ROTORCRAFT DESIGN TECHNOLOGY TRENDS AT BELL HELICOPTER TEXTRON

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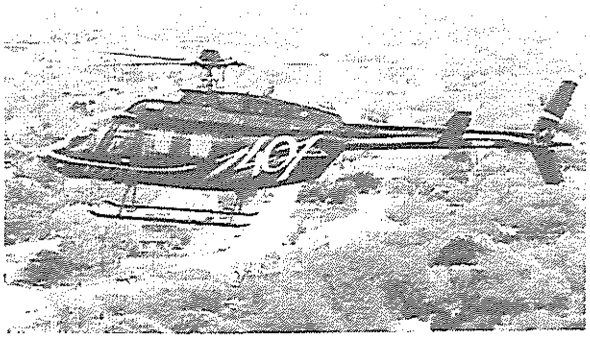
Abstract

This paper summarizes some of the advanced technologies that Bell Helicopter Textron Inc. is incorporating into its product line. Selected components and design and process initiatives are reviewed. Specific elements that provide the customer with cost-effective, mission-enhancing capability are described, and opportunities for future opportunities are indicated. The activities under way demonstrate Bell Helicopter's dedication to bringing its customers the most cost-effective technology that the rotorcraft community desires.

Introduction

Over the past few years, Bell Helicopter Textron, Inc. has implemented a major modernization of its product line. In addition to the ongoing production of the leading-edge technology embodied in the V–22 Osprey tiltrotor, significant changes are being made to the helicopter fleet Bell delivers to the world market. In 1996, both the Model 407 light single and the Model 430 intermediate twin were certificated and introduced to the marketplace (Fig. 1). Also in 1996, the Model 427 light twin was initiated in a cooperative effort with Samsung Aerospace, and on a truly historic note, the Bell-Boeing Team initiated the first commercial tiltrotor —the Bell-Boeing Model 609 (Fig. 2). In addition to the V–22 program, on the military side, both the AH–1W and the UH–1N are being modernized under the Navy's H–1 Upgrade program (Fig. 3). Important elements of these new products are the advanced technologies incorporated to improve productivity, increase reliability, and most critically, provide the customers of Bell Helicopter with cost-effective products.

Bell's research and technology activities have for some time focused on advancements in our technology base that improve the mission capability of our varied products while striving to enhance the affordability of the fielded systems. With the array of new products being fielded, we in the technology community are most fortunate to have multiple windows of opportunity for application of our research and technology activities. A key requirement for a successful technology initiative today is to achieve product enhancement at the same time that costs are contained or reduced. Thus, an important measure of the success of a technology effort is the cost effectiveness of the initiative.



Model 407

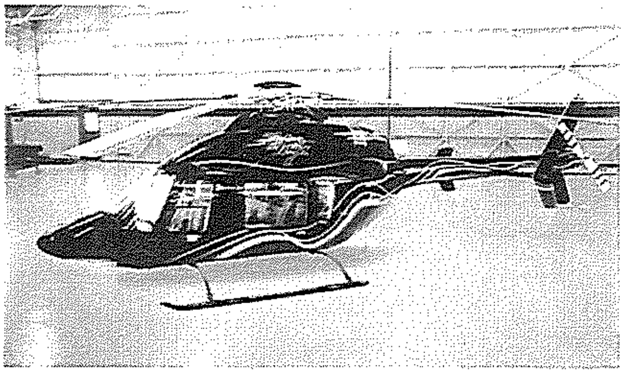
Model 430

Fig. 1. Model 407 and Model 430.

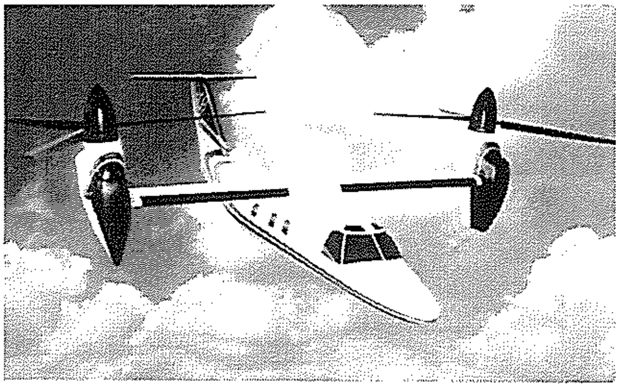
In the following sections, some of the ongoing technology efforts at Bell are described, and the benefits associated with these advanced concepts highlighted. Some of the advanced processes being used to develop the products are also described.

Design Technologies and Processes

Product development programs today are far different than they were only a few short years ago. Much of the difference can be attributed to changes in the design processes being used by the engineering community. Integrated Product Teams now play a major role in development of new products. With a core team made up of people from engineering, manufacturing, purchasing, and program management, programs no longer are executed sequentially, but rather reflect a concomitant process whereby the total product development is considered from the outset.



