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Rotorcraft Design
Takes Flight

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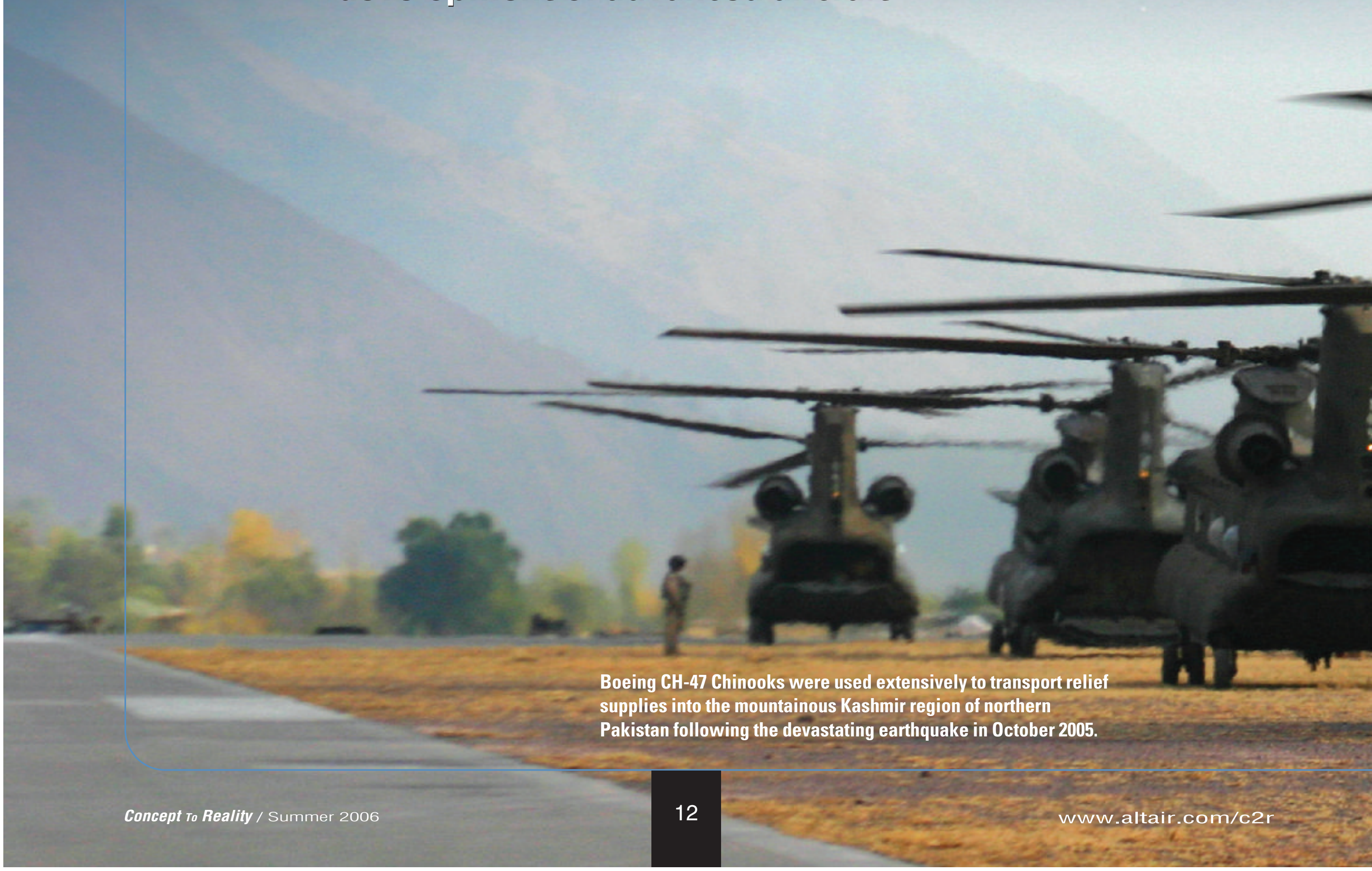
Rotorcraft Design Takes Flight

Optimization tools enable Boeing to balance form and function in the development of advanced aircraft.



