Isogeometric Discontinuous Galerkin method with deformable domains

Stefano Pezzano

Université Côte d'Azur, Inria, CNRS, LJAD
e-mail: stefano.pezzano@inria.fr

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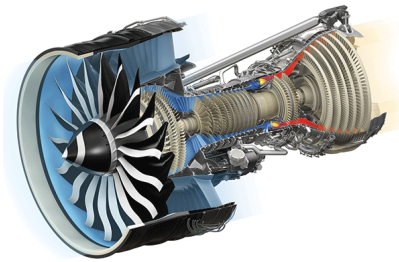
Work done in collaboration with Régis Duvigneau

Outline

Outline

Flows with evolving geometries

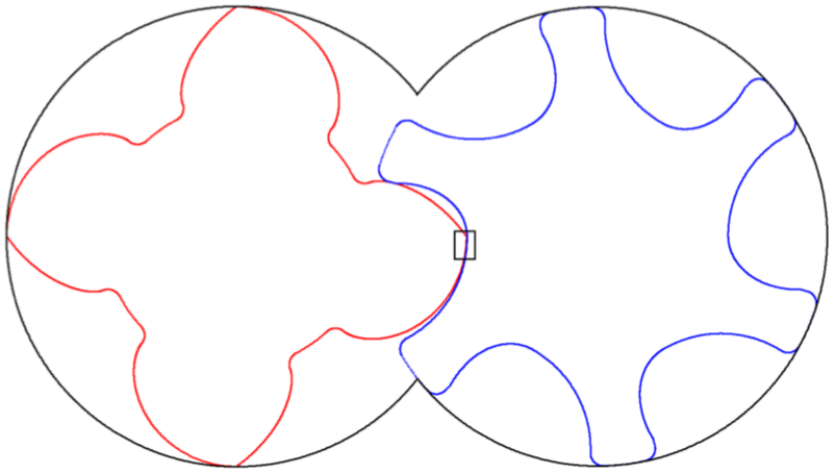
- Aerospace Engineering



- Energy generation

- Civil Engineering

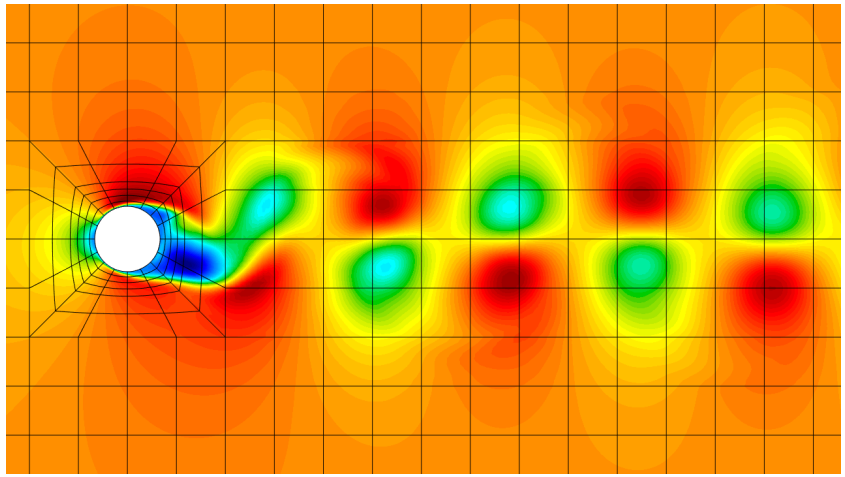
IsoGeometric Analysis



- Different representations used for design and analysis
- Expensive conversion from CAD to CFD format
- IsoGeometric Analysis: CAD description used in numerical methods

Discontinuous Galerkin methods

- High accuracy solvers are needed
- Uses polynomials of degree $p \geq 2$
- Allows very coarse meshes...
- ...if geometry description is accurate



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- Isogeometric DG[1]: employs a CAD-consistent representation
- Open-source implementation in the **Igloo** suite