Model 427



Model 609

Fig. 2. Model 427 and Model 609.

In addition, computer-aided design tools are used that provide the development team significantly improved design data concerning the product. This paper would be remiss if it did not address some of these design tools and processes.

3–D Modeling

All new product development activity at Bell is committed to the use of 3–D modeling. With the arrival of 3–D solids modeling, component design takes on a whole new dimension. The solids model provides so much in the way of downstream benefits that the additional time and training are well worth the effort. Fig. 4. gives some perspective to the benefit of 3–D design. Not only is a particular component fully defined, but in the case illustrated, its relative position with surrounding components can be assessed for potential interference. When coupled with weight equations, weight estimates are readily available to the designer. In addition, there are downstream benefits regarding tooling, producibility, and maintenance manual illustrations.

Stereolithography

Stereolithography allows one to rapidly create a three-dimensional solid model from the three-dimensional virtual model of the computer image. A number of

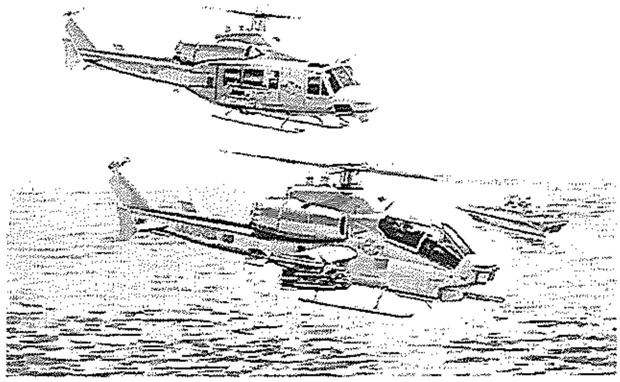
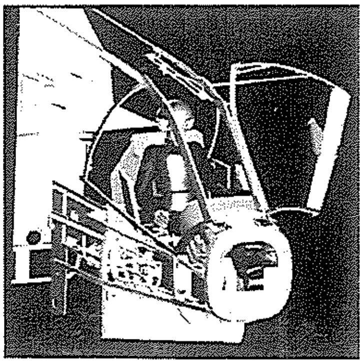


Fig. 3. Model AH–4BW and Model UH–1N.

applications of stereolithography are in use at Bell to assist in rapid prototyping as well as to perform fit and function assessments. In more recent applications, we are using stereolithography parts as a step in developing molds for investment castings. Results to date have been exceptional, with demonstrated savings of approximately 66% in cost and an equally impressive savings in time to create a casting.(Fig. 5). These significant cost and cycle-time reductions enhanced our ability to move rapidly through the product development cycle.

Computational Fluid Dynamics (CFD)

A by-product of today's high-speed computer is our increasing ability to use CFD in the design process. Rotorcraft provide a real challenge to the fluid dynamists by virtue of the complexity of the flow-field. However, great strides are being made in both the grid mesh generation as well as in the solution times for a given flow condition. There is still a long way to go but progress is being made. CFD is being used to design and analyze components such as advanced rotor tips, which have the potential to reduce the troublesome blade/vortex interaction (BVI) noise of rotorcraft. Fig. 6 illustrates the modeling of a sub-wing-tip that shows promise to reduce the trailing tip vortex strength and thereby minimize the BVI signature.



- Clearances / fit
- R&M / access
- Accuracy of placement
- Cycle time
- Tech pubs

Fig. 4. Computer mockups for fit, function, and human factors.

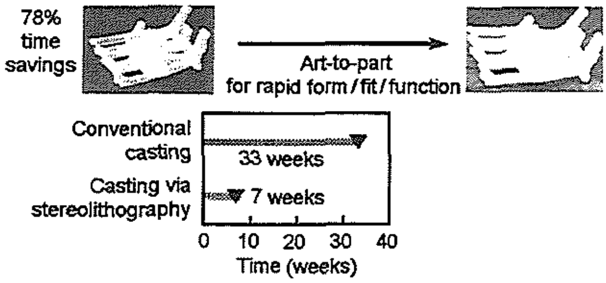


Fig. 5. Stereolithography–a multi-purpose technique for cost/schedule savings.

A subwing reduces blade-vortex interaction noise by splitting the tip vortex into two.

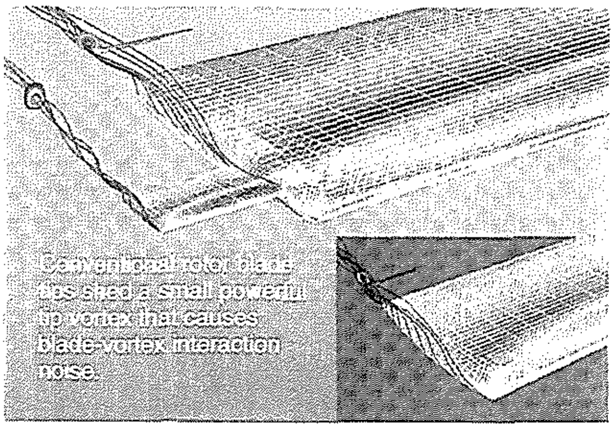


Fig. 6. Noise reduction by modifying tip vortices.

