NEW materials in BUSINESS AIRCRAFT

Composites, metals vie for supremacy

Special report by Thierry Dubois

Raytheon Hawker 4000

The Cincinnati Milacron Viper fiber-placement machine lays the carbon-fiber ribbons that eventually form the fuselages of Raytheon's composite Hawker 4000 and Premier I.

The use of composite materials has been gaining traction among business aircraft manufacturers. Some suggest that as new technologies refine their characteristics, composites are progressively forcing metal out of airframes. How accurate is that assessment?

For its very light jet, the Eclipse 500, start-up manufacturer Eclipse Aviation has chosen conventional aluminum because it enables a faster assembly process, the company said. Many established manufacturers have also opted to stay with metal. Nonetheless, designers now have a number of choices for business jet primary structures.

Composite Construction

When addressing the subject of new materials, the word that first comes to mind is "composites." A key advantage of carbon fiber-reinforced plastics (CFRPs), now the most common family of composites, is their strength-to-weight ratio. "Weight savings and structural stiffness are major benefits," said Frank Simmons III, Gulfstream's structures staff scientist. He firmly believes that composites can provide a significant advantage over metal structures in stiffness, particularly in applications where aeroelasticity is a major concern.

Weight savings can be a benefit. For example, the composite Spectrum S-33 Independence now under development weighs 7,300 pounds at mtow, placing it in the very light category, but it will offer nine seats, typically the complement of seats in a light jet. Some manufacturers have elected to incur a weight penalty for a more robust material. "We have chosen forgiving materials in terms of resistance to chemicals and humidity during production," Grob Aerospace COO Andreas Strohmayer explained. He noted that higher-performance composites do exist, which translates into lower weight. "But we prefer robustness," he said.

Another benefit of composites is that they do not corrode. They behave well in fatigue. Moreover, they do not allow damage propagation, Strohmayer added. Honda Aircraft, too, has chosen composite materials for its HondaJet.

"They enable shape and contour optimization for better aerodynamics," Raytheon's Paul Jonas, Hawker 4000 chief engineer, and Bill Jones, director for manufacturing technology, told **AIN**. Sandwich construction, without frames or stringers, allows a reduced cabin wall thickness. Therefore, for a given cabin volume, the aircraft's wetted area (and thus drag) is reduced. The designers of the Hawker 4000 emphasized that its six-foot interior diameter and the fuselage's one-inch wall thickness yield a six-foot-two-inch external diameter. "For an equivalent interior, we reduced the total diameter by 14 percent," Raytheon's Jonas told **AIN**.

Composite Improvements

Recent progress has been significant. Gulfstream's Simmons noted that in the last few years fiber stiffness has doubled and fiber strength has improved by more than 50 percent. In addition, advances in resin chemistry are yielding lower cure temperatures and pressures.

Serge Dellus, head of Dassault's advanced technologies development center, sees the development of injection techniques as another recent advancement in the field. "Resin transfer molding [RTM] and resin film infusion [RFI], for example, enable more integrated parts, with more precise geometries," he said. In addition, better resins provide improved damage tolerance.

Also, more suitable tooling is now available. "Some clips we use during the manufacturing process can be found for composites now, as opposed to the aluminum-optimized clips we could find until recently," Raytheon's Jones told **AIN**. Grob's Strohmayer expects that by 2015 composites will no longer be a specialist process.

Standardization also helps certification. "The FAA and the EASA now understand these materials better. It used to be a mess," Strohmayer said. Raytheon experts agreed, adding, "We had to bring the FAA with us."

Indeed, switching to composites involves significant rethinking of cost and expertise. Raytheon, whose Beech Starship was the first all-composite design in business aviation, has since leveraged this experience to build two composite-fuselage business jets. The Premier I entered service in 2001 and the super-midsize Hawker 4000 got its FAA certification in November.

The company's investment in tooling and processes has been huge, Jonas told **AIN**. "We have built a database that helps us find the right material for the right application," he added, noting that Raytheon teams have gained "critical mass in their intellectual property base."

Raytheon builds the two composite jets with five 11-axis Cincinnati Milacron Viper fiber-placement machines that use laser projection to orient the plies. Five autoclaves provide the single-cure process. All this provides a high level of automation.

