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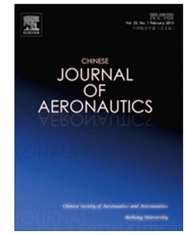

An efficient aerodynamic shape optimization of blended wing body UAV using multi-fidelity models

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Move limit strategy;
Unmanned aerial vehicle (UAV)

Abstract This paper presents a novel optimization technique for an efficient multi-fidelity model building approach to reduce computational costs for handling aerodynamic shape optimization based on high-fidelity simulation models. The wing aerodynamic shape optimization problem is solved by dividing optimization into three steps—modeling 3D (high-fidelity) and 2D (low-fidelity) models, building global meta-models from prominent instead of all variables, and determining robust optimizing shape associated with tuning local meta-models. The adaptive robust design optimization aims to modify the shape optimization process. The sufficient infilling strategy—known as adaptive uniform infilling strategy—determines search space dimensions based on the last optimization results or initial point. Following this, 3D model simulations are used to tune local meta-models. Finally, the global optimization gradient-based method—Adaptive Filter Sequential Quadratic Programing (AFSQP) is utilized to search the neighborhood for a probable optimum point. The effectiveness of the proposed method is investigated by applying it, along with conventional optimization approach-based meta-models, to a Blended Wing Body (BWB) Unmanned Aerial Vehicle (UAV). The drag coefficient is defined as the objective function, which is subjected to minimum lift coefficient bounds and stability constraints. The simulation results indicate improvement in meta-model accuracy and reduction in computational time of the method introduced in this paper.

1. Introduction

In recent years, in order to reduce fuel consumption and improve the performance, the optimization of UAV shapes has been the main focus of the competitive aerospace market. The development of Blended Wing Body (BWB) design is such an effort. In addition to the elimination of the tail for this particular kind of UAV and the significant reduction in equivalent weight, drag force, and radar cross-section, the available space for installing equipment inside the wing and the effective range

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have also been increased. Despite all these mentioned advantages, instability is the negative outcome of eliminating the tail. Correcting this flaw requires designing a combination of control surfaces and reflexed wing sections and using sophisticated computer control systems. Therefore, the aerodynamic shape design optimization of BWBs, along with the need to meet the design requirements, has inspired several researchers to overcome its challenges.

However, BWB and pure flying wing have some differences in definition; their optimization design approaches and some principles of aerodynamic design are practical for each other. The BWB design challenges along with necessity of developing aircraft efficiency impose more computational effort on the preliminary design process.

Various objectives and different constraints in the design of BWB make them a proper candidate for the application of multi-objective and multi-disciplinary design optimization techniques.[1,2] The characteristics of their shape makes their geometry parameterization easier. A study on improving the Concurrent Subspace Optimization (CSSO) structure on the basis of response surface and Monte Carlo analysis for the robust, single-objective optimization of the flying wing was conducted in this field.[3] Multidisciplinary Design Optimization (MDO) architecture of aerodynamic shape optimization was developed for battery-powered composite BWB with Delta wing.[4] The results of implementing this architecture and conventional optimization process were compared to demonstrate the presented formulation. Pan et al.[5] presented a systematic technique in aerodynamic and stealthy MDO issue for double-sweep flying wing. They utilized the hybrid structure of global optimization and gradient algorithm as an optimization strategy in conceptual design. Morris et al.[6] devoted attention to multi-disciplinary multi-level optimization for the simultaneous optimization of aerodynamic shape and structure.

The mere design of the aerodynamic shape was the main objective of optimization in certain studies, while only the airfoil cross-section was the focus in some others.[7,8] The definition of geometry and surface meshing was investigated by Truong et al.[9] to enhance the quality of the mesh modified during optimization. The robust design of airfoil shape optimization is investigated to reduce the sensitivity of small random geometry perturbations and uncertain operational conditions.[10] The construction of meta-models based on Kriging and gradient-enhanced Kriging is based on a relatively small number of CFD evaluations. Since the optimization of the fixed geometry aircraft demands satisfying conflicted constraints in various flight conditions, aerodynamic shape optimization of morphing wing is the subject of the study by Hunsaker et al.[11] This method increases allowable wingspan with induced drag reduction for a given structural weight.

In addition to putting forward an optimal Lifting-Fuselage Configuration (LFC) shape for BWB in the research by Reist and Zingg,[12] the aerodynamic shape was optimized for the best cruise altitude and reduced fuel consumption. In another study, the hybrid design of the aerodynamic shape and structure of the flying wing was optimized by combining the multi-bump method with automatic optimization and flow control to increase the lift-to-drag ratio and improve longitudinal static stability.[13] The presented approaches differ mainly in the definition of the geometry of the problem, objective functions, optimization constraints,[14] and finally, the accuracy of the adopted models.[15]

In complicated engineering design problems such as BWB, Surrogate-Assisted Optimization (SAO) methods have been developed to enhance the accuracy and reliability of optimization process.[16] In particular, due to the high computational cost of solving the CFD models, the researchers use the meta-model in aerodynamic optimizations.[14,17,18] However, constructing accurate meta-model would still be time-consuming and is often associated with insufficient accuracy in order to ensure a great degree of change in variables and the presence of local extrema for the objective and constraint functions.

The concept of sequential approximation method is introduced to overcome the mentioned limitations of the meta-models imposed by large-scale and complex design space.[19] The simulation outcomes show that building appropriate low-fidelity model reduces the computation costs and improves model accuracy. Using the response correction techniques for aerodynamic shape optimization introduced by Koziela et al.[7], the precision of the alternative models derived from low-accuracy models is improved. An automated selection of low-fidelity model for aerodynamic shape optimization is proposed in another study.[20] This approach utilizes low- and high-fidelity model misalignment.

In the variable-fidelity shape optimization, the hierarchical kriging technique is utilized for modifying low-fidelity kriging model.[21] Since the low-fidelity model is constructed based on a single design point, some weighted aerodynamic data correct the meta-model as high-fidelity data. Other studies consider the effects of boundary layer transition for optimizing the shape of a lifting body with adjustment of the meta-models.[22] The sample selection method for correcting the model plays a key role in such architectures.[23] Maximizing the Expected Improvement function (EI),[24] Probability of Improvement function (PI), and the Mean Squared Error (MSE)[25] and minimizing the Lower Confidence Bound (LCB)[26] are some examples of these methods—known as infilling strategies.

K-means algorithm classifies the solutions for selecting points and modifying the database of the meta-model, whereas genetic algorithm is tasked with optimization of the aerodynamic shape.[27] The application of the parallel processing capabilities to the optimization of aerodynamic problems is facilitated by combining these techniques in order to mitigate the defects of each.[23,28]

The other method for reclaiming local adaptive meta-model building is the move-limit strategy. The main merit key of these approaches is the suppression off design space in the current optimum point neighborhood and refining of the model in this space. The vital importance of selecting the move limit strategy is controlling optimization performance. These strategies—both fixed[29] and adaptive[30]—differ from one another by different bound-adjustment methods.[31] Among them, the global convergence can be achieved by utilizing the trust-region method.[32]

On the other hand, the selection of design variables in shape optimization has an important effect on the appropriate covering design space and reduction of computational cost. Poole et al.[33] proposed a novel method for the proper orthogonal decomposing set of training airfoils, which increase the num-