While great progress is being made to analyze components and relatively simple bodies, the total flow field including the rotor represents a challenge both from the standpoint of griding the mesh for analysis as well as the computing time to achieve a solution. As an example, Fig. 7 illustrates the flow solution for a CFD model of the V–22 Osprey. Grid mesh generation of this model currently represents weeks of effort and CPU time for a solution is measured in hours. This obviously is not yet a production design process, but that will come eventually.

Rotor System Technology

Bell Helicopter has been actively developing the technology for application of composites for bearingless rotor hubs and blades for a number of years. In 1975, the initial composite main rotor blade was introduced on the Model 212 helicopter, and essentially all subsequent new models have incorporated composite rotor blades. In early 1996, the Model 430 helicopter was introduced with a fully composite bearingless main rotor hub.

Composite Bearingless Main Rotor

The Model 430 bearingless hub system represents a third-generation derivative of the very successful Model 680 rotor flown initially in 1982. Fig. 8 presents a sketch of the four-bladed rotor. Each arm has a torsionally flexible feathering element outboard of an inboard flapping flexure. In-plane bending of the long feathering beam moves the blade cuff relative to the hub. Elastomeric lead-lag dampers are incorporated between the cuff and hub to provide adequate damping to preclude air or ground resonance problems.

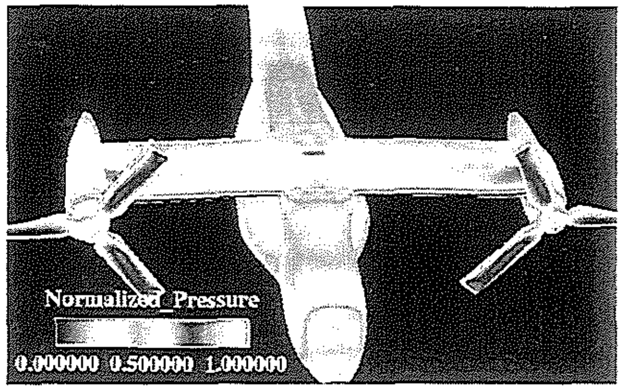


Fig. 7. V–22 surface static pressure contours.

Over the course of the development of Bell's bearingless rotor, significant improvements were made to the concept. The original 680 hub was a single-piece four-arm construction. To facilitate producibility as well as part transportability, the hub was fabricated in two identical yokes and then mounted in a stacked arrangement on a flanged main rotor mast. The feathering flexure was also changed. Whereas the original 680 hub had a triple-H cross-section, the newer design uses a radial flange cross-section. Two distinct advantages of this newer version are the ease of manufacture and a 50% reduction in torsional stiffness of the flexure, thereby significantly reducing control loads. Further, the fatigue life of the feathering element at higher displacement was greatly increased. In summary, the composite bearingless rotor represents a new generation of rotor technology, offering greater than

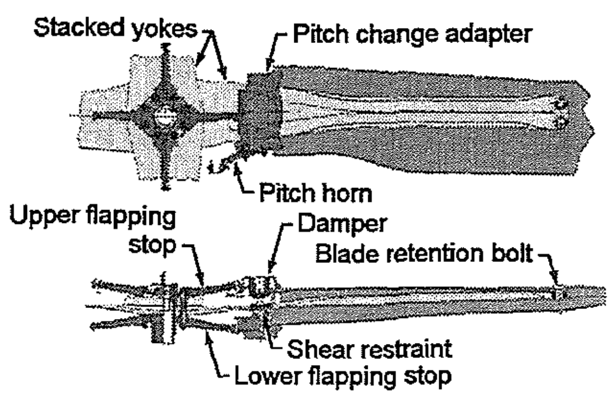


Fig. 8. The Model 430 rotor is a derivative of the 680.

50% reduction in number of parts, a 20% reduction in weight, and increased component life with the benign failure modes of composites. This technology is now being applied to the Marine Corps AH–1W in the H–1 Upgrade program (see Fig. 9).

Antitorque Systems

The antitorque system for helicopters has been a subject of research for many years, the objective being to provide antitorque and directional control in the most efficient manner possible. Trade studies that consider only cost, weight, and performance generally show that the most effective antitorque device is a large diameter two-bladed rotor. However, noise and tail rotor strike prevention place additional discriminators into the trade study factors. Studies indicate an opportunity to minimize the weight and cost penalties to address noise and protection improvements. Several configurations have been tested at Bell, including a successful ring fin configuration that was adopted on an early production prototype. More recently, an experimental ducted tail rotor was successfully evaluated and is described herein.

