I. Research Program

The Design of a Simulation-based Framework for the Development of Solution Approaches in Multidisciplinary Design Optimization

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Background and Motivation:

A primary goal of Multidisciplinary Design Optimization (MDO) is to decompose a large multidisciplinary system into a related grouping of smaller, more tractable, coupled subsystems. Often, the resulting decomposition is not fully hierarchical in nature and thus requires iterative techniques to attain a converged system analysis and associated optimal design solution. The optimal design of such multidisciplinary systems as automobiles and aircraft might require hundreds or even thousands of iterative cycles to attain numerical convergence. As might be expected, this high level of iteration is both timely – the process might take months or years for a true multidisciplinary system – and computationally costly. Broadly speaking, the goal of the present research is to increase the efficiency associated with the design of large-scale, multidisciplinary engineering systems. To accomplish this task, the current work contributes four areas of unique research to the MDO community.

Progress and Results:

The first research area presents the design and continual development of the CASCADE simulation tool, which generates analytical representations of coupled multidisciplinary design problems corresponding to both the system analysis and the optimization portions of a large-scale multidisciplinary design. Due to the lack of availability of real-world multidisciplinary design data, there is a research need for a capability to simulate the coupling structure and behavior of a decomposed engineering system. CASCADE suits this research need - its simulations can be useful for testing a variety of new tools and technologies in MDO. Once the system representation is constructed and converged, CASCADE offers numerous post-convergence features. Each of these features is written to an output data or language file, and can be used by other simulation modules downstream. For example, an initial set of total system derivatives are computed and written to an output file. These derivatives could then be used for a formal system optimization procedure. All of the numerics concerning the final solution point, (namely, the converged values of the system variables, and the initial values of all optimization functions), are written to a data file. In addition, all representative equations (analysis behavior variable functions, objective function(s), and design constraint functions) are written to output files by way of character strings. The output files themselves are ANSI C header files, and can be compiled and linked with other codes such that meaningful MDO research can then be conducted.

The second area of research contribution involves the development of a new heuristic means for the convergence of a multidisciplinary analysis, called the Data Fusion Analysis Convergence (DFAC) algorithm. This algorithm utilizes a neural network scheme to model the input-output behavior of each subsystem output quantity. Thereafter, gradient-based optimization is used to correct the errors in each of the neurons, concurrently. As a means for coordination, a data fusion-based approach is then implemented to intelligently blend together discrepant information resulting from the error minimization process. Thereafter, a new estimate for each subsystem output is formed, and the process repeats until convergence. The DFAC algorithm aims to build upon the strengths of two well-known formal means for analysis convergence, Fixed-point Iteration (FPI) and Newton’s Method (NM). CASCADE has been used to generate simulations that allow for the comparison of these formal and heuristic means for analysis convergence. Through preliminary testing, DFAC has shown itself to be more efficient than FPI in all simulations thus far, and more reliable than NM, which tends to diverge in situations where little is known about the starting solution point.

The third area of contribution involves a large-scale comparison of three popular means for posing and solving the entire MDO design cycle - the Multiple-Discipline Feasible (MDF), All-At-Once (AAO), and Individual-Discipline Feasible (IDF) approaches. Each strategy varies in how it treats the system analysis and optimization portions of the MDO cycle. A large-scale comparison of these strategies had not before been possible, due to the deficiency of test problems in the MDO community. The existence of the CASCADE simulator erases this deficiency. Initial results have shown that MDF is the most reliable strategy for attaining the greatest design improvement, but at the largest associated cost, by far. AAO usually attains substantial design improvement at a much lower cost, and IDF typically attains a solution whose characteristics are intermediate to these two extremes. The disparity in performance between the solution strategies tends to increase with problem size and nonlinearity.

The fourth and final area of research contribution presents the development of a computational MDO framework, entitled FACETS (Framework for the Analysis of Coupled Engineering Techniques in Simulation). FACETS provides designers with an all-encompassing computational infrastructure, which contains a multitude of MDO tools and techniques intended for large-scale system reduction. In addition to the problem generation simulator (CASCADE), numerous feature modules have been incorporated into FACETS thus far. These include a module for comparing MDO solution strategies (MDF/IDF/AAO), a module for comparing analysis convergence methods (FPI/NM/DFAC), as well as secondary modules used for system planning, formal optimization, and result post-processing. Globally speaking, FACETS strives to encompass a multitude of research areas within the MDO community, and can provide an “all-in-one” infrastructure for preliminary investigation of MDO solution methods *in a simulation-based setting*. The primary benefit of FACETS is that it allows the user to quickly simulate the structure of a real-life coupled system, view its initial characteristics, perform some meaningful baseline calculations in simulation, and then view the initial results. Thereafter, the user can then make judgements and subsequent modifications based on these results, and can quickly and easily re-run a new simulation in hopes of attaining “better” results and more useful insight to the true multidisciplinary design problem at hand.