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Scale Resolving Aerodynamics Optimization Leveraging High Order Methods

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ABSTRACT

The demand for increasingly efficient and precise aerodynamic designs calls for optimization frameworks capable of resolving complex flows without compromising computational efficiency. High-order computational fluid dynamics (CFD) solvers, such as those employing the discontinuous high-order unstructured formulations, offer spectral accuracy and improved resolution of small-scale flow structures, making them indispensable in this domain. However, resolving small-scale can still be computationally intensive, especially when coupled with optimization algorithms, necessitating strategies to accelerate convergence without compromising accuracy.

This work focuses on the development and acceleration of a scale-resolving optimization framework specifically tailored for high-order methods. The framework integrates the flux reconstruction (FR) scheme with the orthoMADS variant of the mesh adaptive direct search (MADS) optimizer. The FR scheme is selected for its ability to achieve spectral accuracy on unstructured meshes and its exceptional parallel scalability on modern accelerator hardware, making it a natural choice for high-order simulations. Meanwhile, the orthoMADS algorithm employs orthogonal positive spanning sets of polling directions, providing a robust foundation for gradient-free optimization in high-dimensional design spaces. Additionally, an adaptive mesh refinement strategy enhances the selection of polling directions, improving overall search efficiency. To further improve performance, we introduce a gradient factor to refine the optimizer's search directions and a relaxation factor to expedite convergence. These enhancements aim to reduce computational overhead, allowing faster and more effective aerodynamic optimization.

Preliminary results demonstrate the efficacy of the proposed methods, showing that over-relaxation significantly improves convergence for benchmarks objective function, while integrating gradient-based polling directions provides an additional enhancement in convergence rates. These findings underscore the potential of our framework to improve the practicality of high-order solvers for large-scale optimization problems. The results presented will extend to chaotic problems and aerodynamic applications.