Ducted Tail rotor

A conventional tail rotor housed in a duct offers several attractive features: obstacle strike avoidance, improved performance for a smaller diameter rotor, lower component loads, and enhanced personnel protection. Flight testing of a ducted tail rotor (DTR) was initiated in 1994 (Fig. 10). The configuration incorporated a four-bladed cantilevered rotor within a duct with a thickness of 20% of the rotor diameter. Performance, handling qualities, and loads were well within the design expectations. However, even though the noise level was equivalent to the baseline Model 222U test aircraft, which operated at a much lower tail rotor tip speed, the sound quality was completely unacceptable. Additional ground-based evaluations were conducted along with analytical assessments, and a five-bladed rotor configuration with uneven blade spacing was determined to be very effective in reducing noise as well as improving the tonal quality (Fig. 11). Flight tests of this configuration showed significant noise reductions due to the DTR during the takeoff, approach, and flyover conditions.

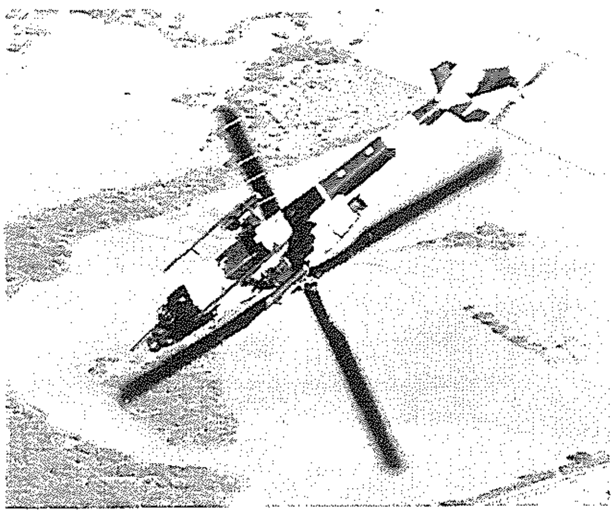


Fig. 9. AH–1W (4BW) test aircraft in split "S" maneuver.

Fig. 10. Bell's ducted tail rotor enhances rough terrain operations.

Drive Systems

Drive system technologies have moved on three fronts—new materials, design allowables, and loss-of-lube capabilities. Each of these elements has played a significant role in the development of our latest products, including the V–22 tiltrotor and both the Model 407 and Model 430 helicopters. These products all use X–53 alloy steel, a second-generation modification of AISI 9310 alloy steel, in the main power gears. For the same bending fatigue strength and toughness of 9310, X–53 alloy steel provides higher operating temperature as well as improved scoring resistance. In addition, the B_1 pitting

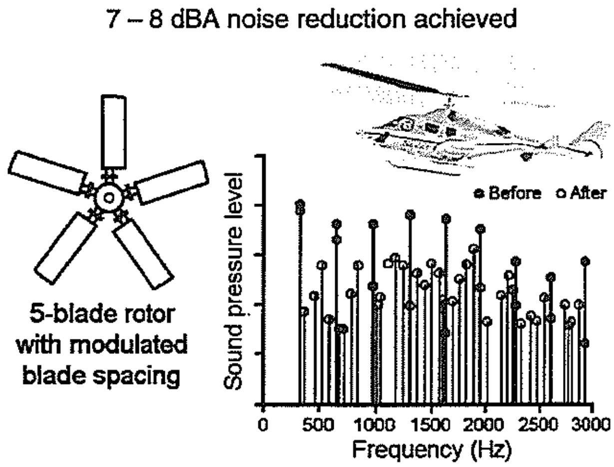


Fig. 11. Significant reduction in anti-torque noise signature.

life of X–53 is approximately 235% better than that of 9310, based on spur gear pitting tests. As illustrated in Fig. 12, Bell has invested heavily in bringing X–53 technology into our product line to ensure that our drive systems are the most reliable and efficient in the industry.

Loss-of-Lube Operations

Because of its military application, the V–22 Osprey may be subject to ballistic damage that has the potential to cause loss of the primary lubrication systems in any of the five gearboxes in the drive system. Because of this, the drive system gearboxes are required to continue to transmit normal operational drive torque for 30 minutes after loss of the primary lube system. This requirement is easily met for the tilt-axis and midwing gearboxes, since these systems only transmit accessory power during normal operation. However, the proprotor gearboxes (PRGB) represent a real challenge because of the high torque and high-speed operation of these gearboxes in the helicopter mode. The PRGB houses gears with a pitch-line velocity in excess of 24,000 ft/min and a planetary system that has a sun gear speed in excess of 5,000 rpm. To meet this challenge, a combination of emergency flight procedures and an emergency lube system was designed and incorporated into the aircraft. The lube system provides lubricant to either PRGB for a minimum of thirty minutes in the event the primary lubrication system becomes inoperative. The operational procedure is used to minimize torque loads in the affected PRGB by converting to the airplane flight mode and reducing power on the engine of the affected PRGB. With the cross-shafting between rotors on the V–22, the aircraft can maintain 25 minutes of flight with a torque split prior to resuming full engine power to the affected PRGB for full hover landing in the helicopter mode at a safe destination.

