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Optimizing
Aircraft Structures

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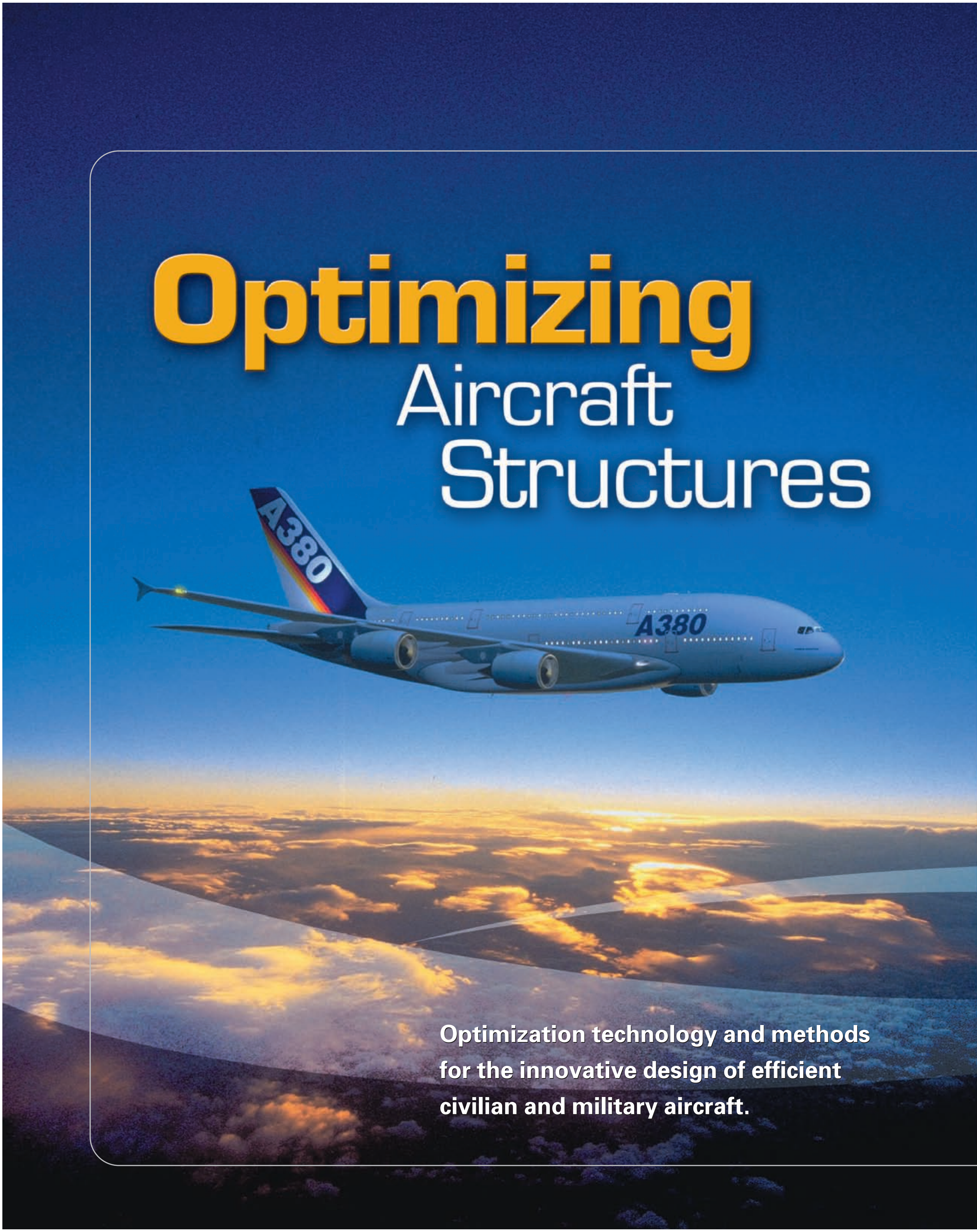

Optimization technology and methods for the innovative design of efficient civilian and military aircraft.

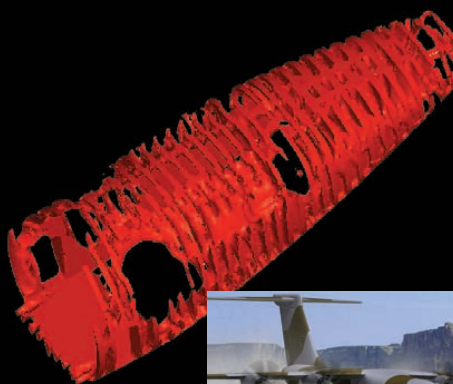

Fig. 1. Optimum material distribution for the A400M rear fuselage (Ref. AIAA-2004-4641: "Optimization Assisted Design of a New Military Transport Aircraft")

by **Dr. Gerd Schuhmacher**

Building aircraft is a complex balancing act. Manufacturers must design structures that are robust, yet lightweight. Planes must be capable of carrying increasingly heavy payloads, without sacrificing fuel efficiency. And above all, aircraft must be completely reliable under every circumstance.

