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Airfoil Optimization Using Far-Field Analysis of the Drag Force

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ABSTRACT

Far-field analysis for drag prediction and decomposition is here explored and applied to aerodynamic shape design problems. This kind of methods, based on formulae derived from the integral momentum equation, gives a *physical* decomposition for the aerodynamic force splitting it in viscous, lift-induced and wave contributions which have a main relevance for the aerodynamic designer. On the contrary, the straightforward computation of the aerodynamic force by stress integration on the body surface (*near-field* method) allows the decomposition of the aerodynamic force in two components: friction and pressure forces. In this work, a far-field method based on entropy variations has been implemented. A detailed description of the method is given in [Paparone and Tognaccini, 2003]. Moreover, this method showed the capability to improve the accuracy in the calculation of total drag from a given CFD solution by removing part of the so-called *spurious* drag implicitly or explicitly introduced by the artificial viscosity of the adopted numerical scheme. Hence, a reliable drag calculation even on very coarse grids is possible. Thus, the aim of the work is the illustration of how the far-field approach may allow substantial reductions of the computational effort which is still a significant concern. Furthermore, the possibility to decompose drag in viscous, wave and lift-induced contributions allows for a selection of the objective function among these three terms. This particular characteristic has already been considered in [Gariepy *et al*, 2015]. In particular, the approach is shown by optimizing the wave drag of a NACA 0012 (466dc) in transonic flow conditions ($M_\infty = 0.85$) at zero angle of attack. Two different set of optimization runs have been performed. The first one used the near-field formulation to evaluate the drag coefficient, while the second one relied upon the far-field method. The near-field method has been applied using three different grid levels, whereas the far-field only the coarsest one. The performance comparison of the optimum airfoils was made using the C_D calculated using the finest grid level.

Table 1: *Drag coefficient, $C_D \cdot 10^4$, using finest grid size*

Optimization using near-field approach	100
Optimization using far-field approach	77

In table 1, the performance of the optimum airfoils obtained by optimizing with the coarsest grid level has been compared. It shows that a higher drag reduction is achieved employing the far-field approach (83.5%) than in the optimization made using the near-field formulation at the same grid level (78.5%). Therefore, it can be concluded that the use of the far-field approach, since only the wave drag is minimized, allows the optimization algorithm to reach to a significantly better solution refinement than that obtainable with the near-field method. Part of this work will be presented at AIAA SciTech Forum 2019.

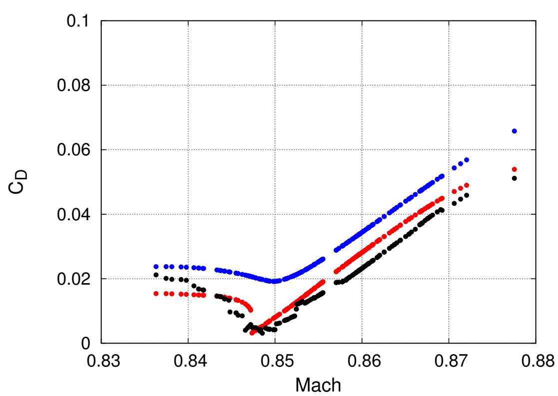

Figure 1: *Drag coefficient obtained using the near-field approach with a fine grid level (●), near-field approach with a coarse grid level (●), far-field approach with a coarse grid level (●) versus the Mach number, M_∞.*

The advantage showed by the far-field method, concerning CPU costs, in the deterministic optimization could be even more evident in robust design problems when the objective function and related constraints are statistical quantities (such as expected values, variances or risk measures [Quagliarella and Iuliano, 2017]). Therefore, a robust optimization problem of the optimum deterministic airfoil obtained with the far-field approach will be performed. The Mach number is considered as an uncertain parameter that may be uniformly located in the interval $[0.83, 0.88]$. Figure 1 illustrates the potential advantage of the far-field method with respect to the near-field one. It can be observed that the C_D obtained at the coarsest grid level using the far-field method gives a much better approximation of the value obtained with the near-field calculation at the finest level with respect to the one found using the near-field approach. Nevertheless, the far-field method still presents problems for a robust design loop as, in some cases, its predictions are not fully validated. This is due to the not yet complete reliability of the shock sensor mechanism that in some cases could lead to a not precise selection of the grid cells to consider in the far-field drag computation. Work is ongoing to improve its reliability and to allow its safe use in a robust design optimization loop.

References

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