Trends in Composite Construction

Automation in composite airframe manufacturing enables better repeatability. "Advances in automation as well as low-temperature curing materials are beginning to bring [the cost and quality of] fabrication within more acceptable levels," Gulfstream's Simmons said.

In addition, composite manufacturers are trying to streamline or even eliminate the curing phase and the cost and the autoclave-capable tools that accompany it. An autoclave can create production bottlenecks, and it is more expensive to operate than an oven.

In response, the industry has been developing systems that allow curing without high pressures or temperatures, Tim Shumate, marketing manager at Cytec Engineered Materials, told **AIN**. One needs only relatively low temperatures of 180 to 250 degrees F (80 to 120 degrees C), local vacuum and a post-cure phase.

Post curing is essentially an additional temperature exposure, with or without pressure applied. "To get a complete cross link in a thermoset, sometimes you need to take the resin to a higher temperature in an oven," Shumate said. Often this can be accomplished "free standing," because the cured structure holds its shape and does not need to be restrained by a tool. A two-phase process, with a low-temperature cure and higher-temperature, free-standing cure, requires less expensive tools than a single-phase, high-temperature cure process.

According to Shumate, the holy grail could be advanced fiber placement and "in situ curing," curing the material as it is laid down on the tool by the fiber placement machine. Techniques have been studied in which thermoset resins are cured in place using pressure and temperature applied by the fiber placement machine. Post curing would probably be necessary, but that would not be a significant disadvantage. However, Shumate believes that porosity could still be an issue with such a process.

So there is probably even more potential in manufacturing thermoplastic (as opposed to thermoset) resin-based systems in situ. "I say in situ manufacture versus cure since thermoplastic materials do not cure like thermosets. Thermoplastics are heated to a temperature that allows them to flow. So if you can develop a fiber-placement machine that applies temperature and pressure at the correct levels, you could make a part out of thermoplastic composites and totally avoid the autoclave and oven. This would be a game changer," Shumate explained. Such R&D is going on today but the technology is still years away from production, he said.

How close have Spectrum Aeronautical and its partner, Rocky Mountain Composites, gotten to such breakthroughs? For the construction of its S-33 Independence and S-40 Freedom, the company touts a technology called Fibex. Spectrum says only that the process is similar to fiber placement but uses no autoclave. "Our strengths are not really in speed or cost, but rather in the amount of precision and integrity," Spectrum president Austin Blue told **AIN**.

A majority of aerospace composites are thermosets (like epoxy). Is this because they outperform thermoplastics? Maybe not. Roughly speaking, Shumate said, the preference for thermoset stemmed largely from their availability when composites hit the market. In fact, thermoplastics do have some advantages: easier storage and, arguably, mechanical superiority.

But thermosets were adopted first and are well established. They are easier to handle when using a hand lay-up process, which was the predominant way to manufacture composites in the 1980s and early 1990s. But automated processes for thermoplastics are gaining popularity, Shumate asserted. "Change is slow in the industry, but one day thermoplastics might suddenly catch on," he said. Dutch-based Stork Aerospace is already offering floor beams made of fiber-reinforced thermoplastic.

Asked whether some materials or processes are more suited to small aircraft such as business jets–as opposed to large airliners–Shumate indicated that the size of the aircraft matters. "Honeycomb core sandwich construction has obvious benefits: it is very efficient in providing stiffness for the weight. Therefore, it lessens the need for the frames that reduce the interior volume of the aircraft–the smaller the aircraft, the more important this becomes," he said. The Premier I and Hawker 4000 both use sandwich construction.

The Spectrum S-33 (right) is constructed using the company's Fibex process, which requires no autoclave.

However, some manufacturers adopt a different approach, closer to that of metal construction. These designs use solid laminate (as the skin), frames and stringers. Dassault uses this kind of design in Falcon empennages.

The suitability of a given process is dictated by the component application. For example, fiber placement works fine for wing skins and fuselages, but other processes are better for deep-cornered parts. "There is no one-size-fits-all process," Shumate said.

Composite Use in Business Aviation

Raytheon could justifiably claim to be the leader in the application of composite technology in business aviation. But some other major manufacturers have been quietly using these materials for a long time on primary structures. For example, in 1983 Gulfstream introduced a composite rudder on the GIII.