Boeing CH-47 Chinooks were used extensively to transport relief supplies into the mountainous Kashmir region of northern Pakistan following the devastating earthquake in October 2005.

by **Ahsan Iqbal**

At The Boeing Company, understanding the art of using current and emerging technologies is essential to the century-old aerospace organization's ongoing success. That awareness drives improved capabilities of existing products as well as delivers new solutions to meet Boeing customers' changing needs. That understanding has been clearly demonstrated in recent projects by Boeing's Integrated Defense Systems (IDS) business unit, the world's largest military aircraft manufacturer.

Using the latest in design optimization technology, IDS is continuing to refine tried-and-true rotorcraft designs to reduce weight and enhance affordability, reliability and manufacturing efficiency. The same state-of-the-art technology is being used by IDS to explore and deliver breakthrough rotorcraft systems faster.

Weight vs. Performance

Perhaps more so than for any other flying machine, designing rotorcraft – an all-inclusive term for aircraft, like helicopters that are kept airborne by airfoils that rotate around a vertical axis – is a complex conundrum of form and function. Put simply, however, the goal is to provide the greatest functionality possible at the lowest overall weight.

Weight is a primary design consideration because it affects the rotor's capacity for vertical lift, which, in turn, affects the aircraft's range and ability to fly at safe altitudes. Lighter may also mean a sparser primary structure, making the aircraft a more survivable target for ground fire. On the other hand, it's important to tune the stiffness of the airframe to reduce vibration, which has a detrimental effect on passenger stamina,

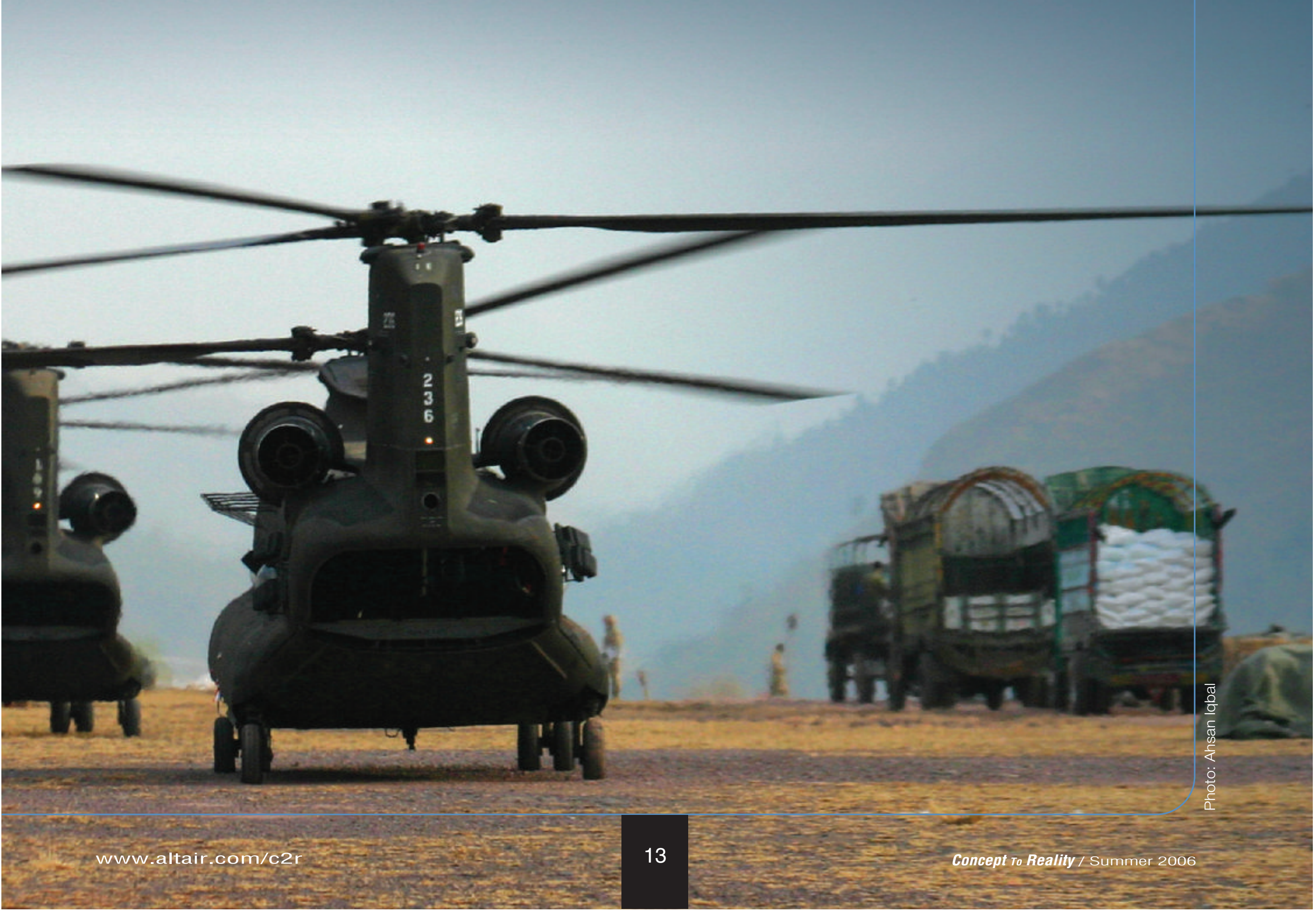
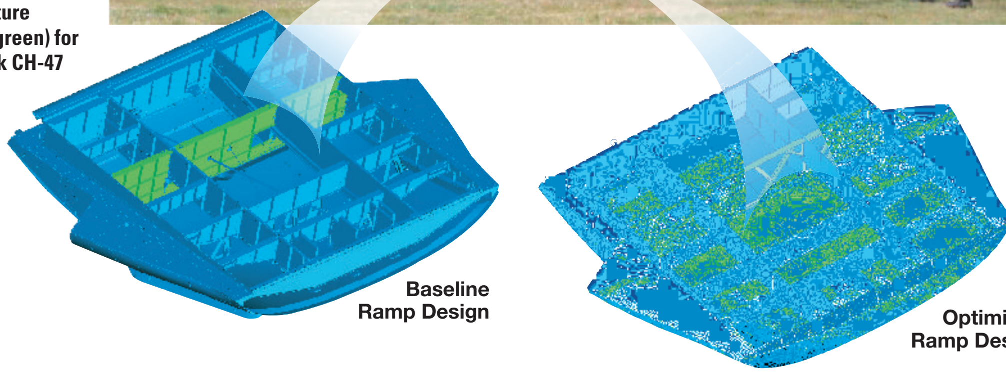


