MULTIDISCIPLINARY DESIGN ARCHITECTURES AND COLLABORATIVE OPTIMIZATION

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1. Summary

These notes describe some recent ideas for distributed design and their application to large-scale aerospace systems. In this type of multidisciplinary optimization, design tasks are decomposed into domain-specific subproblems, and coordinated to achieve an optimal system. Focusing on collaborative optimization, one form of design decomposition, the notes detail the methods, summarize recent results, and suggest new variants of these approaches that improve performance.

2. Introduction

Initial applications of multidisciplinary optimization (MDO) involved the direct integration of multiple disciplinary analyses and an optimizer. For small problems, wiring together such a system is quite feasible and usually leads to a efficient, but sometimes hard to explain, procedure. As computational capabilities grew, engineers scaled this approach to larger problems and its limitations became apparent. The need for analysis and data management became better recognized and a second generation of MDO methods came into use. Distributed analysis systems could utilize multiple computers, increasing the practical scale of MDO problems (figure 1). Database management and modular analysis coordination improved efficiency and maintainability.

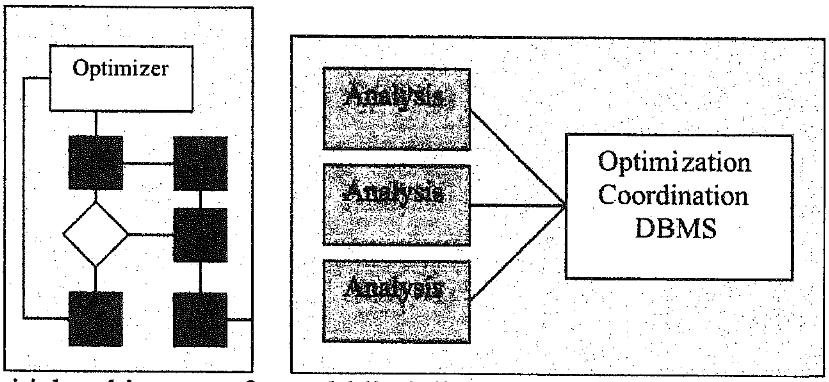

Figure 1. Initial architectures for multidisciplinary design involved integrated analysis and optimization. This was followed by application integration frameworks.

Despite these improvements, the reliance on a central optimizer as decision maker on all matters, is not a practical approach to enterprise-level system design. This deficiency has led to the development of what may be considered the third generation of MDO methods: strategies for distributed design optimization. This concept, illustrated in figure 2, involves decomposition of the design process itself into more manageable pieces.

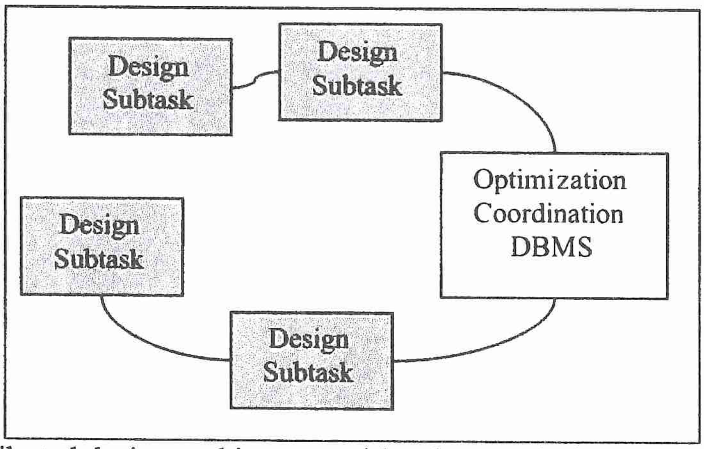

Figure 2. Distributed design architecture with subspace design problems and system-level coordination.

In fact, distributed design is the way any large-scale system is designed now. However, the approach to distributed design is often not well-planned. Sequential disciplinary designs and informal iteration can lead to designs that are sub-optimal. In many ad-hoc design procedures, individual design teams are assigned subsets of the design variables, parts of the analysis, and a local objective function that is only vaguely aligned with the overall goals of the system. Sequential choices by these design teams lead to a kind of non-cooperative game, which may reach an equilibrium that is not an optimum for the system.

Even when the goals of the subtasks appear aligned, problems may arise. Consider the problem of minimizing: $J = x^2 + y^2$ subject to the constraint: $g(x,y) = x - y - 2 > 0$. If the first group is responsible for the design variable y, and tries to minimize J for a given x, while the second group must vary x to minimize J subject to the constraint, $g>0$, the system will find the solution $y=0$, $x=2$. The correct solution $y=-1$, $x=1$ is not discovered because the decomposition introduces a feasible, but poor, equilibrium point.

An important current challenge for large scale MDO is the development of practical methods for distributed design optimization that are efficient and lead to good designs. The task of decomposing a problem whose components are strongly coupled is usually undertaken in an informal way, but may require more careful consideration.

The first step towards solution of a large-scale design problem involves decomposition of analyses that may be coupled in complex ways. Methods for decomposing and managing the analysis process formed the basis of much of the early work in MDO [1,2]. One method that has been very successful in multidisciplinary optimization with several analysis modules is termed optimizer-based decomposition (OBD). The concept is based on the analysis management structure shown in figure 3.