Offer #2023-06914

PhD Position F/M High order boundary conforming adaptive meshing, and boundary conditions (AIRBUS/INRIA)

Contract type: Fixed-term contract
Level of qualifications required: Graduate degree or equivalent
Fonction: PhD Position
Level of experience: Recently graduated

Context

The proposed PhD program is a CIFRE program between Airbus and Inria. The student will be employed by Airbus and academically supervised by Inria researchers and Airbus engineers. They will spend half of their time at Inria (Bordeaux) and half at Airbus (Toulouse).

Safer and cheaper aircrafts require new concepts, and increasingly complex geometrical, physical, and numerical modeling. These new models must integrate multi-physical interactions between aerodynamics, propulsion, structures and materials. The systematic verification and validation of these models allows to integrate CFD in the certification process, reducing our reliance on costly experimental testing. It is with this goal in mind that AIRBUS, DLR, and ONERA have launched a new common CFD software project, called CODA.

This new CFD platform, designed for efficient parallel and heterogeneous architectures, permits the integration of advanced interoperable CFD components, including in particular Finite Volume (FV) as well as Finite Element (FE) methods, namely Discontinuous Galerkin (DG) schemes. For both FV and DG approaches, CODA provides an extension towards high-orders of accuracy in the form of the consideration of approximating polynomial degrees greater than 1 for DG and high-order k-exact formulations for FV. Both classes of schemes have demonstrated a strong potential for aerodynamic problems of applied interest. Contrary to low order FV schemes commonly used in the industry, DG and k-exact FV schemes provide high-order of accuracy on unstructured meshes, furthermore, high-order approximations offer a flexible framework in which the spatial resolution can be conveniently adapted, not only by local mesh modification (h-adaptive), but also by locally varying the degree p of the polynomial reconstruction. Local p-adaptation can reduce dissipation and dispersion errors in regions where the solution is smooth thus allowing for the accurate resolution of flow phenomena with a lower number of degrees of freedom (DOFs) as compared to standard FV methods. Regarding DG methods, thanks to their compactness, they can also easily handle complex geometries and irregular meshes with hanging nodes, which simplifies the implementation of h-adaptive techniques.

An important issue in aircraft design concerns the accuracy and efficiency of predictive numerical tools for cruise conditions. The potential of adaptive high order methods in providing error reduction, as well as automated error control and related CPU time savings in flow simulations is nowadays well established. There is however an essential element which must absolutely be taken into account to tap into this potential: the proper treatment of boundary conditions. This involves several independent aspects. The first is the availability of an appropriate high order geometrical representation of the boundaries. In this project this is somehow expected to be available from the design process under the form of appropriate CAD descriptions, with underlying spline approximation. A second necessary aspect is the ability to produce a discrete approximation of such geometry with accuracy compatible with the high order approximation used to discretize the flow equations. The last one is a numerical approximation of the boundary condition itself. This approximation must be equally compatible with the error levels of the discretization scheme.

The availability of a high quality curved mesh is a necessity to obtain the desired accuracy, and is still one of the bottlenecks to allow the adoption of higher order techniques as operational tools in an industrial environment. For realistic applications involving complex curved 3D geometries (e.g. ONERA M6 wing, of full wing-bod models as the CRM or XRFL), especially in the transonic regime, the impact the geometrical accuracy on the correct prediction of shock structures and boundary layer separation may be enormous. A lot of progress has been made in recent years on different techniques allowing to obtain with an acceptable level of automation good quality curved meshes. These techniques involve either curving straight faced meshes, or the use of some optimization or variational approach. An important aspect is the ability of combining the above techniques with metric based mesh adaptation techniques built from error indicators extracted directly from the flow solver. Concerning the approximation of the boundary condition itself, when dealing with finite elements, the most classical approach is to work with an iso-parametric approximation in which the geometry as well as the flow solution are approximated by some
Initial work on metric based hp adaptation techniques within CODA for DG discretizations on unstructured meshes has been successfully applied to a range of flow configurations and models, including 2D and 3D detached turbulent and laminar flows using Navier-Stokes, RANS and ZDES model equations.

**Assignment**

The objective of this PhD is to develop adaptive techniques compatible with high order boundary approximations. The aim is to be able to efficiently reduce the error associated to the approximation of the boundary conditions, via some reliable technique to obtain curvilinear meshes, and with some efficient numerical integration of the boundary conditions, while still being able to exploit metric based h-adaptive methods. The primary objective is the improvement of simulations of flows around curved shapes, allowing to obtain optimal accuracy, while minimizing the associated computational cost. To do this, this project will pursue the following scientific objectives:

- Develop a robust method to generate high order (at least quadratic) surface meshes as well as high quality volume meshes conformal with the curved surface mesh
- Propose some metric based h-adaptation method compatible with the above curved mesh generation processes
- Assess and extend existing boundary integration methodologies in CODA. We will evaluate hybrid approaches in which correction terms to a Pk solution are included to account for geometrical errors on a Pm mesh. The objective is to seek the combination of degrees k and m providing the lowest error at a given cost
- Verification and validation of the above techniques on state of the art benchmarks, as e.g. those proposed within the International Workshops on High Order CFD Methods (HiOCFD), and on aircraft configurations with particular emphasis on the prediction of
  - supercritical wings with strong trailing edge aerodynamic loads, as those used in the PhD by G. Sporschill, plus some confidential Airbus configurations;
  - high-lift configurations both clean, and including complex ice accretion shapes.