[1] R. Duvigneau, *Isogeometric analysis for compressible flows using a Discontinuous Galerkin method*, Comput. Methods Appl. Mech. Engrg. 333 (2018), 443-461

Outline

ALE Methodology

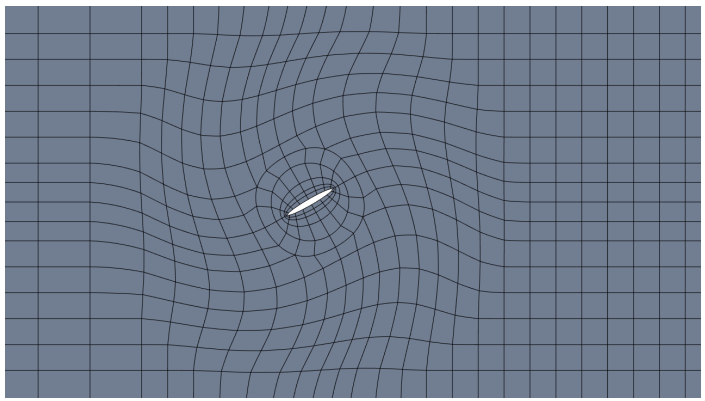
- Isogeometric DG, Eulerian:

$$\left(\int_{\widehat{\Omega}} R_k R_i \, |\mathrm{J}_{\Omega_j}| \, \mathrm{d}\widehat{\Omega} \right) \frac{\mathrm{d}\mathbf{w}_i}{\mathrm{d}t} = \int_{\widehat{\Omega}} \nabla R_k \cdot \mathbf{F} \, |\mathrm{J}_{\Omega_j}| \, \mathrm{d}\widehat{\Omega} - \oint_{\partial\widehat{\Omega}} R_k \, \mathbf{F}^* \, |\mathrm{J}_{\Gamma_j}| \, \mathrm{d}\widehat{\Gamma}$$

- Isogeometric DG, Arbitrary Lagrangian-Eulerian[2]:

$$\frac{\mathrm{d}}{\mathrm{d}t} \left(\mathbf{w}_i \int_{\widehat{\Omega}} R_k R_i \, |\mathrm{J}_{\Omega_j}| \, \mathrm{d}\widehat{\Omega} \right) = \int_{\widehat{\Omega}} \nabla R_k \cdot \left(\mathbf{F} - \mathbf{V}_g \mathbf{w}_h \right) |\mathrm{J}_{\Omega_j}| \, \mathrm{d}\widehat{\Omega} - \oint_{\partial\widehat{\Omega}} R_k \, \mathbf{F}^*_{ale} \, |\mathrm{J}_{\Gamma_j}| \, \mathrm{d}\widehat{\Gamma}$$

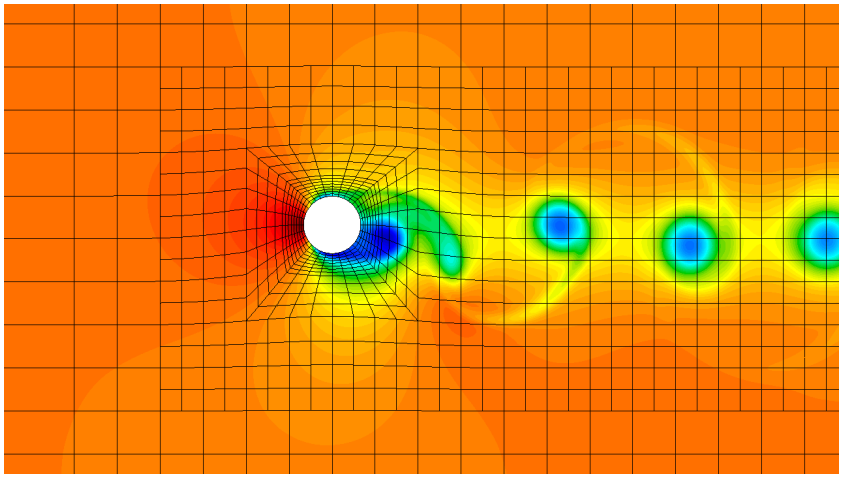
- Mesh movement algorithm
- Unified mathematical description