During the design process, strength, buckling, durability, damage tolerance requirements, etc. must be adressed — under time restrictions. Therefore, the design process for new aircraft strongly builds on the experience generated during development, testing and in-service operation of previous aircraft. Traditionally, that is why manufacturers only change past design concepts very gradually when developing a new aircraft.

The increasing use of sophisticated simulation software, however, is changing the way manufacturers design aircraft. Computer-aided engineering (CAE) tools, such as topology and structural optimization software, now enable engineers to create innovative aircraft structures — resulting in lighter and more efficient components — in a shorter period of time.

EADS Military Aircraft — part of EADS, a global leader in aerospace, defense and related services — knows firsthand how CAE tools can impact the aircraft design process. The company has employed them to reduce the number of required design cycles in the conceptual design of civilian and military aircraft.

Taking Small Steps

A revolution in aircraft development is under way. Whereas new aircraft used to be designed exclusively by experienced engineers, today topology and structural optimization tools contribute significantly to this innovative work.

For example, EADS Military Aircraft engineers used "Free-Material" topology optimization methods to develop the conceptual design of the leading-edge ribs of the new Airbus A380 wing, part of the 555-seat A380 airplane due to enter commercial service in 2006. The design features next-generation engines as well as an advanced wing and undercarriage.

The innovative rib concepts provide the required load-carrying capacity at the lowest possible weight. The result — over 40% weight savings compared to the classical concepts — impressed Airbus and was subsequently incorporated into the new A380 megaliner.

Building on its success with the A380 rib development, EADS Military Aircraft engineers applied topology optimization not only to the rib components but also to a complete rear fuselage (Fig. 1) in an all-new military airlifter, the A400M. Its first flight will take place in 2008 with first deliveries beginning in 2009.

Rear Fuselage Refinements

The topology optimization method converts a structural design task into a mathematical optimiza-

Fig. 2. Section 19 of the A350-800

tion task. The starting point is a computational model that includes the design space and the loads to be carried.

As part of a business acquisition study, EADS Military Aircraft engineers used Altair OptiStruct to develop a new design concept for the A350 rear fuselage section 19 (Fig. 2). The A350 aircraft, designed for long-range operation, is expected to enter service in 2010.

The A350 rear fuselage section 19 is a highly loaded structure as the attached vertical and horizontal tail plane introduces significant loads into the fuselage. Both the internal structure and the outer skin of section 19 were included in the optimization process.

To start, the optimization team used the corresponding section of the A330 — the longest-range, twin-engine Airbus aircraft in service — as the basis to refine the A350 rear fuselage section 19. The team removed the existing internal structure (frames, brackets, etc.) from the initially available finite-element (FE) model of the A330 rear fuselage. This entire volume of the remaining internal structure was then considered as available design space and was filled with solid elements for topology optimization (Fig. 3).

The horizontal tail plane (Fig. 2) runs through section 19 and is reflected by the cutout in the design space (Fig. 3). Furthermore, a cutout is considered for the trim screw that moves the horizontal tail plane up or down for certain flight maneuvers.

Design variables were assigned to the material density of each solid element as well as to the various thicknesses of the outer skin. It was then a matter of determining the optimal distribution of the material within the available design space by minimizing the deformation energy (compliance, external work) for a given total mass.

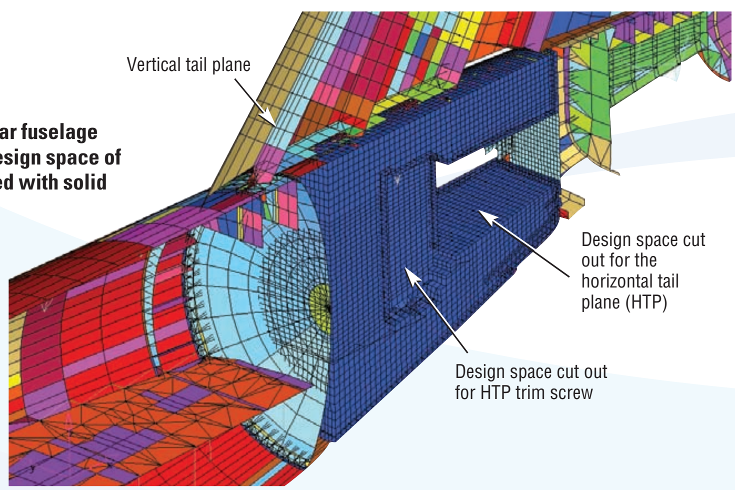

Fig. 3. A350 rear fuselage half-model: Design space of section 19 filled with solid elements