Photo: Ahsan Iqbal

Boeing engineers used Altair Engineering's OptiStruct topology optimization technology to develop a new, open truss structure (shown in green) for the Chinook CH-47 ramp.



weapons use, airframe durability and onboard electronics operation. This, too, is a weight-related issue. Every pound saved is also an opportunity for additional improvements in efficiency, performance, ballistic tolerance, soldier survivability, maintenance and repairability. While it is difficult to imagine a new design that addresses all of these issues, smart design trade-offs can translate into additional functionality. For example, weight savings realized on the airframe structure can allow designers to add more armor to increase soldier survivability or increase the payload of emergency medical supplies for humanitarian missions.

Good, Better, Best

In the late nineties, Boeing began manufacturing rotorcraft airframes by machining a single block of aluminum rather than constructing them of formed and riveted sheet metal. The new manufacturing process has significant cost, production efficiency, maintenance and stiffness benefits. However, when designed using traditional engineering tools and methods, the airframe structures are heavier than before, primarily because thin shear webs may not be the lowest weight solution.

This new challenge provided Boeing with the opportunity to take a fresh look at the design process itself. How could Boeing engineers meet strict customer specifications while maintaining a weight-neutral status, especially in the improvement of legacy designs? What tools could help increase the functionality and performance of their products? What if they could shorten overall design time? What if designers could test and evaluate ideas without the tedious iterations inherent in the traditional design process? What if new concepts could be incorporated and analyzed earlier in the process? Boeing found that optimization technology provided these benefits while still keeping development time within the extremely restrictive existing window.

Today, topology and topography optimization technologies are beginning to gain acceptance and make a significant impact throughout the aerospace design community. At the forefront of this development is

Altair OptiStruct. This software designs and optimizes the performance of mechanical structures by defining the best material distribution for a given design space, target mass and method of manufacture for a given set of objectives and constraints. Compared to the time-consuming trial-and-error approach to optimize designs, OptiStruct enables engineers to develop robust, efficient designs that have a higher probability of success in a shorter period of time.