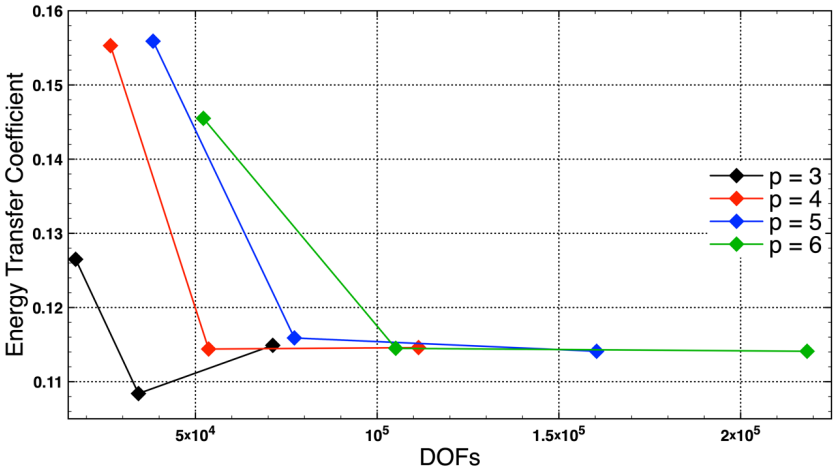


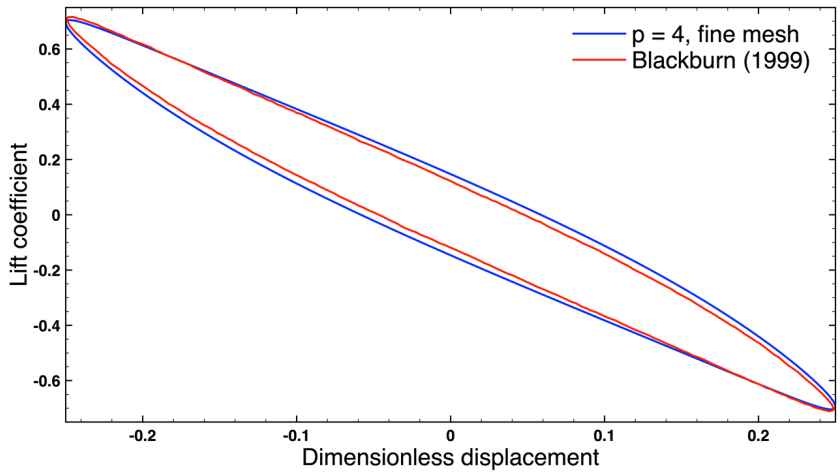
[2] Pezzano, Duvigneau, *A NURBS-based Discontinuous Galerkin method for conservation laws with high-order moving meshes*, under review, 2020

Oscillating Cylinder

- Simulation of Lock-in phenomenon
- Faster convergence with $p \geq 4$
- Good agreement with references

