Multidisciplinary Unmanned Combat Air Vehicle system design using Multi-Fidelity Model

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ABSTRACT

This paper describes the Multidisciplinary Design Optimization (MDO) of Unmanned Combat Air Vehicle (UCAV) using Multi-Fidelity Model (MFM). Multidisciplinary feasible approach is implemented to decompose a coupling variable in a mission and a weight analysis module effectively. The necessary low-fidelity codes, which are based on empirical equations, are developed and validated for aircraft conceptual design. Meanwhile, the strategy of MFM, which constructs accurate and reliable meta-models by using the high-fidelity analysis, is implemented to improve the accuracy of the design method for UCAVs without any noticeable increase in design turnaround time. Minimization of multi-objective design optimization which consists of range and weight is performed and the design result shows the feasibility and effectiveness of the present multi-fidelity technique under MDO problem.

1. Introduction

Arecent trend in aircraft design is to focus on seeking adequate or optimum design solutions by compromising disciplines or design parameters. In fact, an aircraft system consists of highly-coupled subsystems or disciplines [36]. For example, the design of Unmanned Aerial Vehicles (UAVs) requires flexible and modular design environments [10]. However, the classical approach typically considered a single discipline and essential phenomena might not be captured and reflected in optimum results. Therefore, the concept of multidisciplinary design optimization (MDO) was developed during the 1980s. In addition, many MDO techniques and approximations have been gradually developed to support the solving of complex design problems [36]. MDO has been widely applied in aerospace, mechanical, automobile, and electric/electronic engineering since the 1990s [5,23].

In generally, aircraft design optimization is based on semi-empirical equations that have been well-established since the beginning of aircraft design. These methods, based on Jan Roskam [32], GASP [14], ACSYNT [13], and Raymer [31] methods, have been used extensively and efficiently to acquire rapid analysis results in MDO frameworks. However, these low-fidelity models are basically built on the conventional fixed wing aircraft regression data. Hence, the

design of unconventional aircraft, such as UAVs and Unmanned Combat Air Vehicles (UCAVs), can run into problems when the low-fidelity analyses are used.

More recently, to obtain more reliable aircraft design results, high-fidelity approaches such as Computational Fluid Dynamics (CFD) and the Finite Element Method (FEM) have been used in MDO frameworks. In addition, the rapid improvement of computer resources during recent years has helped to overcome the expensive computational cost of using the high-fidelity analyses. Nevertheless, obstacles are still encountered when applying them to large multidisciplinary design optimization problems. For example, Kazuhisa et al. [18] performed a coupled aero-structural wing shape design by using high-fidelity simulation tools such as a Reynolds-Averaged Navier–Stokes (RANS) solver for aerodynamics and NASTRAN for structures and aeroelasticity. They mentioned in their paper that the Euler/RANS solver may still be too expensive for the real-world design environment. Moreover, Variable Complexity Modeling (VCM) is an approach for linking low-fidelity and high-fidelity analyses, managing them by using a trust region (defined by Alexandrov et al.) to guarantee the convergence of a low-fidelity model to high-fidelity model [1–3]. The trust region provides adaptive management of the allowable move limits for the approximate design space [2]. VCM is an effective and feasible approach for matching low- and high-fidelity models for wing design optimization with a single aerodynamic discipline. The low- and high-fidelity analyses are Euler and Navier–Stockes equations, respectively [3]. In addition, the complexity of MDO problems

