A propos du centre ou de la direction fonctionnelle

Located at the heart of the main national research and higher education cluster, member of the Université Paris Saclay, a major actor in the French Investments for the Future Programme (Idex, LabEx, IRT, EquipeX) and partner of the main establishments present on the plateau, the centre is particularly active in three major areas: data and knowledge, security and reliability; modelling, simulation and optimisation (with priority given to energy).

The 450 researchers and engineers from Inria and its partners who work in the research centre’s 32 teams, the 60 research support staff members, the high-level equipment at their disposal (image walls, high-performance computing clusters, sensor networks), and the privileged relationships with prestigious industrial partners, all make Inria Saclay Île-de-France a key research centre in the local landscape and one that is oriented towards Europe and the world.

Contexte et atouts du poste

Numerical simulation has been booming over the last thirty years, thanks to increasingly powerful numerical methods, computer-aided design (CAD), the mesh generation for complex 3D geometries, and the coming of supercomputers (NCP). The discipline is now mature and has become an integral part of design in science and engineering applications. This new status has led scientists and engineers to consider numerical simulation of problems with ever increasing geometrical and physical complexities. A simple observation of this chart CAD --> Mesh --> Solver --> Visualization / Analysis shows no mesh = no simulation |along with “bad” mesh = wrong simulation. We have concluded that the mesh is at the core of the classical computational pipeline and a key component to significant improvements. Therefore, the requirements on meshing methods are an ever increasing need, with increased difficulty, to produce high quality meshes to enable reliable solution output predictions in an automated manner.

Mesh adaptation is an innovative method for controlling errors in numerical simulations by generating meshes that are adapted to the geometry and physics of the problem being studied. It results in a powerful methodology that reduces significantly the size of the mesh required to reach the desired accuracy. Thus, it impacts favorably the simulation CPU time and memory requirement.

Moreover, as the generated adapted mesh is in agreement with the physics of the flow, for some applications, this is the only way to obtain an accurate prediction. In fact, mesh adaptation enables a full control of discretization errors on the geometric model and the solution. Thus, it is a first step in the certification of numerical solutions by the obtention of mesh converged solutions, i.e., providing high-fidelity numerical simulations.

Nowadays, mesh adaptation is a mature tool which is well-posed mathematically. And, as it is fully automatic, it has started to be used in industrial R&D departments (Safran Tech, Boeing NASA,...). Indeed, it has already proved, throughout many publications and applications, its superiority with respect to fixed mesh.

Mission confiée

The PhD student will first learn all the concepts related to mesh adaptation. He/she will perform several adaptive simulations of turbulent flows (RANS). The goal-oriented mesh adaptation consists in generating the best mesh to observe a given scalar output functional such as the lift or the drag in aerodynamics. Goal-oriented error estimates are based on the primal solution and also on the adjoint solution; thus it requires to solve the adjoint problem. However, we saw difficulties in converging the adjoint problem on very fine meshes (several million vertices in 2D and several dozens of million vertices in 3D). In the first part of the thesis, he/she will focus on developing improved algorithms to solve the adjoint problem.

First, he/she will study other Krylov subspace methods such as Biconjugate Gradient Stabilized method (BiCGStab) instead of the GMRES and other preconditioners such as ILU instead of the SGS. All developments will be compared to the reference method which is the GMRES-SGS method.

Second, he/she will develop a pseudo-transient approach to solve the adjoint problem. The main advantages of a pseudo-transient approach are the following:
- we can restart from the previous adjoint solution to make the process faster and more robust
- a mass matrix is added to the adjoint matrix making the linear system to solve less stiff.

The main difficulty being to develop a pseudo-transient method which is able to converge to machine zero.

Informations générales

- Thème/Domaine : Schémas et simulations numériques
  Calcul Scientifique (BAP E)
- Ville : Palaiseau
- Centre Inria : CRi Saclay - Île-de-France
- Date de prise de fonction souhaitée : 2022-09-01
- Durée de contrat : 3 ans
- Date limite pour postuler : 2022-09-30

Contacts

- Équipe Inria : GAMMA
- Directeur de thèse : Alauzet Frederic / Frederic.Alauzet@inria.fr

A propos d'Inria

Inria est l'institut national de recherche dédié aux sciences et technologies du numérique. Il emploie 2600 personnes. Ses 220 équipements projets agiles, en général communes avec des partenaires académiques, impliquent plus de 3500 scientifiques pour relever les défis du numérique, souvent à l'interface d'autres disciplines. L'institut fait appel à de nombreux talents dans plus d'une quarantaine de métiers différents. 900 personnels d'appui à la recherche et à l'innovation contribuent à faire émerger et grandir des projets scientifiques ou entrepreneuriaux qui impactent le monde. Inria travaille avec de nombreuses entreprises et a accompagné la création de plus de 180 start-up. L'institut s'efforce ainsi de répondre aux enjeux de la transformation numérique de la science, de la société et de l'économie.