More than 130 load cases were considered during the optimization process. Altair OptiStruct determined an optimum material distribution for the Fig. 3 solid model concept. This first result was studied carefully, and refined optimization models were derived in follow-up steps.

The sequential refinement process was necessary as it is impractical to model a complete fuselage section with a fine mesh typically required for the topology optimization. The final material distribution for the internal structure and outer skin that was determined by this sequential optimization process is shown in Fig. 4.

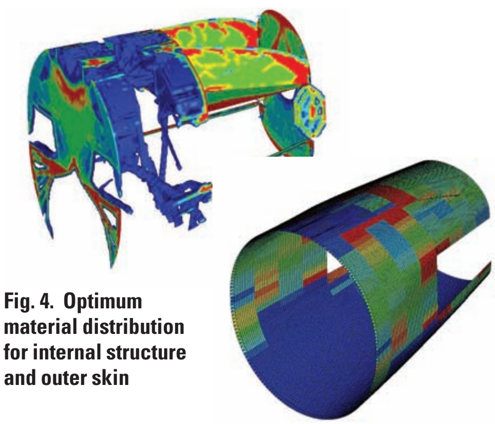

Fig. 4. Optimum material distribution for internal structure and outer skin

Material distribution was interpreted by experienced engineers from different departments and translated into a CAD design concept. Compared to the A330 design, this new A350 concept features additional shear walls and spatial struts, but fewer frames. The internal load paths, as well as the load-sharing between the structural parts, are significantly different to the A330 concept, resulting in a significant reduction of the internal loads.

In a further step, a new FE model was created on the basis of the CAD model of the new A350 design concept. This FE model served as the basis for subsequent sizing optimization.

The thicknesses of all individual elements were used as design variables, and the compliance was minimized for all design load cases as well as the mass constraint. Fig. 5 compares the stresses of the new A350 design concept, which includes a 10% weight reduction, to the stresses of the original A330.

Even with a 10% reduction in weight, the stress level, as well as the stress peaks, were significantly lower for the new A350 concept. The A350 de-

Setting New Standards

by ***Beverly A. Beckert***

EADS Military Aircraft engineers are hard at work finalizing their contribution to the A380 airliner that will go into service in 2006. Simultaneously, they are supporting the development of the newest members of the Airbus family, the A350-800 and A350-900, which will enter service in 2010.

The A380 is a 555-seat, double-deck passenger airliner designed for major long-haul routes. Its efficiency and advanced technology result in 15% to 20% lower seat-per-mile costs. Its flying range is 10% greater than that of other large aircraft.

Currently, the A380 is undergoing tests to meet aircraft certification by the European Aviation Safety Agency and the Federal Aviation Administration. Vibration tests, for example, examine the behavior of the aircraft's structure and aerodynamics when subjected to structural vibrations while flying at very high speeds.

Static tests demonstrate how the A380's structure behaves when subjected to both normal and exceptional loads. To date, the wings and fuselage have successfully been submitted to maximum loads. A yearlong certification test program will examine how the aircraft resists ultimate loads under a range of flight and rolling conditions.

Fatigue tests will simulate the effects of pressurization and depressurization to which the aircraft will be subjected during its lifespan.

Five developmental A380s will be used in the testing program. Data collected during these test flights will further refine the A380's aerodynamics and help to validate the computer models of aircraft handling and performance.

The newest members of the Airbus family — the A350-800 and the A350-900 — are also being designed for long-range flights. The A350-800 will carry 253 passengers and fly a distance of 10,106 miles; the A350-900 will accommodate 300 passengers and fly up to 8,618 miles. Innovative materials, refined aerodynamics and enhanced engines will contribute to their performance.

The new airliners feature a composite wing and a fuselage primarily made of aluminum lithium alloys and carbon fiber reinforced plastics that help to create a lightweight airframe. The A350's wing generates a weight savings of approximately 10,000 lbs and, through better aerodynamics, has been shown to be extremely efficient over a range of speeds, with reduced fuel burn. A reshaped rear fuselage and curved cockpit side windows also play a role in improving aircraft performance.