Nomenclature

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$\alpha_{CL=0}$	Angle of attack at zero lift coefficient	M	Mach number
$\alpha_{\max}$	Maximum angle of attack	SM	Static margin
AR	Aspect Ratio	T/W	Thrust weight ratio
$C_{l\alpha}$	Section lift coefficient	P_{avail}	Power available
C_L	Lift coefficient	SFC	Fuel Specified Consumption
C_D	Drag coefficient	$\bar{X}_{cg}$	Aircraft longitudinal location of gravity
C_{Lmax}	Maximum lift coefficient	V_{avail}	Available speed
$C_{L\alpha}$	Lift curve slope	W/S	Wing loading
$C_{n\beta}$	Weathercock or static directional derivative	W_{empty}	Empty weight
$C_{Do,W}$	Wing parasite drag	W_{guess}	Guess weight
C_{Do}	Total drag	W_{fuel}	Fuel weight
R/C	Maximum rate of climb	W_{to}	Takeoff gross weight
M_{cr}	Critical Mach number	W_{dg}	Design weight
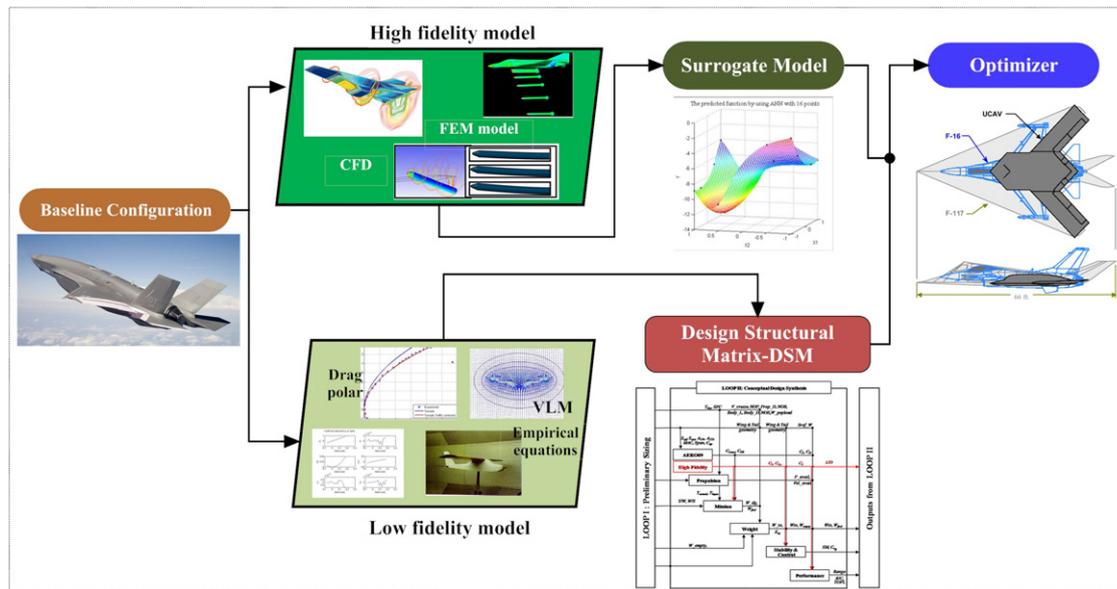
Fig. 1. Multi-Fidelity Model (MFM) concept.

typically increases as more disciplines are considered; hence, the computational cost becomes extremely high [36].

In the present study, a Multi-Fidelity Model (MFM), which constructs the meta-modeling by using both low-fidelity and high-fidelity analysis, is proposed in order to improve the accuracy of the design method for UCAVs with a reasonable increase in design turnaround time. Actually, many research works have been made using the MFM approach. Rajnarayan et al. performed an aerodynamic design using MFM [30]. Ghoreyshi et al. used MFM for generating aerodynamic models for a flight simulation [11]. However, the proposed approach implements the MFM in aerodynamic modules at cruise condition for UCAV design optimization with the low-fidelity analysis codes development and validation for UAV and UCAV. The response surfaces [38] are generated by using high-fidelity analysis data for cruise conditions. A UCAV preliminary design optimization result has been found using the MFM approach under MDO environment. The UCAV optimization configuration is compared with the low-fidelity analysis only.

2. Multi-Fidelity Model (MFM)

Multi-Fidelity Model (MFM) is a concept to implement the high-fidelity analyses into Design Structural Matrix (DSM) in order to increase reliability and accuracy on the design results under Multi-Disciplinary Optimization (MDO) environment. The detailed MFM process is shown in Fig. 1. The low-fidelity models, which implement the empirical relations, are developed for aircraft design and analysis. Several analysis modules such as geometry, aerodynamics, weight, propulsion, mission, stability & control, and performance are formed the Design Structural Matrix (DSM) as shown in Fig. 7. In this study, the high-fidelity model is performed on design variables separately to construct lift C_L and drag C_D coefficients at cruise analysis condition. Then, these coefficients are used to replace the C_L and C_D in aerodynamic module in the cruise condition for the UCAV design optimization.

In order to implement the MFM under the Multidisciplinary Design Optimization (MDO) environment, the low-fidelity codes development and validation are presented in the next section. The high-fidelity analysis is selected by using the commercial software which is shown in the next section as well.

3. Multi-fidelity analysis codes development

3.1. Low-fidelity analysis code development and validation

3.1.1. Aircraft Design Synthesis Program (ADSP) introduction

Aircraft Design Synthesis Program (ADSP) is the integrated design analysis tool for aircraft sizing and design at the conceptual