Consignes pour postuler

Sécurité défense :
Ce poste est susceptible d'être affecté dans une zone à régime restrictif (ZRR), telle que définie dans le décret n°2011-1425 relatif à la protection du potentiel scientifique et technique de la nation (PPST). L'autorisation d'accès à une zone est délivrée par le chef d'établissement, après avis ministériel favorable, tel que défini dans l'arrêté du 03 juillet 2012, relatif à la PPST. Un avis ministériel défavorable pour un poste affecté dans une ZRR aurait pour conséquence l'annulation du recrutement.

Politique de recrutement :
Dans le cadre de sa politique diversité, tous les postes Inria sont accessibles aux personnes en situation de handicap.

Attention : Les candidatures doivent être déposées en ligne sur le site Inria. Le traitement des candidatures adressées par d'autres canaux n'est pas garanti.
Third, as we saw difficulties in converging the adjoint problem on very fine meshes but not on coarser meshes, it will be very interesting to look at multigrid method to solve the adjoint problem. Indeed, the multigrid approach uses several meshes with different refinement level to solve the problem.

The second part of this thesis will focus on extending the non-linear corrector to the RANS problem and developing the new norm-oriented error estimate.

The non-linear corrector is a non-linear error transport equation which provides an estimate of the error made at each degree of freedom of the mesh. From this non-linear corrector, it will develop a new error analysis to quantify the uncertainty on the numerical solution due to the discretization. The computation of the non-linear corrector is based on a local refinement of the mesh to estimate the local discretization error. This local refinement becomes complex in the boundary layer region for RANS problems as the curvature of the geometry may cross many layers of elements. To take into account properly the curvature of the geometry, we propose to consider a cavity operator to locally refine the mesh and compute the non-linear corrector.

Then, a new norm-oriented error analysis will be derived. The norm-oriented error analysis aims at generating an adapted mesh which minimizes a norm of the approximation error of the PDE solution. The approximation error is the difference between the exact PDE solution $u$ and the numerical solution $u_h$. The design of the norm-oriented optimal method will take into account the PDE features and will produce an approximate solution field which does converge to the true one. This will allow us to control simultaneously multiple functionals of interest as lift, drag, momentum, without the need to solve multiple adjoint states. The procedure is based on the derivation of a corrector term that is then used as a functional for adjoint-based mesh adaptation.

All the above developments will be applied to realistic aeronautics applications in collaboration with NASA/Boeing and to turbomachinery applications in collaboration with Safran Tech which are ongoing industrial collaborations.

With NASA/Boeing, we will mainly focus on high-lift prediction application from the 4th AIAA High-Lift Prediction Workshop. The scientific goal is to state if we will be able to predict the $CL_{max}$ using RANS model.

With Safran Tech, we will focus on complex stator and rotor geometries (involving the cooling system, the maze, …). Today, how to mesh such geometries to have correct prediction is still unknown. The expectation is that mesh adaptation will provide enough resolution to get accurate prediction.

In this work, the PhD student will be confronted to both theoretical issues (error estimate theory, numerical analysis, linear algebra) and scientific computing issues (numerical schemes, fast and efficient implementation of the numerical methods, parallel computing, ...).

Principales activités
The following schedule is proposed for the 3 years of thesis:

T0+6: Learn how to use the Gamma project software and environment by running RANS simulations using the Inria's mesh adaptive solution platform.

T0+12: Development of new methods to solve the adjoint problem.

Other Krylov-like methods will be analyzed and compared to the GMRES-SGS approach.

A specific focus will be done on pseudo-transient approach for the adjoint problem.

Analysis of the robustness of the new adjoint resolution methods on the AIAA High-Lift Prediction Workshop 4 geometry.

T0 + 18: Development and validation of a multigrid approach to solve the adjoint problem.

Analysis of the robustness of the new adjoint resolution methods on the AIAA High-Lift Prediction Workshop 4 geometry.

T0+30: Extending the non-linear corrector for RANS using the cavity operator in the boundary layer region to take into account the geometry curvature.

Development of the quantification of the uncertainties on the numerical solution for RANS.

Development and validation of anisotropic mesh adaptation platform based on the norm-oriented error estimate.

Comparison with previous studies.

T0+36: Writing the thesis manuscript.

Compétences
Le candidat doit avoir suivi une formation en mathématiques appliquées ou une formation d'ingénieur, il serait très appréciable que le candidat ait suivi des cours en :

- langage de programmation en C et python
- analyse numérique (Eléments finis, Volumes finis)
- calcul matriciel
- calcul parallèle (MPI, multithread)
- mécanique des fluides.

Ce serait un vrai plus si le candidat a pu travailler sur des méthodes de maillage durant son stage.
bon niveau d'anglais est requis pour ce travail.

Avantages

- Subsidized meals
- Partial reimbursement of public transport costs
- Leave: 7 weeks of annual leave + 10 extra days off due to RTT (statutory reduction in working hours) + possibility of exceptional leave (sick children, moving home, etc.)
- Possibility of teleworking (after 6 months of employment) and flexible organization of working hours
- Professional equipment available (videoconferencing, loan of computer equipment, etc.)
- Social, cultural and sports events and activities
- Access to vocational training
- Social security coverage

Rémunération

First year remuneration (gross salary): 1,982 euros/Month
Second year remuneration (gross salary): 2,085 euros/Month