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COMPARING MULTIDISCIPLINARY OPTIMIZATON ARCHITECTURES WITH AN AIRCRAFT CASE STUDY

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ABSTRACT

This research describes a comparison study of different ways to formulate and solve a Multi-Disciplinary Optimization (MDO) problem. Two MDO architectures, multidisciplinary feasible (MDF) and interdisciplinary feasible (IDF), were tested on a simulation-based aircraft model. The aircraft's aerodynamic performance is modeled with computational fluid dynamics, and its structure is modeled with finite element analysis. The results show that the MDF architecture finds better solutions when it comes to optimality, but it requires more computing resources, time, and has higher variability than IDF.

1 INTRODUCTION

Multi-Disciplinary Optimization (MDO) is a set of methods used to manage optimization problems that involve analysis models from more than one disciplinary field. It takes into account the interactions among the disciplinary models when solving for one or more optimization objectives. Since different subsystems and disciplines will sometimes constrain one another, optimizing in a holistic way using MDO can be an effective, and sometimes necessary, way to achieve optimal solutions. There are many different ways to formulate a multi-disciplinary optimization problem, and these formulations affect the optimality of the solution as well as the computing resources required to find it. In this study, these different formulations are referred to as "architectures" (Martins and Lambe 2013). While differing architectures have been compared in previous studies, real-world problems are needed to support generalizable findings that provide guidance for architecture selection in a given optimization problem. This research compares two single-level MDO architectures, multidisciplinary feasible (MDF) and interdisciplinary feasible (IDF), with a fixed-wing aircraft model. The contribution of this study is to examine how these architectures perform for a simulation-based multidisciplinary problem. Previous studies have largely used analytic equations for their disciplinary models (Martins and Lambe 2013).

2 METHODOLOGY

The case study is a fixed-wing aircraft modeled with four disciplinary sub-models: geometry, aerodynamics, structures, and performance. The geometry is modeled using a parametric modeling tool, the aerodynamics and structures are modeled with simulations, and the performance is modeled with analytic equations. Range is used for the objective of all optimization routines. These architectures were created with the Phoenix Integration ModelCenter^{TM} MDO framework (https://www.phoenix-int.com/). The Phoenix proprietary Design Explorer algorithm is used, which is a surrogate-based algorithm based on kriging models, and it introduces stochasticity in the results during the creation of these surrogates. The MDF architecture is straightforward, with the workflow set up so that the disciplinary models run sequentially in the following order: geometry, aerodynamics, performance, structures. Since the inputs of each subsystem are dependent on the outputs of the preceding subsystem, this architecture will find a feasible point at the system level for every iteration; however, since the disciplinary models are always run sequentially, this architecture cannot take advantage of parallel computation. The IDF architecture allows disciplinary models to be run independently; in this case study, the structural model is independent of the other three. In order to ensure system-level feasibility, coupling constraints are introduced so that the aerodynamics outputs will match the structural inputs within a small tolerance. To reduce the number of coupling constraints, proper orthogonal decomposition (POD) is applied to parameterize the 14x1 aerodynamics output to a 2x1 vector (Alexander et al. 2011).

3 RESULTS

As the Design Explorer algorithm is stochastic, the optimization routine was run fifteen times for each architecture. The optimal results from MDF had an average range of 9514.6 miles and took an average 13.32 hours to converge, whereas the optimal results from IDF had an average range of 9122.2 miles and took an average 8.80 hours to converge. Moreover, the standard deviations in MDF were higher than IDF, with standard deviations of range being marginally so at 3.3 percent higher, and convergence time showing much more variation, at 190.6 percent higher. On average, MDF optimal solutions had approximately 4.3 percent higher range than the IDF solutions. Comparing only the best and worst solutions for each architecture, this trend held with the MDF best solution having a 5.3 percent higher range than IDF (10724.5 vs 10184.3 miles), and the worst solutions having a 5.7 percent difference (8908.4 vs 8426.1 miles). On the other hand, MDF results featured an average 51.4 percent higher total time to converge. Comparing the fastest and slowest from each architecture, the fastest MDF took 1.5 percent more time to converge than the fastest IDF (4.63 vs 4.56 hours), and the slowest MDF took 110.8 percent longer than the slowest IDF (29.44 vs 13.96 hours).

A Student's t-test found the range and time elapsed have confidence levels of 93 and 98 percent, respectively. This calls for further routines to better increase the confidence range to at least 95 percent. Overall, these results confirm that the MDF architecture can find a better result, though it requires more computational time than IDF. The optimality results match the results found by Hulme and Bloebaum (2000), and, if these results hold up over additional runs to improve the statistical confidence, then the findings would indicate that MDF architectures provide better solutions with higher computational expense than IDF architectures for real-world, simulation-based MDO problems.

4 CONCLUSIONS AND FUTURE WORK

This research compares MDF and IDF architectures with a fixed-wing aircraft MDO case study. The study extends previous work with a simulation-in-the-loop MDO problem. The results confirm that the MDF architecture is preferable for finding the optimal design, but it requires more computing resources and a more coordinated model integration effort to do so.

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