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Industry Perspectives on Integrated System Optimization and MDO

PANEL: P. Cassidy[1] (Boeing), K. Alexander[2] (Rolls Royce), J.B. Staubach[3] (Pratt & Whitney), S. Zink[4] (LM), F. Villeneuve[5] (Siemens), W. Hurwitz[6] (Northrup Grumman)
Co-ordinators: S. Burton[7] (AMOPTI/AFRL), S. Nagendra[8] (P&W)

Abstract
This panel shall focus on MDO as applied to problems seen in Industry. Multidisciplinary design optimization (MDO) is a field of engineering that focuses on the use of numerical optimization for the design of Complex Engineered Systems (CES) that involve multidisciplinary physics, subsystems and components. Computational Structural Mechanics (CSM)/Computational Fluid Dynamics (CFD) continue to be instrumental MDO design and development tools for a vast array of engineering systems from military fighter aircrafts to power generation equipment and bio-engineering devices.

Keywords: MDO, Complex Engineered Systems, Methods, Preliminary Design

Panel Introduction

As computing power is expected to increase, usage of higher fidelity, fast CSM/CFD/MDO tools and processes will significantly improve structural and aero-thermal performance of airframe-propulsion systems, as well as greatly reduce, development cost. By solving the MDO problems early in the design process and taking advantage of advanced computational analysis tools, designers can simultaneously improve design and reduce time and cost incurred during every design cycle. It is the challenge of enabling this vision into reality for today's engineered products ranging from the classic Aircraft/Aircraft Engine Design to the design of tablets, ipads and noise cancelling earphones that drives new designs into the future. The main motivation for using MDO is that the performance of a CES is driven by design of its components and their disciplinary interactions.
Shape, flow physics, load paths and related physics phenomena drive design constraints and influence these interactions in an optimization problem. MDO requires a sound practical mathematical formulation with the end performance objective in mind. The CSM/CFD/MDO Paradigm has cultural and computational challenges that need to be addressed in the near future. Increased CSM/CFD/MDO fidelity for complete vehicle or engine configurations holds the promise of significantly reducing development costs, by enabling limited testing based validation and "certification by analysis".
One of the most important considerations when implementing CSM/CFD/MDO Paradigm is how to organize the discipline analysis models, approximation models (if any), and optimization software in concert with the problem formulation so that an optimal design is achieved. The CSM/CFD/MDO architecture defines both how the different models are coupled and how the overall optimization problem is solved. As the CSM/CFD/MDO developments in academia focus on developing algorithms and enhance the numerical optimization and modeling aspects of design, Industry has adopted the approaches recommended by academia and translated the same to methods for designing complex engineered systems.
Over the years the CSM/CFD/MDO Paradigm has enabled development of new approaches as well as new products that reflect many years of training and learning. This panel from Industry would represent the practitioners of the trade, who have had many years experience in enabling the transition from the disciplinary-silo driven approaches of the 1990's to a more multidisciplinary approaches of today. Panel discussions will focus on the experience, and difficulties endured during this transition. In particular, the panel discussion will focus on the following aircraft-propulsion topics:

[a] ***Methods and Modeling of Complex Engineered Systems:*** The algorithmic approaches to design developed based on academic idealizations of problem management, may be impractical to a degree in the real world of design. Several challenges both technical and cultural have been ingrained and it needs to be worked out in developing stages of design. The airframe-engine system has its typical internal and external flow challenges which include : Integrated propulsor /airframe flows, Unsteady flows due to turbomachinery blade row interactions, Secondary flows, including endwall and tip vortex structures, Time-accurate coupled component interactions, Rotational and curvature effects on flow turbulence for rotating turbomachinery, Transitional flows over a wide range of Reynolds number, pressure gradient, and free stream turbulence, Real gas thermodynamic models for high temperature flows with dissociation. Challenges remain in understanding and translating physics into computationally efficient, validated design tools.