Putting Tools to the Test

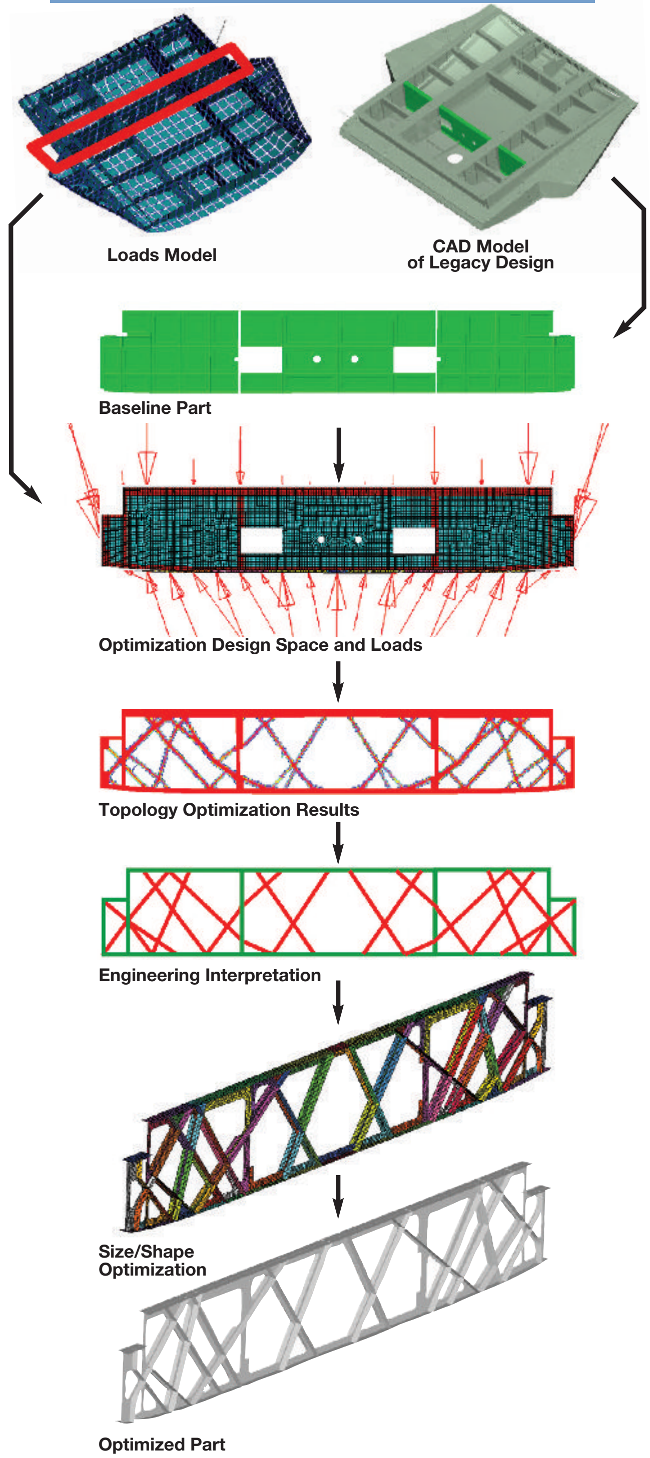
The Boeing CH-47 Chinook heavy-lift transport helicopter has been in the U.S. Army and allied service for more than 42 years – and is the longest-running production program in Boeing's history. Its primary mission is to move troops, artillery, ammunition, fuel, water, barrier supplies and equipment on the battlefield. Secondary uses for this hard-working rotorcraft include medical evacuation, disaster relief, search-and-rescue operations, fire fighting, heavy construction and civil development.

More than 1,179 Chinooks have been built since it was introduced in Vietnam in 1962. Over the past 40 years, continuous technology improvements, such as a new cockpit section with common avionics, have kept pace with expanding mission requirements. The result of the modernization of the Chinook's proven configuration is an aircraft with greater functionality and enhanced survivability.