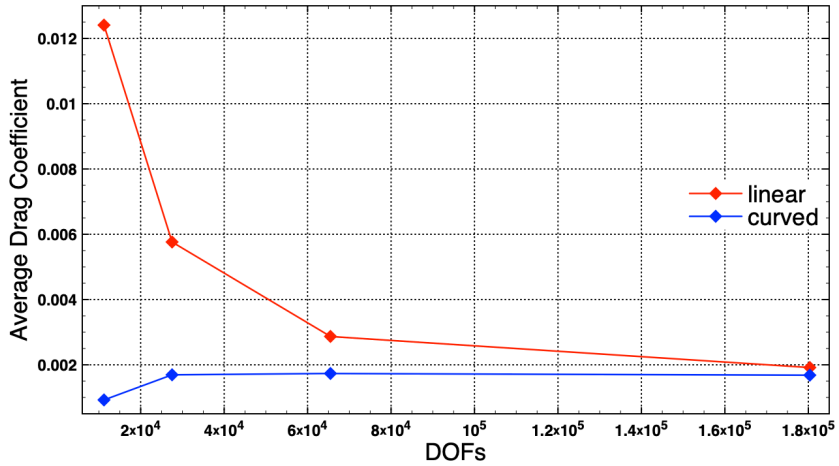


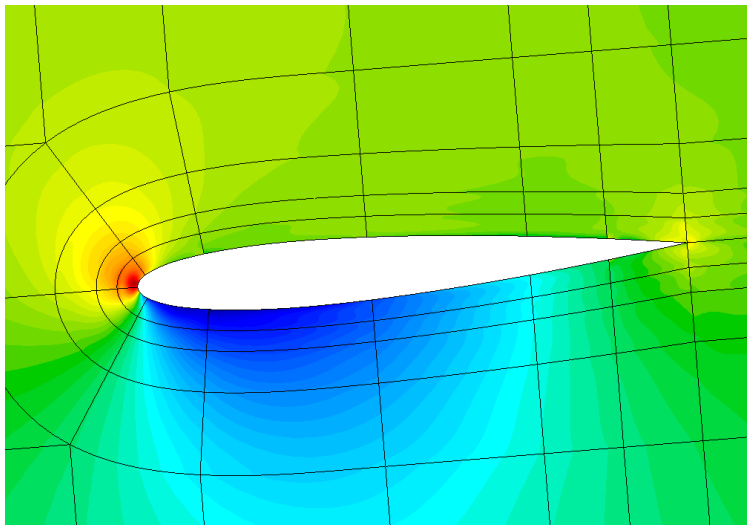


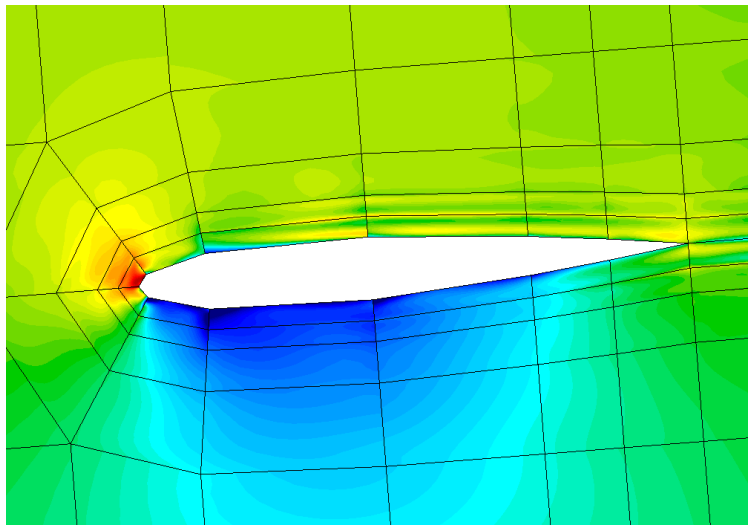


Influence of the geometry

- Oscillating airfoil flow
- Curvilinear vs rectilinear grid
- Non-physical effects with linear grid