More recently, the Dassault Falcon 7X's tailfin box has been made using the RTM process. However, Dassault is staying with metal for most of the airframe, mainly because of production costs. But the French-based manufacturer has been preparing for the possibility of going all-composite. Through Fubacomp, a U10 million ($13 million) research project, the company manufactured a one-piece business jet fuselage. It used pre-impregnated carbon fiber slit tape and honeycomb core, the same process and material used for the Premier I and Hawker 4000.

The proof-of-concept barrel was produced at a BAE Systems facility in the UK. It is 14.7 feet long and 6.5 feet wide. It passed static tests in Toulouse, Dellus told **AIN**.

A follow-on to Fubacomp, Alcas, has started and will yield four demonstrators, including two related to business jets. "One will be an aft fuselage; the other will be a 'boxed structure,' demonstrating a wing or empennage," Dellus said. Infusion processes, such as RTM or RFI, will be used.

As demand for composite materials grows, suppliers are endeavoring to boost supply. For example, Hexcel last year launched a $100 million investment to increase its carbon-fiber production by 50 percent. The first carbon-fiber line in Europe will be operational near Madrid next year. Another line will be added to the existing U.S. facility in Salt Lake City.

Moreover, pre-impregnated composite material (prepreg) factories are to be built in Nantes, France, and Stade, Germany, near Airbus production facilities. Expansion is also planned at Hexcel's plants in Duxford, UK, and Parla, Spain.

There are limits to the application of composite material. Grob originally planned to install a carbon-fiber wing leading edge on its SPn utility jet. However, since deicing bleed air temperature was not compatible with the material, designers switched to aluminum for the leading edges. "We are still researching high-temperature compatibility for future projects," Strohmayer pointed out. Grob's target is 250 degrees Celsius (480 degrees F).

Friction Stir Welding

The way parts are put together has a significant influence on a manufacturer's choice of material. Eclipse Aviation originally planned to use composites for its Eclipse 500, but the company opted to use conventional aluminum alloys when it discovered that they were the only

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From Composites to Compost

The prospects of oil depletion have spurred research into vegetable-based (rather than oil-based) composite materials. "In some ways, oil-based composites can be seen as dinosaurs," Grob COO Andreas Strohmayer said. He sees vegetable-based composites as an easy solution to recycling issues. Such materials could decay like compost in one's garden, Strohmayer asserted.

Is this wishful thinking? Serge Dellus, head of Dassault's advanced technologies development center, pointed out that these materials need to be compatible with an airframe life of 30 to 40 years. Therefore, they should not decompose so easily, he said.

Raytheon experts noted that, although the new generation of composites holds some promise, its application to aviation is still far off. –*T.D.*

Are composites as repairable as metal?

Composite material repairability has long been a concern among manufacturers. "We do not want our customers to worry about structural repairs," said Andy Upinie, Cessna's director for research and advanced technology. This is a major reason why Cessna is staying with metal for primary structure.

German-based Grob Aerospace, a long-time promoter of composite materials with its light trainers, pledges easy field repairs on the SPn light jet. For small repairs, "no high pressure is needed, only vacuum, which can be handled in the field," COO Andreas Strohmayer said. If the airplane sustains damage larger than half the size of a standard sheet of letter paper, Grob has to become directly involved in the repair. The SPn's entire primary structure, including hinges and brackets, is made of composites.

Raytheon has developed two specific repair procedures. The first one involves a pre-cured piece that can be either chemically or mechanically bonded to the area of damage. The other one uses prepreg, which has to be cured.

Composites indeed may have some advantages over metal in terms of repair. "We have aerodynamically flush repairs; a composite airframe looks new after damage repair," Strohmayer pointed out. Paul Jones, chief engineer for the Hawker 4000 program, noted that much damage on metal airframes stems from corrosion and fatigue, neither of which is a factor with composite airframes.

"Composites are repairable with either metal or composite patches, but not enough technicians in the field have the required skills yet," Serge Dellus, head of Dassault's advanced technologies development center, said. Some types of repair have become commonplace. But a lot need a tailored answer, suggesting that the design office should be in the loop, he added. Repair processes, like the manufacturing process, still lack standardization. Once this is accomplished, the process would be simplified, Dellus maintained. –*T.D.*

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materials compatible with the fast assembly it sought.