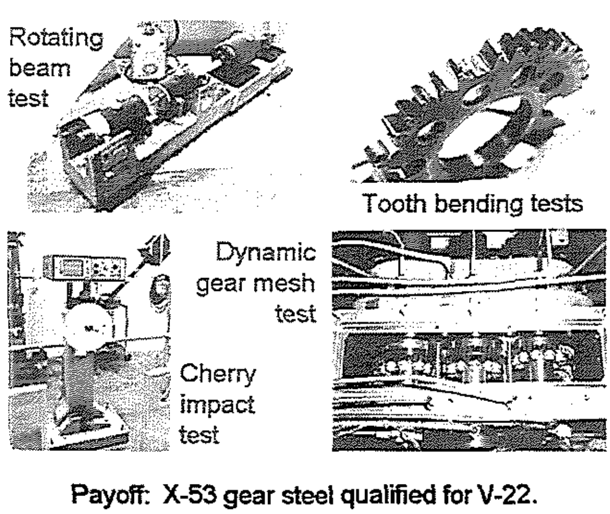


Fig. 12. X–53 gear steel improves V–22 run-dry time.

Composite Gearbox

A challenge which offers major benefits relative to weight reduction and corrosion prevention is the application of composite materials to gearbox cases. Under a technology program with the Great Lakes Composites Consortium, Bell Helicopter is addressing that challenge. The gearbox selected for the initial effort is the accessory gearbox on the V–22 Osprey. After some consideration of an implementation strategy, however, a decision was made to shift the effort to the topcase for the H–1 upgrade program. In either case the benefits are significant. The two components are illustrated in Fig. 13. The topcase will be fabricated with a braided carbon preform using a resin transfer molding (RTM) process. Successful completion of this program will validate the technology to produce a 30% reduction in the weight of the gearbox while incorporating the corrosion resistance properties of composites.

Health and Usage Monitoring System (HUMS)

A technology that is rapidly expanding within the rotorcraft community is the application of health and usage monitoring of the propulsion and drive system. A total HUMS incorporates both aspects that the acronym implies— health monitoring and usage monitoring as defined in Fig. 14. One of the distinct advantages of a health monitoring system is that it allows early detection of faults and also more productive maintenance planning. Both the V–22 Osprey and the Canadian Forces Model 412 helicopter incorporate health monitoring technology. The efficiencies of improved maintenance are but one aspect of the HUMS benefit. A far more effective benefit

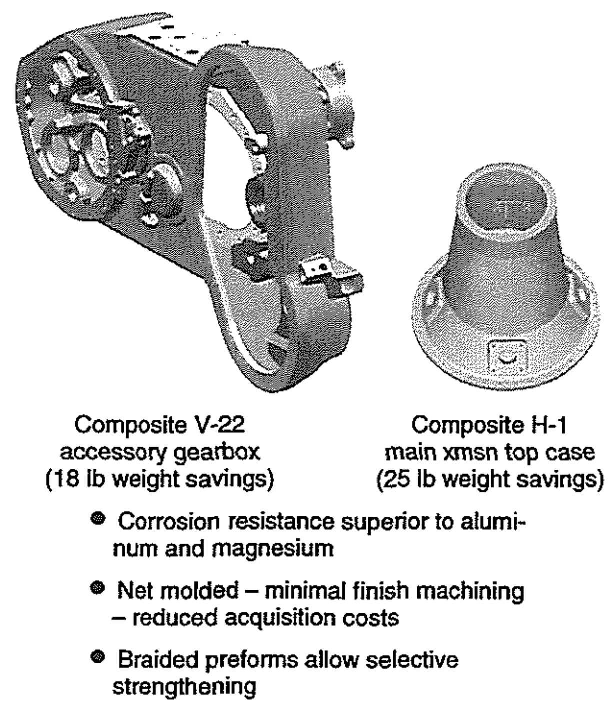


Fig. 13. Gearbox housing structures.