[b] *System Integration Vs Sub-System Integration:* – Problem Formulation / Methods. Over the years, software development and computational approaches have dramatically improved tool suites. Several CSM/CFD/MDO problems have been addressed and have proven learning's that have enabled application, products and system design. There has been a better understanding of coupled analyses and system level requirements (CTQs). Current challenges include working stable physics legacy codes that can act as design tools require a lot of work to get compatible needs of the CSM/CFD/MDO or approach. There are several computational simulation problems and challenges that need to be addressed in order to significantly impact the future CSM/CFD/MDO design and development of air and space vehicles across flight regimes. Benchmark challenges remain in flow physics and design tool validation across the flow regimes Problems of critical interest to the Airframe – Propulsion community include: MDAO of low boom / low drag design / high efficiency, low distortion inlet design, Airframe/nacelle design and shock/viscous interactions, Slender wing vortex flows, Aero-propulsive-servo-elastic interactions for slender configurations (eg Blended wing), Engine/jet nose acoustics.

[c] *Optimization Strategies and Recommendations*: In order to effectively meet the design simulation challenges a number of specific technology requirements are anticipated. The requirements are broadly classified into three categories: solution accuracy, effective use of high performance computing (HPC), and technology robustness. Solution accuracy considers the components of the CSM/CFD/MDO technology that are needed to ensure numerical simulation of the appropriate physical models, numerical algorithms, and relevant flow physics to an acceptable level of accuracy for design validation. Challenges include the ability to predict lift/drag/moment/efficiency/performance/noise/emissions characteristics with certifiable accuracy on the same order as, or better than, experimental accuracy, over the complete flight envelope (across all Mach nos),

[d] *What is desired in MDO for the next generation?* CSM/CFD/MDO Paradigm requirements at the system level for fixed wing, rotary wing, and high-speed (supersonic and hypersonic) vehicles, along with the engine and propulsion system technology to enable flight, need to be considered from a system perspective. Improved validation and valuation approaches are needed to bring bear MDO principles at the system level.

Designers needs a highly streamlined, integrated CSM/CFD/MDO process using fully automated CAD incorporation, grid generation, and adaptive mesh refinement for entire vehicle and propulsion system. It should have minimal user intervention and an ability to accept probabilistic inputs and return probabilistic outputs across multi-platform computing environments. Contain self-correcting simulation execution for robust usage of CSM/CFD/MDO workflows and be seamlessly integrated into visualization and data mining techniques that make full, efficient use of results from time-resolved, physically complex flow field simulations. Effective Use of HPC that will provide required computational speed for CSM/CFD/MDO simulations for full aircraft–engine system in hours for full aircraft using higher fidelity turbulence closure schemes in days. Integrated airframe-engine simulations overnight, and for an entire engine component (compressor, combustor, turbine) using higher fidelity turbulence closure schemes in days.

[e] *Success stories, key takeaways and lessons learned:* Challenges include the ability to provide higher computational efficiency and accuracy per degree of freedom, principally through solution adaptation and higher-order numerical methods. Suggestions include that programming languages need to provide capabilities to designers to express such algorithms in a high-level way. The design tools would help designers understand system architecture and algorithm adaptivity appropriately. The next generation designer has to be adept in understanding the phenomena of CSM/CFD/MDO paradigm and also the cultural aspects that goes into solving the problems at the integrated system level situation.

Confidence in fast, accurate CSM/CFD/MDO allows engineers to reach out of their existing design space and accelerate technology maturation schedules. In addition, the expected increase in computing power will allow aerospace engineers to tackle probabilistic design paradigms, by enabling fast, automated execution of CSM/CFD/MDO workflows. However, to realize these gains, CSM/CFD/MDO technology, both in terms of flow-physics predictive capability and computational accuracy / speed, must be improved. Furthermore, the dramatic changes in high-performance computing environments will require reassessment of programming paradigms, design approaches and numerical algorithms. In addition to enable coupled airframe/propulsion simulation across collaborative partners, allowing designers in all communities to fully exploit the design trade space there is a need for a communication transformation that would enable to provide standardized and effective interfaces to other disciplines: structures (aeroelasticity), aero-thermal, controls (aero-servo-elasticity), MDO, etc.