The company does use some composite materials on the Eclipse 500 but not in primary structure. Eclipse developed the first civil aerospace application of a process called friction stir welding (FSW) to streamline the production process.

With one FSW gantry, a full set of Eclipse 500 welded panels can be produced in one shift. Every day, one night shift is devoted to maintenance of the FSW machinery. One gantry can therefore produce two aircraft per day. The manufacturer is installing a second gantry, Ken Harness, Eclipse Aviation's v-p of engineering, told **AIN**.

The Welding Institute, based in England, patented the FSW process in 1991. The Eclipse 500 is its first airplane application, after some uses in other transportation industries.

To weld two parts together, a profiled pin is rotated and plunged into the joint line. The parts must be clamped onto a backing bar. Frictional heat causes the work pieces to soften without reaching the melting point. The plasticized material is transferred from the leading edge of the tool pin to its trailing edge as the tool traverses the joint. The resulting "extrusion/forging process," as Eclipse puts it, leaves a solid-phase bond between the two pieces.

With friction-stir welding, unlike rivets, the joint is continuous. The process can be used to join dissimilar aluminum alloys. Eclipse uses it with conventional 2024 aluminum alloy, widely employed in aeronautics.

Other welding processes are poorly suited to aviation, said Jean-Claude Goussain, FSW center manager at the French Welding Institute. These processes involve a liquid-phase joint. Cracks could appear during the solidification of the high-performance alloys in use in aviation. There is no liquid phase in FSW.

Moreover, in FSW the joint coefficient is better than that of conventional joints, Goussain said. This is the ratio between the failure load of the joint in tractive effort and that of the base metal. FSW joint coefficient is one; it is 0.6 to 0.7 for conventional joints.

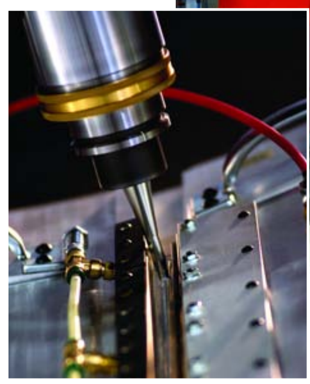
FSW increases throughput by reducing the production time. Harness said the cabin of the Eclipse 500 is made of three panels–two side panels, with door and windows, and one bottom panel. "Whereas an automated riveter would take ten hours, FSW does the job in 40 minutes," he told **AIN**.

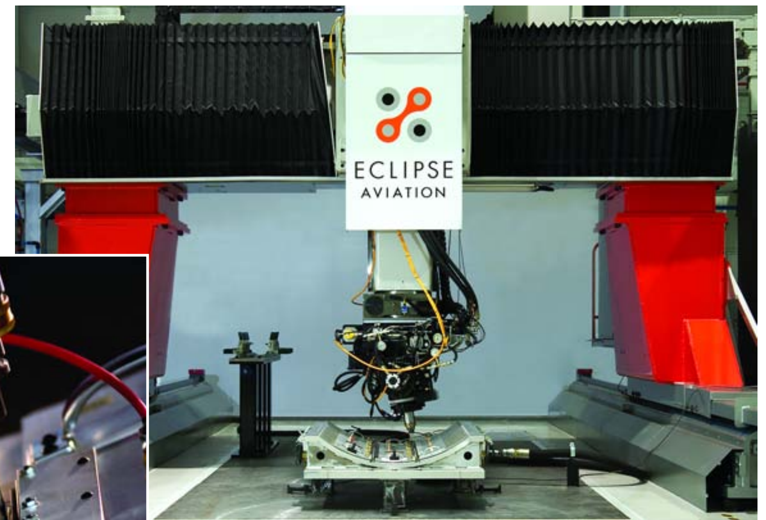
FSW assembly is also much faster than using composites. From the outset of the program in 1998, Eclipse planned to mass produce the airplane. "Autoclaves are not compatible with a production rate of five or six aircraft per day," Harness pointed out.

Advantages of FSW

Getting rid of the rivets brings a host of additional benefits. First, "You save weight by eliminating the rivets and suppressing overlap areas, which were necessary to rivet two parts together," Goussain said. In addition, the maintenance workload is reduced, as mechanics no longer have to check rivets or check for possible leaks due to rivet aging on the wing tanks.

