Ref.: BE-IP-2022-005

INTERNSHIP PROPOSAL

Mesh adaptation for aerodynamic simulations based on high-order methods

Cenaero, located in Gosselies (Belgium), is a private non-profit applied research center providing companies involved in a technology innovation process with numerical simulation methods and tools to invent and design more competitive products. Internationally recognized, in particular through its research partnership with Safran, Cenaero is mainly active in the aerospace, process engineering, energy and building sectors.

Cenaero provides expertise and engineering services in multidisciplinary simulation, design, and optimization in the fields of mechanics (fluid, structure, thermal and acoustics), manufacturing of metallic and composite structures as well as in analysis of in-service behavior of complex systems and life prediction. It also provides software through its massively parallel multi-physics platform Argo, its manufacturing process simulation and crack propagation platform Morfeo and its design space exploration and optimization platform Minamo. Cenaero operates the Tier-1 Walloon high-performance computing infrastructure, with the new supercomputer Lucia ranked among the 250 most powerful machines in the world.

Context

High-order numerical methods present several advantages to simulate aerodynamic problems. In particular, Discontinuous Galerkin (DG) schemes, such as those developed at Cenaero, can handle complex geometries and provide a high-order accuracy on unstructured meshes with a low numerical dissipation, including near domain boundaries. In addition, the scheme is highly compact and allows for a very efficient and scalable implementation. Unfortunately, these methods are highly sensitive to under-resolved flow features. For instance, this can become critical for turbulent wakes in turbomachinery applications or for shocks in supersonic/hypersonic applications (see Figure 1). Generating an adequate mesh with refinement in regions of interest and coarsening in other parts of the domain is crucial for the accuracy, the robustness and the cost of the simulation. However, it can quickly become tedious and time-consuming for the end user.

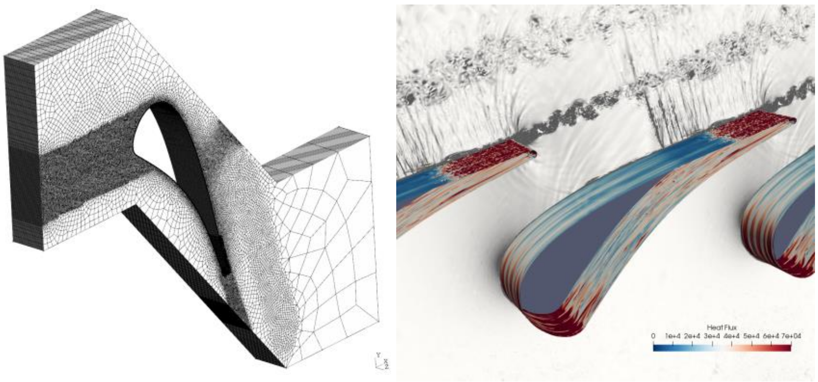

Figure 1: Typical large-eddy simulation of a turbomachine blade profile in a linear cascade configuration, highlighting various complex flow features. Left: Mesh. Right: Flow visualization (pseudo-Schlieren visualization in the x-y plane and heat flux on the blade).

In parallel with the development of numerical schemes, mesh adaptation methods have shown great progress in recent years. Specifically, metric-based adaptation makes it possible to automatically generate an anisotropic mesh that improves the balance between accuracy and computational cost, given a solution obtained on a sub-optimal mesh. Such meshes, in which both the element size and the element shape are optimized, work particularly well with Finite Element methods such as DG. They can even be combined with local adaptation of the polynomial interpolation order (h/p adaptivity). Cenaero has recently developed innovative methods to perform metric-based anisotropic mesh adaptation on high-order solutions of DG schemes and is willing to assess their potential for several applications of industrial interest.

Objective

The objective of this internship is to investigate the benefits of anisotropic mesh adaptation in the context of aerodynamic simulations based on high-order discontinuous Finite Element methods. The student will assess whether such mesh adaptation techniques can deliver a satisfying trade-off between accuracy and computational cost, while relieving the meshing burden on the end user.

Specifically, the student will rely on the discontinuous Galerkin solver Argo, developed at Cenaero, and on the mesh adaptation library MAdLib, co-developed at Cenaero and UCLouvain, to perform the following tasks:

- Selecting a few relevant test cases in two areas of interest, namely i) hypersonic laminar flows representative of atmospheric re-entry, and ii) turbulent flows in channel and cascade turbomachine blade configurations.
- Setting up the computational chain for adaptive simulations based on Argo and MAdLib.
- Performing computational studies to explore the impact of mesh adaptation parameters with two goals of increasing difficulty:
  - Capture in-domain flow features such as wakes and shocks by unstructured mesh adaptation, while maintaining a fixed, classical quasi-structured mesh in the boundary layer zone.
  - Capturing both in-domain flow features and the boundary layer by unstructured mesh adaptation.
- Comparing the performance of adaptive and non-adaptive simulations in terms of accuracy, computational cost and user interaction.
- If possible, investigate opportunities to further automatize the computational chain.

A scientific report and a presentation describing the research work is expected at the end of the internship.

Profile

Candidates should:

- Be a Master's student in Applied Mathematics, Computer Science, Physics, Aerospace/Mechanical Engineering, or a related discipline.
- Have academic experience in:
  - Fluid dynamics and aerodynamics.
  - Numerical methods for Computational Fluid Dynamics.
  - Programming/scripting for scientific computing.
- Have excellent analytical skills and a solution-oriented thinking capacity.
- Be comfortable in English with effective communication skills (both written and spoken).
- Be a team player yet have a proactive and autonomous attitude.

The following skills will be considered as valuable assets:

- Experience with the Linux operating system.
- Experience with C++
- Fluency in French.

Conditions

The internship will last from 4 to 6 months, depending on the academic program of the student.

Partial remote working (2 days/week) is the standard at Cenaero. In case of mobility, Cenaero can refund living expenses of the student up to approximately 500 EUR.

Contact

Interested candidates should send a cover letter and a resume to rh_be-ip-2022-005@cenaero.be.