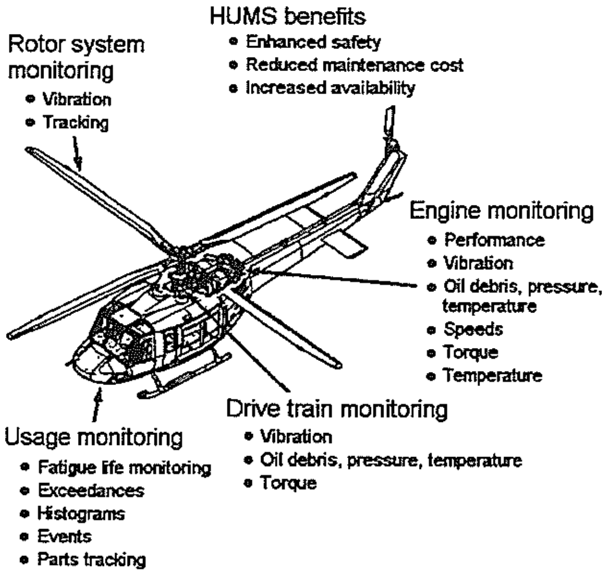


Fig. 14. HUMS provides advanced diagnostics for mechanical systems.

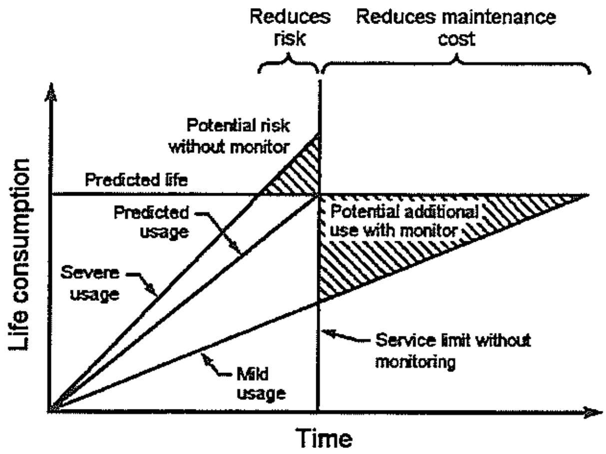


Fig. 15. Potential benefits with actual usage monitoring.

will be achieved as usage monitoring becomes a fully qualified capability. Toward that objective, Bell has been developing the required flight condition recognition algorithm as well as the appropriate fatigue life usage algorithm to allow dynamic components to have a retirement life based on usage rather than purely on hours of flight. As illustrated in Fig. 15, when a part's retirement life is based on a prescribed fatigue spectrum, operational scenarios that are milder than the assumed spectrum will retire parts early, whereas more aggressive operations could conceivably create a potential risk of premature failure unless the spectrum is defined in a most conservative manner. The objective of the usage element of a HUMS is to monitor actual usage and thereby provide extended component life as a function of actual flight hours.

Airframe Structure

Application of composites to rotorcraft fuselage structure has many well-known benefits: weight reduction, corrosion prevention, and structural efficiency, to name a few. The challenge for widespread usage has been to achieve affordability in application to airframe structure. Significant progress is being made; however, much work remains in order to achieve cost competitiveness with metal construction. Over the past decade or so, Bell has made progress in the application of composites to airframe structure. A major step in 1985 was the design and fabrication of the Advanced Composite Airframe Program (ACAP) airframe sponsored by the U.S. Army. Many component initiatives followed the ACAP project and the V–22 Osprey program was committed to the application of composites. One of the lessons learned over these many programs has been the critical role that the type of component and manufacturing process play in the cost of the component. Experience has shown that very small components, on the order of 5 lb or less, do not lend themselves to low-cost composite construction. Conversely, large components that do not take advantage of automation processes can be very costly. The ACAP fuselage shells were an early example of that lesson. Thus, cost-effective application of composites depends on the complexity of component, the material selection, and the manufacturing process selected. The V–22 Osprey is taking full advantage of much of the automation technology including tape layers, fiber tow placement, and laser designation of material placement. The following examples illustrate some of the newer ways Bell is attacking the cost issue of composites.

Thermoplastic Tailboom

The cost of a simple monocoque metal tailboom represents a significant challenge to beat when using composite materials. However, using a relatively new process for *in situ* curing of thermoplastic material, a cost competitive tailboom has been developed and is currently undergoing structural validation testing. The process, as illustrated in Fig. 16, uses a fiber tow placement head that incorporates a heating element. This process deposits the material on the tool, compacts it, and cures the thermoplastic in one operation. Multiple plies can be added to give the appropriate material thickness and fiber orientation. This process has produced the tailboom component pictured in Fig. 17. The tailboom was approximately 5% lower in cost and also had a 28% weight savings. Applying this same fabrication technique to the horizontal tail of the rapid deployment OH–58D produced a part that was 40% lower in cost and 35% lower in weight.

