Multidisciplinary Optimization of Aeronautical Systems

Jaroslaw Sobieszczanski-Sobieski
NASA Langley Research Center, Hampton, Virginia 23665
and
Inderjit Chopra
University of Maryland, College Park, Maryland 20742

THIS special section (this issue and the Jan. 1991 issue) on *Multidisciplinary Optimization of Aeronautical Systems* comes nearly a decade after Holt Ashley surveyed the same subject in a now-classic Wright Brothers Lecture (published in this journal in Jan. 1982). It was a decade of vigorous development from which optimization emerged as a new methodology applicable at all levels and in each phase of the aircraft design process. The papers in this section are representative of the accomplishments and themes of that decade of progress.

Most of the papers were invited by editors and cover a wide range of topics including optimization methodology, sensitivity analysis, algorithms synthesis and efficiency, comprehensive codes, and applications to systems. The objective of this collection of papers is to highlight the potential of optimization as a powerful design tool to the aerospace community. The scope of optimization methodology is expanding rapidly to solve multidisciplinary system problems for both preliminary and detailed designs. In fact, many of the papers discuss application to full-scale practical problems.

At the philosophical level, the notion of "the push button design" that underpinned some early attempts at creating optimization programs of unlimited applicability gave way to a more mature view of the numerical optimization role in design. The view is founded in the recognition of the design as an activity which intrinsically blends the qualitative, judgmental, and creative side with the qualitative, precise, and algorithmic side. Without prejudging the future progress of "artificial intelligence," it is obvious for now that it is the algorithmic, numerical side that may benefit the most from the computer-based optimization methods. The perceived need is also the strongest for that category of methods because they liberate engineers from a tedium as contrasted with the creative side of design. Not surprisingly, then, most of the papers in this section concentrate primarily on the quantitative category of methods.

At the application level, the user demand that drives the optimization development has been intensifying because of the following:

1) Major new aircraft design projects have become fewer and farther apart in time, hence past experience becomes less useful as a guide in making the design decisions.

2) Advanced aircraft tend to be enormously complex systems of interconnecting parts and disciplines, and ultimate performance hinges on the myriad of numerical interplays, some of them very subtle and beyond the power of human judgment to evaluate precisely.

3) Young engineers who have grown up with computers enter the work force feeling very comfortable working with the machine that has been their friend since early adolescence.

4) Data processing capability of modern computers has increased enormously.

The challenge posed by the advanced aircraft as a complex system was taken up by the development of decomposition methods that break the large intractable problem into smaller subproblems while maintaining the couplings among the subproblems. In the design office, this approach maps well onto the natural organization of engineering into groups by disciplinary and task specializations. It preserves and nurtures the advantages of the division of labor, including the concurrence of operations—the time-honored principle of industrial management first articulated by Adam Smith in the classic work *The Wealth of Nations* nearly 250 years ago.

The decomposition approach stems also from the realization that the sensitivity analysis that generates data for optimization algorithms may easily account for more than 90% of the total computational cost. Hence, the recent emphasis on efficient sensitivity analysis applicable to complex systems appears justified. The notion of decomposition is represented in this issue both at the theoretical level and at the level of application to aircraft configuration optimization.

Various decomposition schemes and their applications presented in this volume have one common feature: each offers a particular pattern that unifies the analysis, sensitivity analysis, and optimization itself in a modular framework, whose overall logical structure is problem-independent even though its modules may be so dependent. An ancillary benefit from this is a clear description for each module of its function in the broad scheme of things and of the input and output on which it is expected to operate. This information amounts to the specifications that should aid in future developments of such modules.

The rapid increase in capability of the specialized optimization methods that might be regarded as modules in the above system perspective is evident in the collection—primarily in the papers of structural optimization, aeroelastic optimization, and synthesis of active control. It is apparent that recent progress has brought about a quantum improvement in comprehensiveness of the problems formulation and application robustness. The next logical step will be to bring these modular capabilities into the decomposition-based procedures for overall aircraft optimization.

Several papers in this collection concern the application of optimization methodology to helicopter systems. The helicopter is a truly multidisciplinary system, and its dynamics, aerodynamics, controls, and flight mechanics are highly coupled. Most of the governing phenomena are inherently nonlinear and very involved. It is therefore a challenging task to apply an optimization methodology in a helicopter system to reduce vibration and blade stresses and to improve performance and rotor stability. The dictates of passenger comfort, reduced operating cost, and capabilities to achieve expanding future missions necessitate the search for optimized designs. There are growing optimization activities, and many innovative ideas are emerging that will help build improved helicopters in the future.

One should note that the content of this special section reveals also some deficiencies that need to be corrected in the near future in order to make the above procedures complete. The underrepresentation of aerodynamic optimization and propulsion optimization in the collection points to such obvious deficiencies. Another apparent deficiency is that the tailorability of structural characteristics including couplings with composite material is not fully exploited at this time. With enhanced understanding of the behavior of composite structures including coupling and failure mechanisms, the potential of structural optimization is going to grow. The other important deficiency is in the dearth of methods capable of addressing the problems in which variables and functions are discontinuous. These deficiencies ought to be regarded as particularly fruitful for the near-future developments.

The papers in these issues do not discuss the data base and computer graphics side of the optimization procedures. This is an indirect acknowledgment of the existence of the strong and healthy computer-assisted design infrastructures provided by the software market in recent years that have begun to be taken for granted by most engineers. Another very important aspect of concurrent design operations is acknowledged in the merely tacit discussions of the decomposition schemes. Therefore, one should strongly emphasize that the decomposition methods are natural for the distributed network computing and for the multiprocessor computers toward which the computer technology is obviously heading. There is no doubt that with increasing awareness and efficiency of optimization methodology, enhanced understanding of governing phenomena, growing application of composites, and expanding capability of computers, optimization will emerge as the primary tool for design of aerospace systems.

The overall conclusion is that optimization as a tool in aircraft design is rapidly getting ready, in a synergistic symbiosis with the computer technology, to support the next grand challenges the aircraft industry is facing: the replacement of the aging subsonic transport fleet, the rebirth of the supersonic transport, the development of the aerospace plane, and the progress toward a future highly maneuverable helicopter. In each of these cutting-edge undertakings the optimization methods will be the tool the designers reach for when the face the question: *"How to decide what to change, and to what extent to change it, when everything influences everything else."*