The curved mesh technological bricks will be developed within the Flowsimulator environment of Airbus in order to be used in the h-adaptive process initiated during the PhD of F. Basile.

**Main activities**

- **[M1-M6]** CODA software development project immersion at AIRBUS. Learn and train on CODA software and its environment, namely development environment (IDE, debugger), pre/post-processing tools, mesh generation, AIRBUS HPC environment. Set-up and simulate simple to industrial relevant test cases. Become autonomous with regards to the CODA software development process by developing and integrating a RANS turbulent wall law.
- **[M1-M6]** Thorough literature review of PDE based and optimization based mesh curving technologies, prospection on their implementation in Flowsimulator, and selection of target methods to implement.
- **[M1-M12]** Evaluate existing boundary integration strategies for high-order DG in CODA on HiOCFD benchmarks, on various transonic configurations, and setup of targeted final aircraft configurations;
- **[M6-M18]** Implementation and comparison of selected mesh curving strategies in Flowsimulator. Verification on appropriately chosen benchmarks from HiOCFD, and validation on selected aircraft configurations;
- **[M12-M24]** Implementation of boundary integral corrections to account for mesh unresolved geometric features in CODA. Evaluation of the best compromise in terms of relative accuracy of mesh and boundary integration strategy;
- **[M18-M27]** Coupling of mesh curving method with metric based h-adaptation in Flowsimulator. Evaluation on appropriately chosen benchmarks from HiOCFD, and proof of concept on appropriately chosen benchmarks from HiOCFD, and validation on selected aircraft configurations;
- **[M18-M27]** The student will publish at least one A ranked scientific journal paper and present their work to at least one international scientific conference. The student will assemble and discuss all their research activities relative to mesh curving and boundary integral correction in their PhD manuscript.
- **[M28-M36]** The student will reintegrate the AIRBUS team to carry out the technological transfer of their thesis outputs and take benefit of AIRBUS expertise for the application of the developed high fidelity near curved wall flow description capabilities on industrial configurations.

The time of the student will be split between Airbus and INRIA as follows:

- **[M1-M6]** at Airbus in Toulouse (6 months).
- **[M7-M24]** at INRIA Bordeaux (18 months).
- **[M25-M36]** at Airbus in Toulouse (12 months)

**Additional activities:**

- [M7-M24] at INRIA Bordeaux (18 months).
- [M25-M36] at Airbus in Toulouse (12 months)
- Present the work to colleagues, scientific and industrial partners.
- Present the results of the project at national and international research conferences.
- Participate in the activities of the research team at Inria.

**Skills**

The candidate is expected to hold an M2 degree (Engineering degree, MRes, or equivalent) in applied mathematics or computational mechanics. The candidate should have experience with numerical methods for PDEs, and should have good programming skills in Python or C/C++. The candidate should also be familiar with the domain of computational fluid mechanics. Experience in meshing methods is appreciated but not required.

Good communication skills (both scientific communication and interpersonal communication) are required.

Proficiency in English is a must.

**General Information**

- **Theme/Domain**: Numerical schemes and simulations
  Scientific computing (BAP E)
- **Town/city**: Toulouse (Airbus) / Talence (Inria)
- **Inria Center**: Centre Inria de l’université de Bordeaux
- **Starting date**: 2024-03-01
- **Duration of contract**: 3 years
- **Deadline to apply**: 2024-02-12

**Contacts**

- **Inria Team**: CARDAMOM
- **PhD Supervisor**: Ricchiuto Mario / Mario.Ricchiuto@inria.fr

**About Inria**

Inria is the French national research institute dedicated to digital science and technology. It employs 2,600 people. Its 200 agile project teams, generally run jointly with academic partners, include more than 3,500 scientists and engineers working to meet the challenges of digital technology, often at the interface with other disciplines. The Institute also employs numerous talents in over forty different professions. 900 research support staff contribute to the preparation and development of scientific and entrepreneurial projects that have a worldwide impact.

**Warning**: you must enter your e-mail address in order to save your application to Inria. Applications must be submitted online on the Inria website. Processing of applications sent from other channels is not guaranteed.

**Instruction to apply**

**Defence Security**: This position is likely to be situated in a restricted area (ZRR), as defined in Decree No. 2011-1425 relating to the protection of national scientific and technical potential (PPST). Authorisation to enter an area is granted by the director of the unit, following a favourable Ministerial decision, as defined in the decree of 3 July 2012 relating to the PPST. An unfavourable Ministerial decision in respect of a position situated in a ZRR would result in the cancellation of the appointment.

**Recruitment Policy**: As part of its diversity policy, all Inria positions are accessible to people with disabilities.