JOB OFFER – Internship

# Time stability optimization of a high order Spectral Difference method for hyperbolic problems

## Offer information

**Reference** : AAM-2024-DAV-05 **location :** 42 Avenue Gaspard Coriolis – 31057 Toulouse
**Team :** AAM

**Supervisors :**


- Guillaume Daviller daviller@cerfacs.fr
- Nadir Messai, messai@cerfacs.fr


**Gratification :** 700€ per month- M2 level or last year Engineering school
**Duration :** 6 months – Starting from February 2025

**Keywords**: High-order numerical schemes, CFD, HPC, scientific computing

## CERFACS

Cerfacs is a private research, development, transfer, and training center focused on modeling, simulation, and high-performance computing. Cerfacs designs, develops, and offers innovative methods and software solutions that meet the needs of its partners in the fields of aerospace, space, climate, environment, and energy. Cerfacs trains students, researchers, and engineers in simulation and high-performance computing. Cerfacs works in close collaboration with its seven partners: Airbus, CNES, EDF, Météo France, ONERA, Safran, and TotalEnergies.

## AAM TEAM

The Advanced Aerodynamics and Multiphysics (AAM) team is dedicated to developing innovative numerical methods, physical modeling, and high-performance computing (HPC) techniques for new CFD solvers. In close collaboration with Cerfacs partners, the work focuses on fluid dynamics simulations for aircraft, rockets, and turbomachines.

## CONTEXT

The demand for numerical simulation of unsteady multiphysical phenomena is rapidly increasing in the aerospace and space industries. These simulations provide an economical alternative to testing and experimentation, leading to reduced development time. They also facilitate the design and optimization of aerospace systems (combustion chambers, aerodynamic structures, etc.). To be an effective tool, the underlying simulation methods must accurately represent the physical phenomena of interest in industrial configurations. In this context, CERFACS works closely with ONERA to develop innovative scientific computing methods within the JAGUAR software.

JAGUAR is a high-performance computing code that solves reactive Navier-Stokes equations in both laminar and turbulent regimes using Large Eddy Simulation (LES) modeling. The corresponding system of equations is discretized using a high-order Spectral Difference (SD) numerical scheme. This scheme serves as an alternative to discontinuous Galerkin methods, offering the same general properties (high order, hp refinement, native handling of non-conforming and unstructured meshes) while providing better performance in terms of temporal stability and computational cost.The work carried out during Adèle Veilleux's thesis [1] expanded the choice of elements to triangular and tetrahedral meshes. Meanwhile, T. Marchal's thesis work [2] enabled reactive simulations on hexahedral meshes. To make the method more robust for industrial use, recent efforts have stabilized the method in the presence of shocks [3] and extended it to accommodate all polynomial orders [4].This internship aims to continue these efforts to optimize the functionality of these numerical computing methods, enhancing their capacity to solve industrial problems.

[1] A. Veilleux, G. Puigt, H. Deniau and G. Daviller. S*table Spectral Difference Approach Using Raviart-Thomas Elements for 3D Computations on Tetrahedral Grids*. Journal of Scientific Computing, 91, 2022.

[2] T. Marchal, H. Deniau, J.-F. Boussuge, JF., B. Cuenot and R. Mercier. *Extension of the Spectral Difference Method to Premixed Laminar and Turbulent Combustion*. Flow Turbulence and Combustion, 111, 2023.

[3] N. Messai, G. Daviller and J.-F. Boussuge. Artificial viscosity-based shock capturing scheme for the Spectral Difference method on simplicial elements. Journal of Computational Physics, 2024.

[4] N. Messai and G. Daviller. *A corrected Raviart-Thomas Spectral Difference scheme stable for arbitrary order of accuracy on triangular and tetrahedral meshes.* To appear in Computer Methods in Applied Mechanics and Engineering. 2025.

## MISSION

The main objective of this internship is to evaluate the potential for optimizing the temporal stability of Spectral Difference (SD) schemes for triangular meshes. Indeed, the temporal stability of high-order schemes is currently limiting compared to classical finite volume methods, which hinders the application of SD methods in practical contexts. During this internship, we will explore ways to improve the stability of the scheme. Recent work has shown that the numerical flux of the SD scheme can be modulated using control parameters. This modulation can be interpreted as implicit low-pass filtering of the flux, which reduces high frequencies and significantly improves the CFL number of the simulations.

However, the precise effect of filtering on the dissipation and dispersion properties of the numerical scheme has yet to be clarified. Therefore, the first part of the internship will be dedicated to characterizing the filtering effects on the properties of the scheme within the framework of a linear transport problem. This work will be carried out using a Von Neumann analysis. Subsequently, an optimization effort will be undertaken to determine the optimal values for these parameters to maximize temporal stability without excessively degrading the accuracy and convergence order of the numerical scheme. A metaheuristic optimization procedure (such as particle swarm optimization) is currently being considered.

Finally, filtering does not necessarily have to be constant across the entire simulation domain. In theory, each mesh cell could be assigned a specific and variable filter throughout the simulation duration. The final objective of this internship will be to devise and assess the possibilities of implementing adaptive filtering, for example by taking into account the local flow direction relative to the considered mesh element. The effectiveness and robustness of the method will be evaluated for solving the Navier-Stokes equations across a set of academic configurations.

## DESIRED PROFILE

• Currently in the final year of an engineering program or equivalent, specializing in applied mathematics, scientific computing, numerical analysis, high-performance computing, or CFD.
• A prior experience based on a project in unsteady computational fluid dynamics (CFD) is appreciated.
• In particular, skills in finite volume and/or finite element methods are advantageous.
• This internship is research-oriented; therefore, the candidate, preparing a Research Master's, will be required to present their work in both written and oral formats in English, according to the standards expected in an international research laboratory.

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## How to apply ?

To apply, please send your CV and cover letter to messai@cerfacs.fr. Applications are open until 31/12/2024.

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