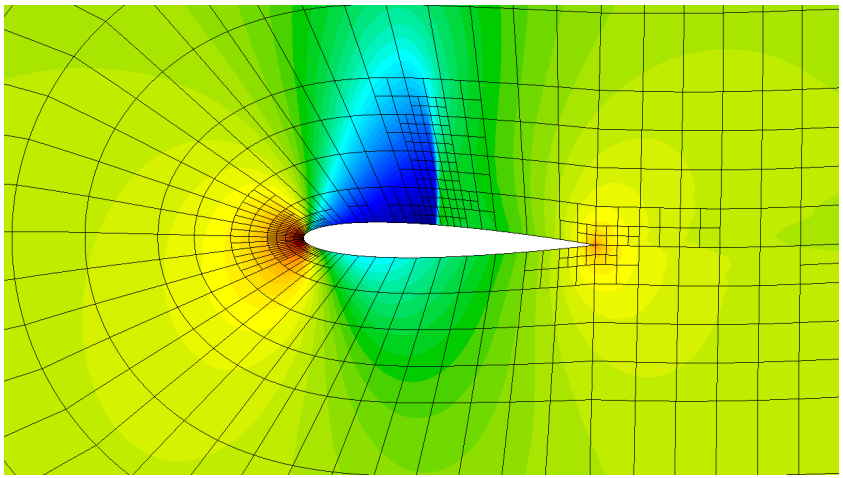


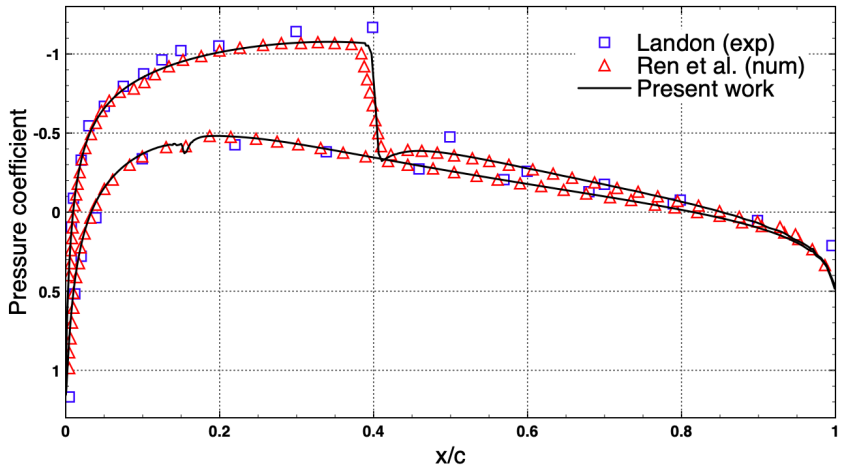




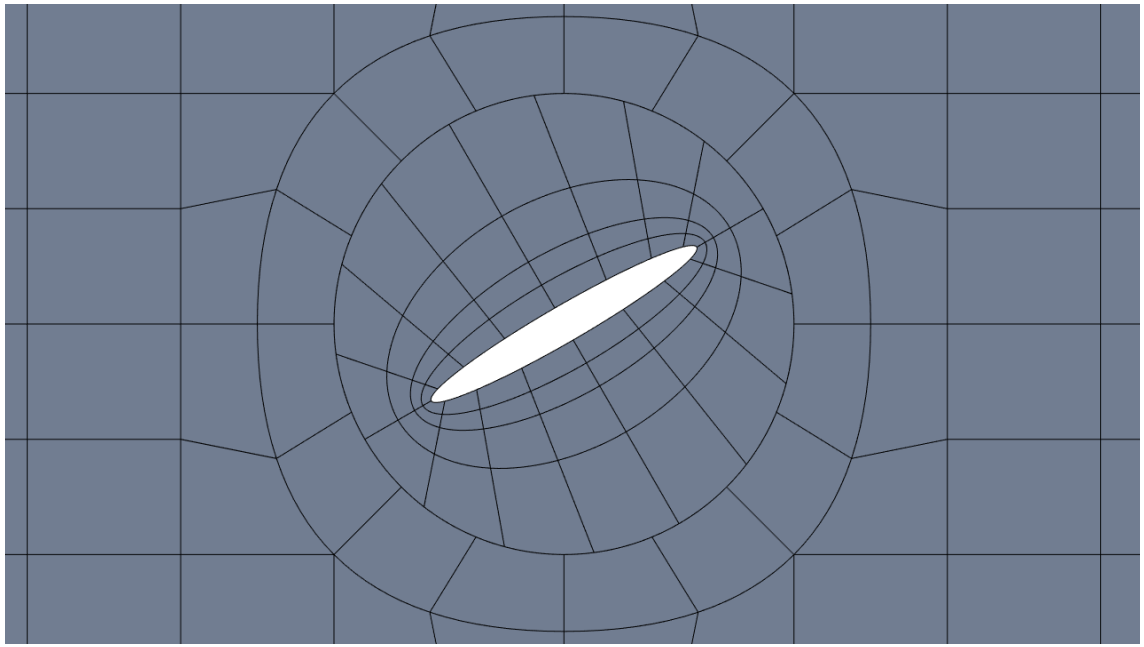
Adaptive Mesh Refinement

- Very coarse, but CAD-consistent, initial mesh
- Automatic refinement based on error indicator
- High mesh resolution only where needed
- Nearly user-independent simulation





Sliding Meshes



