CorWave
- Study the structural dynamics of the membrane in order to predict possible sources of **blood trauma** and **thrombosis**

3. Current Simulation Tools in CorWave

At CorWave, commercial software packages are used to make FSI simulations inside the blood pump and test the effect of different designs on its final performance.

Taking advantage of the cylindrical symmetry of the device, **2D axisymmetric simulations** are performed in order to save computational time.



Snapshot of the recording of membrane motion using an high-speed camera

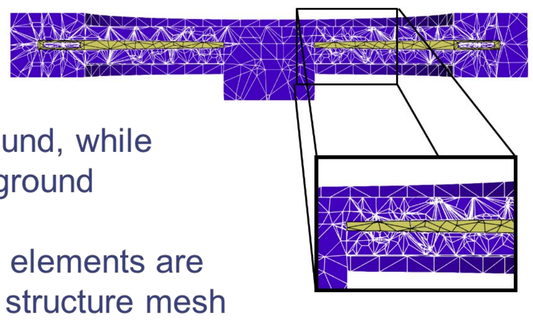
However, such simulations have two drawbacks:

i. experimental evidences showed that membrane vibrational modes present a **three-dimensional nature**, that cannot be captured in a 2D-simulation framework
ii. **frequent remeshing** is needed to overcome undesired configurations with distorted elements

4. Software for 3D Simulations in LIFEV

The proposed computational methodology is based on the coupling of the **Extended Finite Element Method (X-FEM)**[1] with a **Discontinuous Galerkin (DG)** mortaring at the Fluid-Structure interface[2].

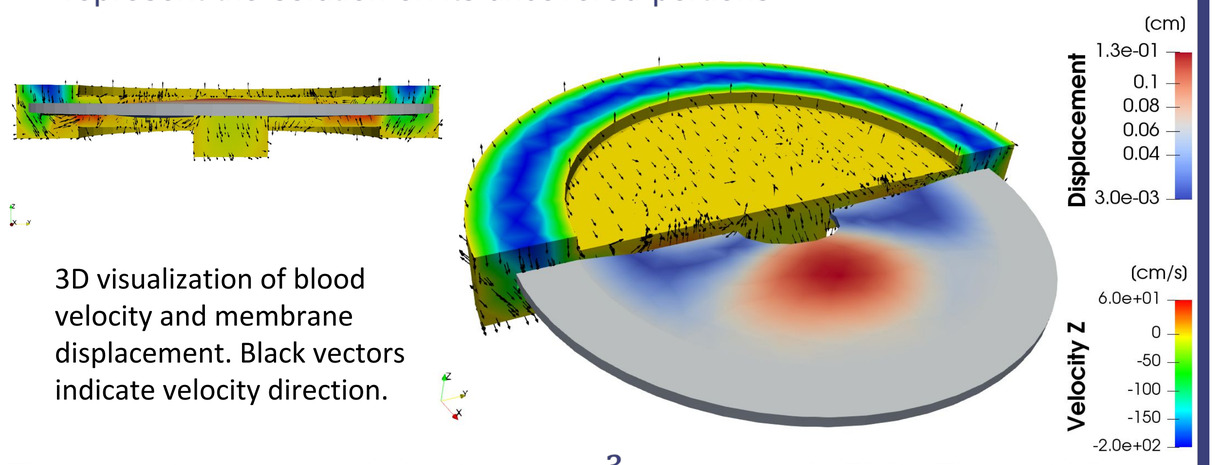
This framework offers two advantages:



i. No need of remeshing, because the **fluid mesh** is kept fixed on the background, while the **structure mesh** moves on the foreground

   ➡ at each time instant, different fluid elements are covered and/or cut by the moving structure mesh

ii. Accuracy is preserved at the Fluid-Structure interface thanks to a local enrichment of the functional space of the fluid cut elements, which allows to represent the solution on its uncovered portions



3D visualization of blood velocity and membrane displacement. Black vectors indicate velocity direction.

The simulations are carried out in **LIFEV**[3], an academic Finite Element Library that has been extensively used in complex real-life PDE problems, particularly in cardiovascular applications.

5. Future Developments

Our current results carried out in simplified scenarios proved that X-FEM is a promising numerical approach for simulating the FSI dynamics arising in the blood pump developed by CorWave.

The main steps to take in the next three years* are the following:

- Implement the **contact model** to analyze the interaction between the membrane with the pump housing
- Enable **parallelization** of the codes in order to decrease computational time
- **Compare** the performance of the new software with simulation tools currently employed in CorWave
- Support CorWave's development team in the optimization of the **pump design** by analyzing new geometries in terms of hydraulic performance and risk of blood trauma

References

1. E. Burman, M. A. Fernàndez, *An unfitted Nitsche method for incompressible fluid--structure interaction using overlapping meshes*, 2014, Computer Methods in Applied Mechanics and Engineering
2. S. Zonca, C. Vergara, L. Formaggia, *An unfitted formulation for the interaction of an incompressible fluid with a thick structure via an X-FEM/DG approach,* 2018, Society for Industrial and Applied Mathematics
3. L. Bertagna, S. Deparis, L. Formaggia, D. Forti, A. Veneziani, *The LifeV library: engineering mathematics beyond the proof of concept, 2017, airXiv:1710.06596*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 765374 "ROMSOC - Reduced Order Modelling, Simulation and Optimization of Coupled systems'*