Fuselage Structure

When one addresses the challenge of producing an affordable composite fuselage, several issues must be examined. First, the fuselage cannot be designed using

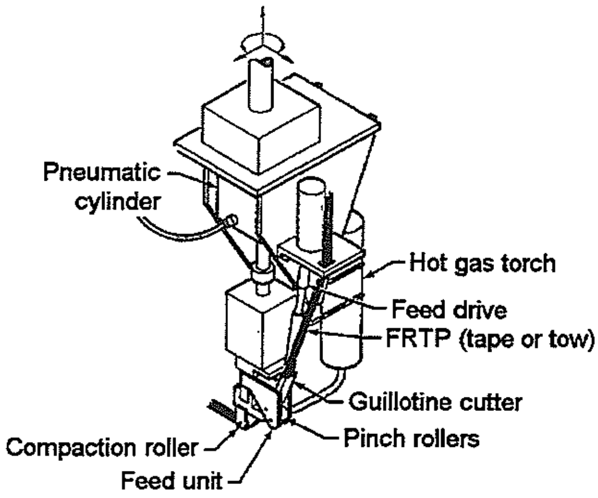


Fig. 16. Hot head winding.

conventional metal design philosophy. Second, the entire design, tooling and manufacturing process must be addressed from the outset to ensure that an integrated process is achieved. To that end, Bell has initiated IPTs on all design/build programs to ensure that design and tooling engineers and manufacturing engineering are communicating and that components are being developed from the outset with the total process being considered.

An IPT tasked to address the fuselage structure for a light helicopter developed some specific keys to achieving low-cost composite structure (Fig. 18). The three guidelines established were to reduce the part count by making fewer but larger components, to minimize fasteners, and to address tooling techniques early in the design to allow innovative techniques to be applied. A product of this process was the implementation of a design which embodied these guidelines. The concept was carried through to full-scale hardware and as shown in Fig. 19, a fuselage section was produced that is very cost competitive to an aluminum construction.

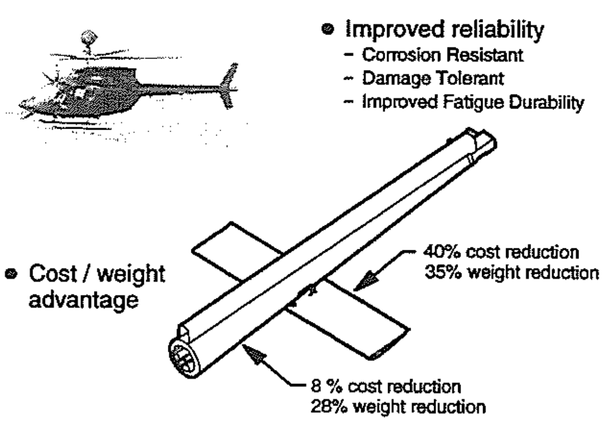


Fig. 17. OH-58D *in situ* cure prototype tailboom.

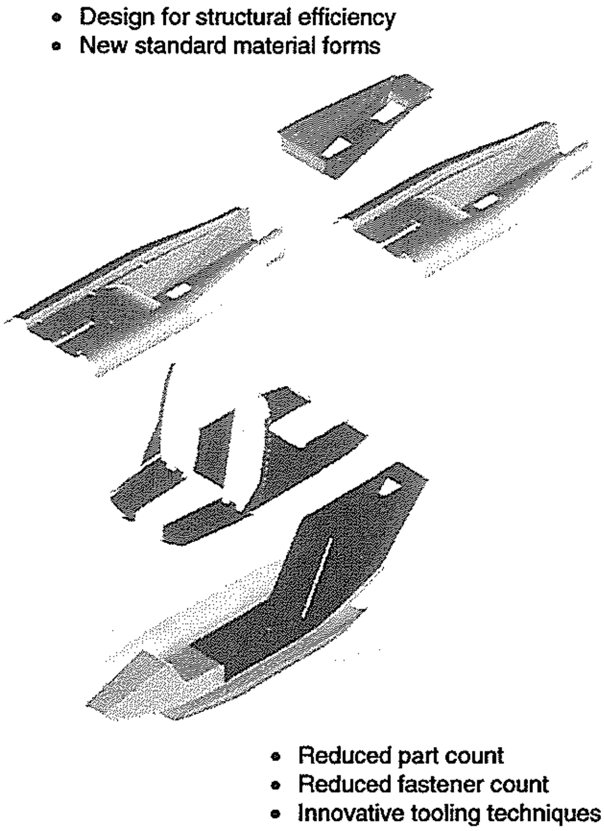


Fig. 18. Keys to lower-cost composite structures.