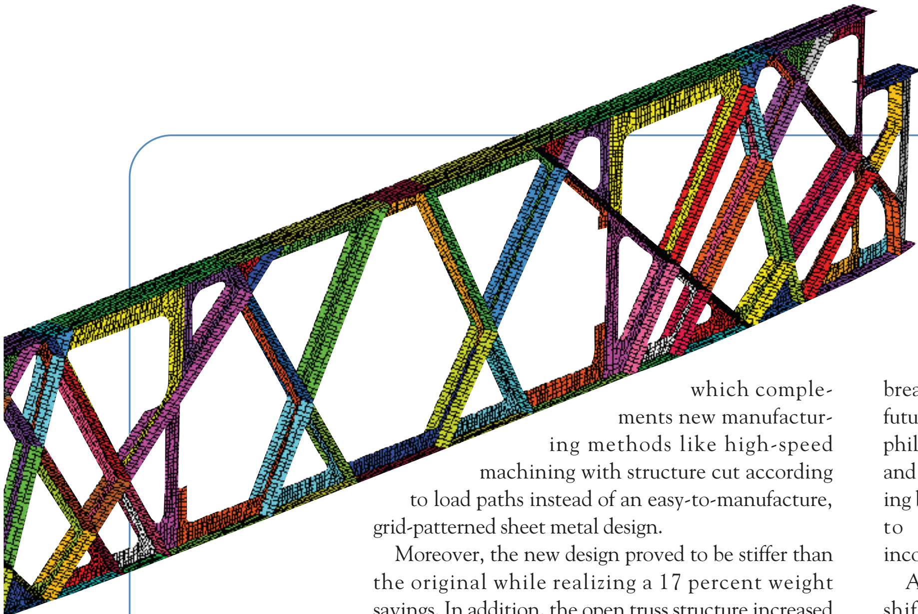
As part of this continuous improvement effort, a team of Boeing engineers led by Ethan Hunter, lead engineer for optimization, Rotorcraft, identified the ramp on the Chinook CH-47 for a weight-savings pilot study. The goal of the study was to examine the benefits of topology optimization technology to accelerate new product development and improve upon legacy designs.

Using OptiStruct topology optimization technology, the engineers produced a "radical" new open truss structure for the ramp. The unfamiliar, organic-looking truss reinforcement pattern initially concerned Boeing's engineers because they were certain it would be less stable than the traditional design and more expensive to produce. After an in-depth analysis, those doubts turned out to be unfounded. This technology represents a paradigm shift in design,

CH-47 Ramp Optimization Process



The optimized Chinook CH-47 ramp structure proved to be stiffer than the original (baseline) while realizing a 17 percent weight savings.



which complements new manufacturing methods like high-speed machining with structure cut according to load paths instead of an easy-to-manufacture, grid-patterned sheet metal design.

Moreover, the new design proved to be stiffer than the original while realizing a 17 percent weight savings. In addition, the open truss structure increased the ramp's ballistic tolerance because the reduced volume of the new design presents a sparser target than more dense webs and stiffeners.

Importantly, front-loading the design process with optimization tools did not compromise an aggressive six- to eight-week analysis window. In fact, optimization tools cut the overall development time in half. Less than three or four years ago, a total design could take 12 to 18 months to develop using conventional means. Now, a typical legacy redesign takes just six to nine months to be validated and released to the manufacturer or supplier in a form that can be turned into an actual product.

The Chinook ramp project was such a success that the Boeing team anticipates using optimization tools in the design of two new helicopters in the near future. In addition, IDS engineers will collaborate with Boeing's Commercial Airplane Group to optimize the wing rib design on the new Boeing 787 Dreamliner, a super-efficient family of three airplanes scheduled to start production in 2006, with deliveries beginning in 2008.

As design optimization technology gains increased acceptance by engineers and customers, the optimization-driven design process will assist Boeing in developing efficient aircraft structures that weigh less, are less expensive to develop and reach the market faster. In turn, the weight savings will lower operating costs for Boeing customers, as well as increase the planes' passenger and cargo capacity.

Cool and Unconventional

While Boeing's 100-year history of using innovative technology to create customer-focused, breakthrough aerospace products is impressive, the future holds even greater promise. The shift in design philosophy – combined with advanced optimization and simulation methods that encourage fresh thinking by cutting development time – will open the door to product possibilities that are virtually inconceivable today.

An evolved design process is already making the shift to newer modes of vertical lift possible. One example is the Boeing V22 Osprey, the first aircraft designed from the ground up to meet the needs of all four U.S. armed services. The Osprey is a tilt-rotor aircraft that takes off and lands like a helicopter, but once airborne, the rotors can be rotated to convert the aircraft into a turboprop airplane.

The Osprey flies twice as fast as a helicopter, with much longer range, at higher altitudes. Easily stored aboard an aircraft carrier, the Osprey also has air-to-air fueling capability, further expanding its mission potential. This advanced design will change how people view rotorcraft flight and represents a game-changing development in the future of rotorcraft.

