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On Improving Efficiency and Accuracy of Variable-Fidelity Surrogate Modeling in Aero-data for Loads Context

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Variable-fidelity surrogate modeling offers an efficient way to generate aerodynamic data for aero-loads prediction based on a set of CFD methods with varying degree of fidelity and computational expense. In this paper, new algorithms, such as a Gradient-Enhanced Kriging method (direct GEK) and a generalized hybrid bridge function, have been developed to improve the efficiency and accuracy of the existing Variable-Fidelity Modeling (VFM) approach. These new algorithms and features are demonstrated and evaluated for analytical functions and used to construct a global surrogate model for the aerodynamic coefficients and drag polar of an RAE 2822 airfoil. It is preliminarily shown in this paper that they are very promising and can be used to significantly improve the efficiency and accuracy of VFM in the context of aero-loads prediction.

I. Introduction

From an aerodynamic point of view, an aircraft is defined by comprehensive datasets regarding performance, loads and handling characteristics. This data, which needs to be determined at a given timescale and cost for every possible flight condition and aircraft configuration, is used to design the structure of the aircraft and the flight control system. Currently, this data is obtained mainly from costly wind tunnel tests or using hand-book methods. The use of higher-fidelity and thus more accurate but also more time consuming CFD methods has been, up to now, impossible due to the large number of load cases that need to be evaluated to achieve aircraft certification. Only a subset of the required data can be computed with high-fidelity CFD at present. The "brute-force" approach of computing all relevant data with high-fidelity CFD is not feasible at present and methods for reducing the computational cost are sought after.

The long-term goal of the work described here is the development of an efficient process chain for the efficient numerical prediction of all certification-relevant aerodynamic data for the elastic aircraft over the full flight envelope, based on a hierarchy of CFD methods from low to high fidelity. The idea is to use Variable-Fidelity Modeling (VFM) to produce this data in a reduced time-frame with guaranteed accuracy and minimum computational effort.

The VFM method for aero-loads prediction uses a set of CFD methods with varying degrees of fidelity and computational expense (potential theory, Euler equations, and RANS equations) or a single physical model evaluated on meshes of varying refinement to approximate the unknown aerodynamic data as a function of input parameters such as Mach number, angle of attack, etc., while reducing the number of expensive high-fidelity computations. VFM as discussed in this paper has the same meaning as “multi-fidelity modeling”, “variable-complexity modeling”, “data fusion” or “data merging”.

A VFM framework for aero-loads prediction was developed by the authors as described in Ref. [1]. It was validated for analytic problems and preliminarily demonstrated and evaluated for the construction of global approximation models of the aerodynamic coefficients and drag polar of a 2D airfoil. It was demonstrated that the approximation method, the bridge function and the refinement strategy are the key elements for constructing a VFM model. Although the VFM method has been shown to be promising, more research has to be carried out to develop new methods and technologies that will further improve its efficiency and accuracy.

Aware of the importance of improving the available VFM algorithm in the context of aero-loads prediction, this paper focuses on the development of Gradient-Enhanced Kriging (GEK) and a generalized hybrid bridge function.

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