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Special Issue: Multidisciplinary Design Optimization of Aerospace Systems

INTENSE activity in aerospace multidisciplinary design optimization (MDO) during the last decade has led to significant progress, as measured by knowledge gained, methods and tools developed, and impact on real products and design practices. This research and development activity spans academia, industry, and government research centers, and is documented by numerous publications in many conferences, symposia, and archival journals, both in the United States and abroad. This special MDO issue of the *Journal of Aircraft* is a follow-on to an earlier effort (December 1990 and January 1991 Issues), the result of a two-year effort initiated by the AIAA MDO Technical Committee. It was motivated by the need to provide a comprehensive overview of the field, and it is intended to serve as a milestone for the knowledgeable as well as a valuable starting point for those undertaking their first ventures in this area.

All papers in this special issue were invited. Some were written specifically for this issue. Others originated as conference papers or as regular journal papers and were then substantially modified for the issue. An emphasis was placed on providing good overviews and extensive bibliographies of developments in all areas covered. A number of the papers are, thus, review papers. If innovation and new contributions were the focus of any paper, the authors were encouraged to present them in a framework that establishes links to current and previous research.

Over the last decade, developments in MDO have become closely linked to developments in general design methodology and practices. Effects of MDO's growing power and influence can now be seen in a wide range of disciplines and applications. In addition to aerospace, such areas include civil, mechanical, automotive, naval, chemical, electromechanical and electronic packaging design, to name a few. It is now widely recognized that in all of these disciplines, MDO has the potential to dramatically improve the efficiency of design processes and the quality of products.

Undoubtedly, the major thrust of MDO research and development today, the toughest, most complex problems to tackle, and potentially, the biggest rewards to be reaped are still in the areas of aerospace systems. To present a comprehensive view of MDO, it is important to put together papers focused on various aerospace systems. This made it necessary to include in this *Journal of Aircraft* issue some papers for which this journal is not a natural home. Papers on spacecraft design, engine design, and structures/control interactions, for example, are usually published in other journals. The multidisciplinary nature of the aerospace MDO problem requires that ties between various disciplines and research areas be strengthened.

The original goal for this special issue was to assemble a collection of aerospace-related MDO papers covering all major areas of activity, including key developments and future directions. A considerable amount of time was spent in consultation with many experts in the field to chalk out potential topics and contributing authors. The original goal proved to be too ambitious. It was extremely difficult for many invited authors to find the time to write the kind of papers requested. The desire to have, in an archival journal issue, a balance of contributions from academia, research laboratories, and industry was also found to be a difficult goal to achieve. Despite a serious effort to invite and include papers reflecting industry needs, experiences, and views, this issue does not have sufficient coverage of the industrial perspective.

The first group of papers in this issue presents an overview of structural synthesis, and aspects of design-oriented airframe structural analysis, as well as sensitivity and approximations for structural and structural/thermal problems. MDO technology continues to be strongly influenced by the ideas and techniques of structural optimization. In fact, following the impressive success of structural optimization, MDO developments in aerospace engineering were, in many instances, extensions, generalizations, and applications of structural synthesis practices to additional disciplines, and to the amalgamation of these disciplines. The number of papers representing the structures discipline in this issue was limited, however, because of the relative maturity of this technology, and the availability of a number of textbooks and review articles in this area.

A major development over the past 10 years is the emergence of aerodynamic mathematical programming-based optimization techniques, for complete aerospace vehicle configurations utilizing computational fluid dynamics (CFD) analysis/sensitivity modeling. Thus, the second group of papers in this issue covers aspects of CFD-based vehicle optimization. Shape optimization with Euler and Navier–Stokes CFD simulations are discussed. Optimization with analytic shape sensitivities based on automatic differentiation is reviewed. Local and global approximations are presented with an emphasis on challenges posed by real configurations in a practical design setting.

Coverage of developments in structural and aerodynamic optimization leads naturally to aeroelastic and aeroservoelastic optimization issues. Aeroelasticity and aeroservoelasticity are at the heart of aerospace vehicle multidisciplinary analysis and optimization. They have historically established the framework in which aerodynamics, loads, structures, weights, controls, flight mechanics, and even propulsion could be integrated, and where multidisciplinary interactions and tradeoffs could be examined. With developments in aeroelastic and aeroservoelastic optimization, we are now closer to practical integrated design practices for actively controlled, structurally tailored, and aerodynamically shaped vehicles. Better integration of steady and unsteady CFD aerodynamics with realistic structural dynamics and flight mechanics modeling is currently leading to analytic/numerical multidisciplinary methods capable of capturing a host of nonlinear aeroelastic problems, which were intractable in the past.

The fourth group of papers covers applications of MDO to various aerospace systems. MDO applications to helicopters, engine structures, launch vehicles, spacecraft, miniature Uninhabited Aerial Vehicles (UAVs), hypersonic vehicles, and actively controlled precision space structures, are reviewed. The important integration of manufacturing considerations into the aerospace MDO framework is also discussed.

The last group of papers discusses optimization algorithms and general MDO methodology. Much has been written and considerable experience gained with gradient-based vehicle optimization. A general discussion of gradient-based local optimization algorithms is not included here. Global optimization and the application of global optimization algorithms are discussed, as well as aspects of the methodology aimed at addressing the large size and complex nature of the practical MDO problem in the aerospace engineering context. In this last group of papers, techniques for decomposing and managing complex design projects and large-scale multidisciplinary optimization problems are reviewed. Different aspects of global response surfaces approximations are described, as well as a design methodology to address uncertainties and modeling noise in design problem formulation.

A number of important areas are not covered in this issue. More in-depth discussion of mathematical programming-based control system optimization and how to integrate it with optimization in other disciplines is missing. A dedicated review paper focusing on MDO developments for airplane conceptual design would have been illuminating. More should have been said about combined vehicle and trajectory optimization. A discussion of modern MDO cannot be complete without review of computer implementation issues, such as database management for MDO, parallel computing, compatibility of information sent and received, and the transfer of large amounts of data. Most noticeably, there is very little view from industry. Despite a sustained effort during the last two years to obtain quality papers in these missing areas, such papers did not materialize. It is hoped that such papers will appear in the near future to complement the collection presented here.

A number of people deserve special thanks. Dr. Jean-Francois Barthelemy, from NASA Langley Research Center, was the chairman of the AIAA MDO Technical Committee at the time this venture was initiated, and was a strong supporter throughout this effort. Professor Inderjit Chopra, from the University of Maryland, was the *Journal of Aircraft* Associate Editor on whose shoulders fell practically all the responsibility for helping with editorial decisions and policies and bringing this journal issue to fruition. His help and many hours of effort were instrumental. A large number of experts from universities, government and industry, agreed to serve as reviewers and were willing to respond quickly to review requests despite their busy schedules. Their contribution is gratefully acknowledged, and all papers in this special issue were thoroughly reviewed. Finally, special thanks to all the authors who contributed to this issue, thus helping to create this state-of-the-art review of aerospace MDO.

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