Another example of how the change in design philosophy is driving new developments in flight is the Boeing A-160 Hummingbird, an unmanned helicopter unlike any other on the market today. The Hummingbird is designed to fly 2,500 nautical miles, with endurance in excess of 24 hours and a payload of more than 300 pounds.

Used primarily in reconnaissance, surveillance, target acquisition and communications, it reaches higher altitudes, hovers longer and is quieter than traditional copters. One feature that makes the Hummingbird especially unique is the optimum speed rotor technology that enables the operator to adjust the RPMs of the rotor blades at different altitudes and cruise speeds. This technology not only saves fuel but also improves the overall efficiency of the rotorcraft.

Boeing is also involved in a conceptual design study of a joint heavy lift (JHL) helicopter, which will meet the future Army and Marine rotorcraft

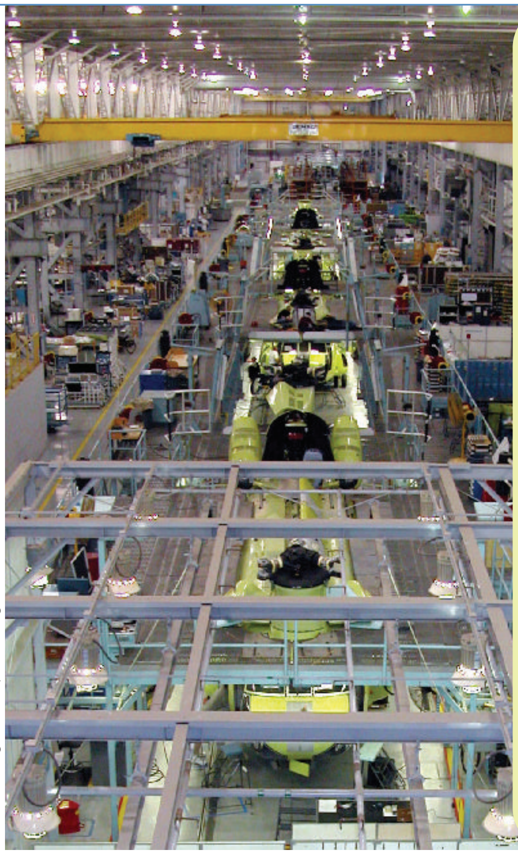


Photo: Boeing Philadelphia/Doug Holmes

Boeing at a Glance

Boeing is the world's leading aerospace company and the largest manufacturer of commercial jetliners and military aircraft, with capabilities in rotorcraft, electronic and defense systems, missiles, satellites, launch vehicles and advanced information and communication systems. The company serves customers in 145 countries.

With a long tradition of aerospace leadership and innovation, Boeing continues to expand its product line and services to meet emerging customer needs. Boeing's broad range of capabilities includes creating new, more efficient members of its commercial aircraft family; integrating military platforms, defense systems and the warfighter through network-centric operations; creating advanced technology solutions that reach across business units; and e-enabling airplanes and providing connectivity on moving platforms.

Boeing IDS, based in St. Louis, with rotorcraft development facilities in Philadelphia and Mesa, AZ, is one of the world's largest space and defense businesses. It is a leading provider of intelligence, surveillance and reconnaissance systems and the world's largest military aircraft manufacturer. IDS is also the world's largest satellite manufacturer and a leading provider of space-based communications; the primary systems integrator for U.S. missile defense; and NASA's largest contractor.

Headquartered in Chicago, Boeing employs more than 153,000 people in more than 67 countries.

requirements of 20-ton or greater payloads. Five different designs are being evaluated. Boeing is participating in two of them. One is an advanced tandem rotor helicopter and the other is a quad-tilt rotor.

On the Horizon

As Boeing engineers continue to explore new ways to meet and exceed customer expectations, conventional design paradigms are shifting to include advanced optimization and simulation technology earlier in the development process. As a result, critical weight considerations are being more efficiently balanced with increasing functionality. Shortened rotorcraft development time not only cuts time to market but also enables engineers to propose and analyze sophisticated design concepts that would otherwise be impractical and costly to investigate.

Boeing is impressed with the potential of design optimization to dramatically cut weight, provide increased functionality and significantly cut development time. While Boeing may not as yet have taken full advantage of the capabilities optimization offers, it represents an important shift in the company's overall approach to design, especially when these tools are brought onboard early in the process. This change, which also is consistent with the advanced lean manufacturing tools and processes that are embedded across the organization, will ensure Boeing's continued business success in a highly competitive world marketplace. C2R

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