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MOO Methods for Multidisciplinary Design Using Parallel Evolutionary Algorithms, Game Theory and Hierarchical Topology: Practical Application to the Design and Optimisation of UAV Systems (Part 3)

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1. SUMMARY

These lecture notes highlight some of the recent applications of multi-objective and multidisciplinary design optimisation in aeronautical design using the framework and methodology described in References 8, 23, 24 and in Part 1 and 2 of the notes. A summary of the methodology is described and the treatment of uncertainties in flight conditions parameters by the HAPEAs software and game strategies is introduced. Several test cases dealing with detailed design and computed with the software are presented and results discussed in section 4 of these notes.

Nomenclature

Δx_f =flap horizontal displacement
Δx_s =slat horizontal displacement
Δy_f =flap vertical displacement
Δy_s =slat vertical displacement
θ_f =flap rotation
θ_f =slat rotation
Cp = pressure coefficient
M_∞ = free stream Mach number
Re = Reynolds number
b = span length
c_r = wing chord
c_l = lift coefficient (2D)
c_d = drag coefficient (2D)
c_m = pitching moment coefficient

t/c = thickness-to-chord ratio
Λ_{LE} =leading edge sweep
AR = aspect ratio
$\Lambda_{R\text{-}B}$ = inboard sweep angle
$\Lambda_{B\text{-}T}$ = outboard sweep angle
$\lambda_{R\text{-}B}$ = inboard taper ratio
$\lambda_{B\text{-}T}$ = outboard taper ratio
$\Gamma_{R\text{-}B}$ = inboard dihedral angle
$\Gamma_{B\text{-}T}$ = outboard dihedral angle
$BP_{Inboard}$ = inboard break point
$BP_{Outboard}$ = outboard break point
α = angle of attack
L/D = lift to drag ratio

2. INTRODUCTION

Over recent years, Unmanned Air Vehicles or UAVs have become a powerful tool for reconnaissance and surveillance tasks. These vehicles are now available in a broad size and capability range and are intended to fly in regions where the presence of onboard human pilots is either too risky or unnecessary. The current technology developments, the availability of compact, lightweight, inexpensive motion detecting sensors and Differential Global Positioning Systems (DGPS) and compact lightweight low-cost computing power for autonomous flight control allow the development of fully autonomous operational systems. Nonetheless similar to the manned counterpart challenges in optimisation process and the integration of multiple disciplines whilst accounting for the trade-offs between the different objectives involved are still present, therefore robust and appropriate optimisation techniques are required. There are difficulties in these new concepts because of the compromising nature of the missions to be performed, like high-- or medium--altitude surveillance, combat environments (UCAV) and many others. Particular care must be taken in aerodynamic optimisation due to the often long endurance and high speed dash requirement; even a small improvement in drag can represent large weight savings over and entire mission.

The common approach in optimisation is the use of traditional gradient bases techniques. These techniques are effective when applied to specific problems and within a specified range and efficient in finding optimal global solutions if the objective and constraints are differentiable. The benefit of population based techniques such as EAs [3, 6, 11, and 14] is now being realized as some complex problems might require its use. EAs have been successfully applied to different aeronautical problems [7-9, 16-20]

As described in the previous notes on theoretical and numerical aspects of evolutionary computation, EAs are good for cases problems where the search space can be multi-modal, non-convex or discontinuous, with multiple local minima and noise, problems where we look for multiple solutions simultaneously, a Nash equilibrium point or a set of non-dominated solutions. The design and search space in UAVs design is complex and might fall in one or several of these categories.

In this direction we developed a framework for the design and optimisation of aeronautical systems and which is applicable to UAV systems design. This framework uses a multi-objective parallel evolutionary technique, and several modules for parallel computing, pre- and post-processing. It can be used for conceptual or detailed studies using combination of fidelity models in search for the optimal or non-dominated solutions. The method couples the Hierarchical Asynchronous Parallel Evolutionary Algorithms (HAPEA) with several aerodynamic analysis tools. The algorithm is based on Evolution Strategies and incorporates with the concepts of Covariance Matrix Adaptation (CMA) [10], a hierarchical topology [20], parallel evolutionary algorithms [2,21], asynchronous evaluation [22] and a Pareto tournament selection that is applicable to single or multi-objective problems [7-9,21-24]. The hierarchical topology can provide different models including precise, intermediate and approximate models. In the different layers of the topology each node can be handled by a different EAs code.

In this research we focus on the application of the framework for conceptual and detailed studies related to UAV system design (figure 1) which show the applicability of the method.