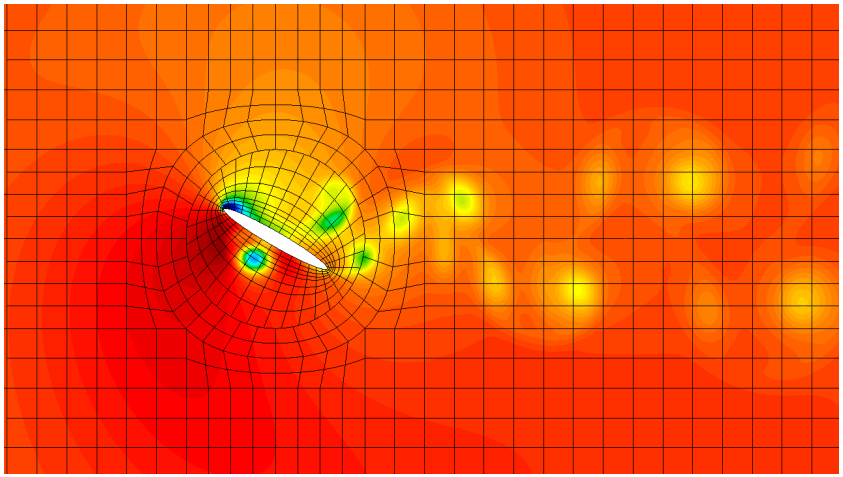
- Rotating machinery requires different mesh movement technique
- Geometrically exact sliding movement
- Fully conservative numerical scheme

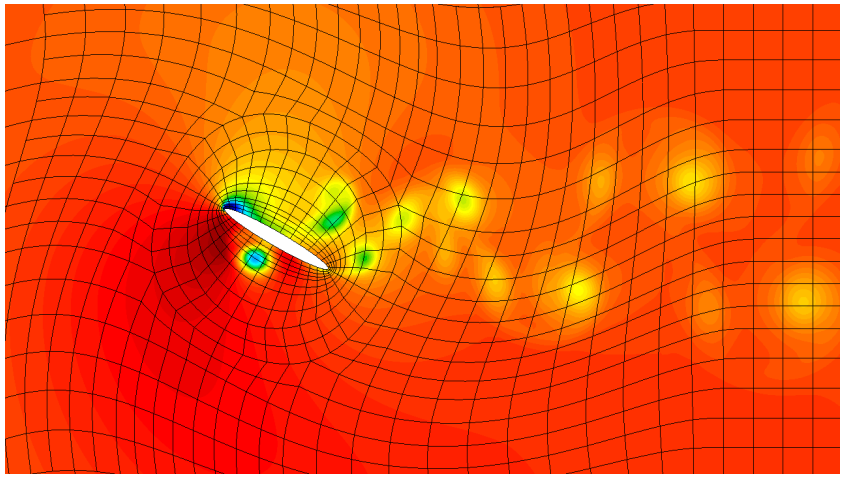
Oscillating Ellipse

- Complex flow configuration
- Comparison with classic ALE
- Same results with sliding and deformation