FLIGHT CONTROLS/AVIONICS

The advent of the electronic age has created more opportunities to enhance the operational capabilities of rotorcraft than can often times be justified from a cost perspective. In some specialized military applications, the cost of the electronic systems can exceed 50% of the total air vehicle system cost. The challenge then becomes one of providing cost-effective solutions to enhance mission performance, reduce pilot workload, and increase safety of the product. The Model 430 helicopter, for example, incorporated an integrated instrument display system which enhanced the pilot's external visibility and at the

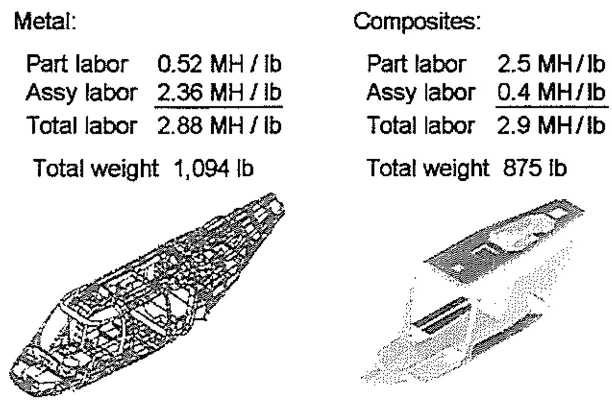
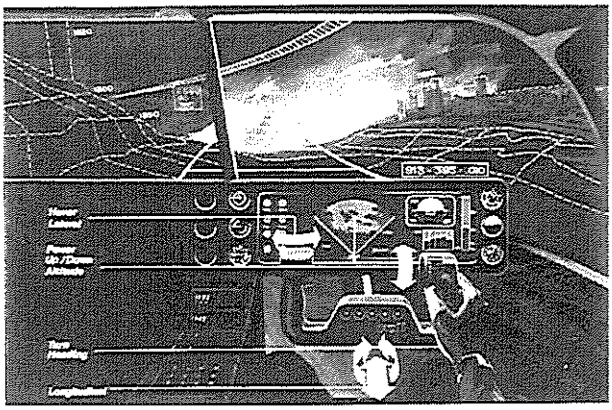


Fig. 19. Comparison of aluminum and composite fabrication labor costs.

same time reduced cost by over $20,000. There are many other examples of Bell product enhancements made possible by the electronic age. Fly-by-wire flight control of the V-22, digital SCAS, FADEC engine controls, and "glass cockpits" are but a few of the innovations of the digital age. As we move forward, the opportunities are boundless. Artificial intelligence in the form of expert systems, neural networks, and fuzzy logic controls show promise of reducing cockpit workload by given decision aiding information to the pilot in a variety of mission enhancement modes. Coupled with these new knowledge-based technologies, advanced displays provided the potential to revolutionize the total pilot/airvehicle interface. Fig. 20 illustrates the trend toward displays providing a "highway in the sky," coupled with fully integrated automated flight path control via a simple vector controller. The benefits are numerous: workload reduction, flight control simplification, and enhanced safety through improved situational awareness.



- Reduced pilotage workload
- Improved control precision
- Decreased time to proficiency
- Enhanced flight safety

Fig. 20. Vector controllers.

Availability of the Global Positioning System (GPS) creates a new spectrum of information to enhance the navigation tasks as well as flight path management. As a tool to investigate the many options available, Bell has installed a differential GPS (DGPS) in the XV–15 tiltrotor research aircraft (Fig. 21) to investigate techniques to provide pilotage cues for flying noise abatement steep approaches. The aircraft has been updated to include a modern digital SCAS as well as a new electronic display. This program will provide valuable data for enhancing the flight procedures of civil tiltrotors used in urban vertiport systems where low noise flight profiles and noise footprints are critical.

XV-15 flying Digital SCAS to reduce pilot workload in precision approches using DGPS.

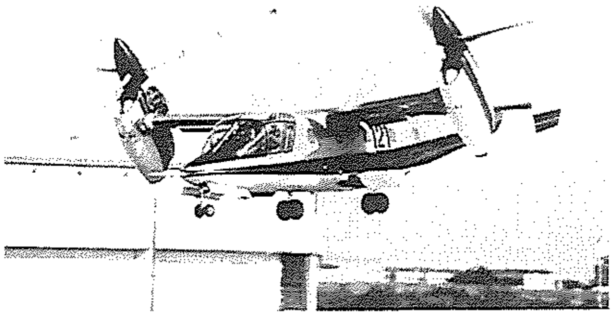


Fig. 21. Research test – bed for tiltrotor technologies.

Summary

This paper has reviewed some of the advanced technologies being developed and incorporated into the Bell Helicopter product line. Each of the major systems has been reviewed and some of the more significant activities underway to enhance the product capability have been described. In addition, some of the design and process tools being used to develop product improvements have been discussed. Each of these techniques is being utilized to improve the product as well as to reduce cycle time in order to deliver a more cost-effective product to the market.

This overview demonstrates that Bell Helicopter is dedicated to bring to its customers the most cost-effective technology that the rotorcraft community desires. Further, Bell is committed to continue to seek opportunities to enhance the mission effectiveness of both its military and commercial product line.