New engines use technologies developed for the A380 that boost low-speed performance, reduce engine thrust levels and ensure low take-off and landing noise levels. The engines will burn at least 15% less fuel than the current generation. What's more, Airbus and the engine manufacturers have developed noise reduction technologies that will allow A350s to reduce the impact of noise on communities near airports by up to 60%.

Airbus announced it already has 155 commitments for the A350 airliner. Customers include operators in America, Europe, India and the Middle East.

Beverly A. Beckert is Editorial Director of *Concept To Reality* magazine. Source for the above information is *www.airbus.com*.

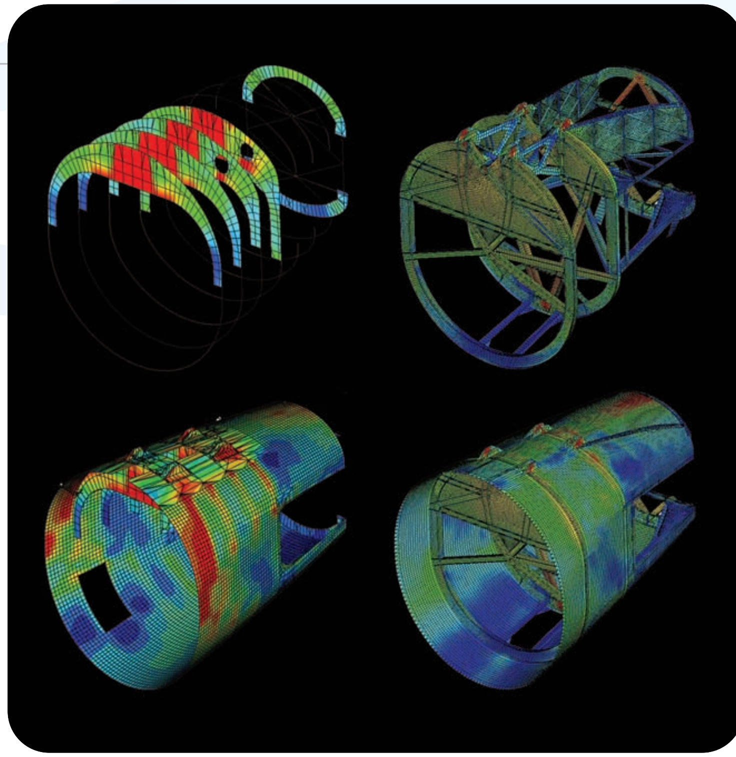

Fig. 5. Stress comparison: A330 and A350 with 10% weight reduction

EADS Military Aircraft

EADS Military Aircraft, an integrated part of the EADS Defense and Security Systems Division, is responsible for the manufacture and support of high-performance combat aircraft, unmanned mission and combat air vehicles, drones, manned mission aircraft and training aircraft. It employs about 7,700 people at sites in Germany, France and Spain.

In the civil aircraft components sector, EADS Military Aircraft is a preferred supplier of aerostructures for the entire Airbus family. At its Augsburg, Germany, plant, large structural components are built, including the rear fuselage for the single-aisle and wide-body aircraft, forward fuselage lower shells, keel beams and wing structures.

sign mass was also the focus of a detailed parameter study. This parameter study provided a total weight savings of up to 20% as compared to the A330 design.

Measured Results

The design study has demonstrated that optimally tailored aircraft concepts with significantly reduced weight can be developed with the help of optimization methods. Of even more significance, among the countless design possibilities in 3D space, this approach results in precisely those load-carrying structures and struts that can withstand all the relevant load scenarios.

No longer is it necessary to analyze and compare a succession of empirically based design concepts. By using a deterministic, mathematical approach, a concept that combines the capability to carry every conceivable load with minimal weight can now be determined with the aid of a computer and advanced software applications.

Thanks to the topology optimization method, the experts at EADS Military Aircraft concluded that fewer frames but additional spatial struts and shear walls were needed for the A350, compared with section 19 of the A330. The study also revealed that a minimum weight design of the frames and tail plane attachment fittings could be achieved by utilizing optimum internal load paths. Moreover, the new method also affects the aircraft development and manufacturing processes: It provides the means to minimize the weight and decrease development time and cost by reducing the number of required design cycles.

The resulting design concept has some similarities to truss-like structures that were also used in vintage aircraft. The topology optimization methods confirm the efficiency of truss-like structures and bring to mind the very intelligent designs already developed by the pioneers of aircraft development. C2R

Dr. Gerd Schuhmacher is Manager of Optimization, EADS Military Aircraft, Munich, Germany.

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