Table: Energy transfer coefficient

DOFs	Sliding	Deformation
13176	-0.7207	-0.7204
21654	-0.7070	-0.7059
45414	-0.7055	-0.7054

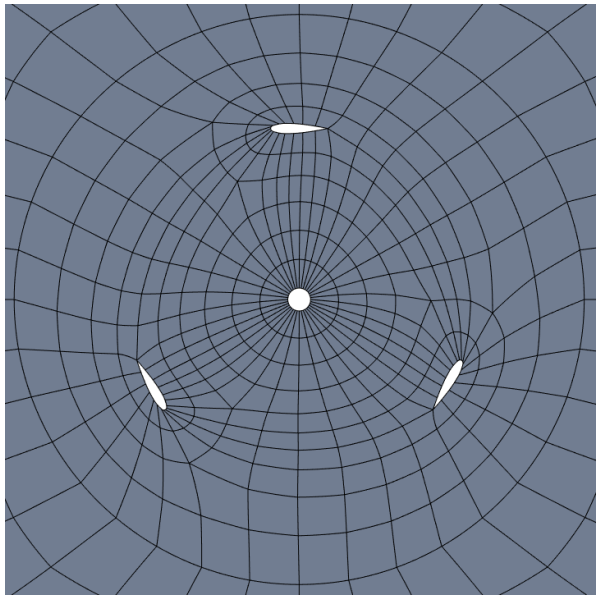


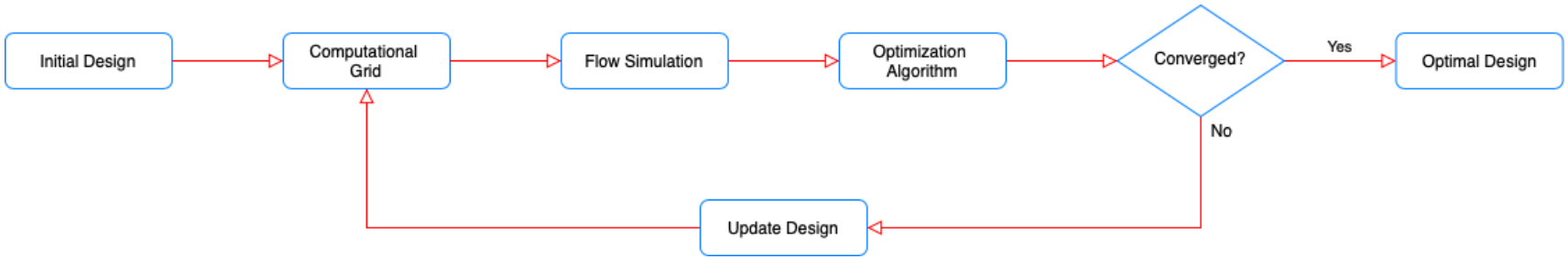


Outline

Application: Vertical Axis Wind Turbine

- Modelling and simulation of VAWT
- Coupling with shape optimization algorithm
- Fully integrated design chain prototype





Conclusion and perspectives

Current status:

- Successful development of a proof-of-concept solver, but...
- ...more powerful geometry manipulation tools are needed

Research perspective:

- Enhance integration with CAD platforms
- Extension to multi-physics problems

Industrial perspective:

- Tighter coupling between CFD and geometry is needed[3]
- Traditional CFD approaches are becoming obsolete

Efficient design methods represent the foundation of innovative products.

[3] NASA, *CFD Vision 2030 Study: A Path to Revolutionary Computational Aerosciences*

Thanks for your attention!

- e-mail: `stefano.pezzano@inria.fr`
- Personal page: `https://stefanopezzano.netlify.app`
- Gitlab repository: `https://gitlab.inria.fr/igloo/igloo`