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Initial Investigation of Aerodynamic Shape Design Optimisation for the Aegis UAV

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Abstract

This paper presents an aerodynamic design optimisation methodology used in further developing an already existing Unmanned Aerial Vehicle (UAV) platform called Aegis. This paper aims to deliver a medium altitude long endurance UAV for civilian purposes. The methodology used is also applicable to conceptual and preliminary design phases of any aerial vehicle platform. It combines a low fidelity aerodynamic analysis tool, Athena Vortex Lattice Code, with a design optimisation tool (Nimrod/O). The meta-heuristic algorithm, Multi-Objective Tabu Search-2 (MOTS2), is used to perform the optimisation process. This new methodological study optimises the UAV wing planform for level flight. It was used successfully to obtain a set of optimal wing shapes for the Aegis UAV flying at different speeds. Prior to the formulation of the design problem, a parametric study was performed to explore the design space and provide an insight into how the objective functions behave with respect to the design variables. The methodology presented here is not finalized, it is a first step to constructing a general framework that can be used to optimise the design of a twin-boom UAV aerodynamic shape. The interfacing of the already successful packages Nimrod/O, MOTS2, and AVL software produces an initial result that shows the capability of the new methodology to provide correct support decisions making for a design optimisation process that will benefit the entire community of UAV researchers and designers when it is complete.

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Keywords: multi-objective optimisation, nimrod/O tool, Tabu search, UAV conceptual design, parallel coordinates;

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1. Introduction

The design of unmanned aerial vehicles (UAVs) has expanded substantially over the past two decades. Although the UAV was initially introduced for military applications, they have now become vital for many civilian uses. The variety of UAV applications requires different UAV configurations. Regardless of the specific UAV configuration, engineers are required to design UAVs that can successfully withstand a wide range of flight conditions, are suitable for long survey periods and have the advantage of low cost. This is made possible by using low fidelity code during the conceptual design phase, which can accelerate the design procedure and enable the design engineers to manipulate large numbers of parameters. Due to the fluid nature of the conceptual design process, it is not recommended to use high fidelity analysis design tools such as Computational Fluid Dynamics (CFD) and Finite Element Methods (FEM) at this stage as they can be costly (Jameson, 1999; Mason et al., 1998). What is required is a tool that strikes a better balance between sufficient accuracy and computational cost. This tool should contain considerable data concerning basic aircraft geometry to minimise the time required for the tens of thousands of necessary computations (Nicolai et al., 2010). At the end of the preliminary design phase, it is possible to utilise more costly and time-consuming software, since by then only one design case is being studied (Raymer, 2002). Ideally, an efficient design configuration of limited cost and less computation time would be achieved by coupling an aerodynamic design code with an optimisation algorithm (Chen et al., 2015; Leifur Leifsson, 2015).

On the other hand, even though the aircraft optimisation process is function of several disciplines; aerodynamics, structural engineering, control theory and aeroelasticity, the design process invariably starts with an aerodynamic shape to satisfy the aerodynamic constraints, and this is followed by satisfying the requirements of the other disciplines (Rajagopal and Ganguli, 2012). Typically, each discipline contains more than one objective, and these objectives commonly conflict with each other. The solution for such a problem is complex and requires a slightly different approach to a single objective optimisation problem. Computational time becomes a significant factor in this case with the final design a trade-off, and it is recommended that a Pareto front should be used to find the optimal decision (Chase et al., 2009; Jones, Mirrazavi, 2002; Tobergte and Curtis, 2013).

To address these needs, we combine the low fidelity flow solver Athena Vortex Lattice (AVL) with a design optimisation tool (Nimrod/O). Nimrod/O is one of the software packages that utilize resources on a global computational grid. It computes the values of objective functions and performs optimisation by parallel processing, so computational time is reduced (Kipouros et al., 2012; Riley et al., 2010). On the other hand, AVL is easy to use and capable of manipulating a large number of design parameters with short computational times and limited cost (Hadjiev and Panayotov, 2013).

The idea of aircraft optimisation design is not new, and much work has been done in this field at last few years. Hicks et al. (1974) optimised the design of an airfoil section by coupling a numerical optimisation method based on the method of feasible directions with an aerodynamic analysis code. This work is considered as the first practical application procedure for aerodynamic shape optimisation (Leifsson et al., 2014). The work of Hicks et al. (1974) has been extended to the design of three-dimensional wing geometry combining an aerodynamic code capable of fully simulating potential inviscid flow, with a conjugate gradient optimisation algorithm based on the methods of feasible direction. Since then, aerodynamic shape optimisation, using either gradient-based optimisers or evolutionary algorithms have been extensively explored. However, use of optimisation techniques for UAVs aerodynamic shape optimisation is much less well developed compared with the optimisation technique used for commercial aircraft design.

Recently, many researchers have started to show an interest in using evolutionary algorithms (EA) instead of gradient base algorithms (Cioppa, 1995). The drawbacks of conventional gradient base methods are the difficulty of getting gradient information on the objective function, and the optimiser usually tends to become trapped in local minima. In contrast, EA has the important ability to compute the global minimum (Jahangirian and Shahrokhi, 2011). Thus, several works have utilised EA to successfully optimise UAV lifting surfaces (González et al., 2005; Rajagopal et al., 2007; Shiau et al., 2010). The reason for investigating different optimisation techniques is to reduce the length of the design cycle, reduce computational cost, and improve the quality of the design (Vanderplaats and Springs, 2001). None of the publications quoted has made a full parametric sweep to explore the design space before the formulation of the optimisation problem. However, by performing a sweeping study, the designer can efficiently