Turbulent Flows Simulation in Aerospace Propulsion Systems through a Discontinuous Galerkin Solver: Shifted Boundary Method and Mixed Averaging Procedures

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Summary

This dissertation presents the development, enhancement, and validation of a high-order numerical solver for the accurate prediction of turbulent and transitional flows in aerospace propulsion systems. The solver is built on a Discontinuous Galerkin (DG) finite-element framework and extends a research code developed at the Aerospace Propulsion Group at the Department of Mechanical and Aerospace Engineering (DIMEAS), Politecnico di Torino. It attains high accuracy on unstructured meshes while remaining computationally efficient for both steady and unsteady problems posed on complex geometries.

The solver's performance is demonstrated on representative propulsion test cases. RANS computations with the Spalart–Allmaras model accurately capture secondary-flow structures in a low-pressure turbine (LPT) cascade, whereas ILES resolves the laminar–turbulent transition and separation phenomena around the T106C cascade. Numerical predictions exhibit excellent agreement with experimental measurements and reference simulations, confirming the reliability of the solver.

A principal contribution is the first coupling of the Shifted Boundary Method (SBM) with a DG discretisation. By weakly enforcing modified boundary conditions on surrogate surfaces—through local adjustments of the gradients of the conservative variables in the surface integral—the method removes the need for body-fitted meshes and the associated difficulties of mesh generation, element distortion near solid walls, boundary–layer overlap for high-order curvilinear elements, and the cut-cell quadrature issues that plague classical immersed-boundary approaches. The new SBM–DG formulation shows promising performance for compressible flows and is effective within Reynolds-Averaged Navier–Stokes (RANS) famework.

To address the statistical convergence issues that afflict the post-processing of coarse-grained turbulence, novel variance-based metrics are introduced. These metrics quantify the relative efficacy of mixed time–space averaging in configurations possessing at least two homogeneous directions, enabling improved turbulence statistics and a reduction of the computational cost of post-processing.