FSW replaces 60 percent of the rivets that would otherwise be on the Eclipse 500. What can't it do? "It can only weld things that are reasonably accessible," Harness said. For example, the Eclipse 500 retains some rivets in the wing and empennage, which are enclosed structures.





Eclipse uses aluminum assembled by the process of friction stir welding, which reduces construction time and parts count.

Eclipse also encountered some challenges with FSW. First, the tooling inventory is said to be "immense," with special tooling to hold parts.

The National Institute for Aviation Research in Wichita has voiced concerns about the susceptibility of friction-stir joints to corrosion. Harness said that Eclipse has developed "a secret sauce that gets mixed in the joint." It was certified in 2002. "We continue to test for aging; results so far are excellent," he added.

Areas prone to corrosion are those where water can accumulate–such as the interface between stringers and fuselage skin, Goussain said. Moisture can form from the air's humidity and altitude changes.

The Eclipse 500 has 460 feet of friction-stir joints on its airframe. The company's design office is studying increasing the use of FSW, thus further reducing the rivets count. It is also trying to make the process even faster.

Airbus was planning to use FSW on the first version of the A350 widebody. But after the company decided to employ more composites on the reworked version, dubbed the A350 XWB, it is uncertain whether FSW will still play any role. Nevertheless, experts agree that FSW is particularly well suited to large structures. On a big airliner, some areas of the airframe are more easily accessible than they are on a light jet, and an FSW gantry could thus be used more extensively.

All aerospace aluminum alloys are compatible with FSW (7000, 6000 and 2000, including aluminum-lithium). In research now under way to use FSW with titanium or steel parts, the main issue remains the tool's resistance to hard metals.

What about structural health?

The debate continues about whether structural health monitoring should be implemented on composite airframes. On future aircraft, Airbus is considering embedding fiber optics in the structure. A crack or delamination would sever the fiber and thus interrupt the light flow, triggering detection.

However, Serge Dellus, head of Dassault's advanced technologies development center, expressed doubt about the usefulness of the system. "We have no maintenance issue with our structures," he said, adding that the idea is premature. He insisted that tolerance for aging is built into structural design and certification. Moreover, impacts leave visible marks on a composite structure.

It might sound like science fiction, but a self-healing composite material is feasible. For example, the manufacturing process could leave tiny drops of resin close to similar drops of hardener in the matrix. A shock would burst and mix the two elements, thus repairing the matrix. However, the repair would be a partial one, as the repair would not heal the fibers in the reinforcement. *–T.D.*

Cessna is exploring FSW for possible applications on its Citation business jets. Friction stir processes can be used for purposes other than welding, such as changing material properties, Andy Upinie, Cessna's director for research and advanced technology, explained to **AIN**. "Similar to heat treatment, a friction process can improve a metal's formability or strength," he said.

The Wichita-based manufacturer also has developed "improved metal bonding" processes that it claims yield lighter, more maintainable bonds. Paradoxically, one of them uses an autoclave, the costly element of composite construction that manufacturers are eager to eliminate.

Improved Conventional Materials

Suppliers of aluminum, such as Alcan and Alcoa, face tough competition from composites and thus are working hard to offer improved alloys. Compared with standard aluminum alloys, aluminum-lithium is said to have higher stiffness, lower density and better corrosion resistance. Airbus has already started using aluminum-lithium alloys, and business aircraft manufacturers, including Cessna and Dassault, are watching closely. When lithium comprises 2 percent of the alloy, there's a 10-percent

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Friction stir processes can also be employed to change material properties, which Cessna is studying for use on its Citation line (left).

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weight saving over regular aluminum, according to Tasadduq Khan, a material expert at French aerospace research office Onera.

On the Falcon 7X, Dassault used a 7000-series aluminum alloy for the upper surface of the wing. Its added stiffness makes it well suited to the surface area, which is larger than that of other Falcon wings, Dellus explained. In a process called edge-forming, sophisticated tooling is needed to avoid shape change during the cooling phase. A 2000-series alloy was retained for the lower surface of the wing, the goal being higher strength at low temperatures.

Dellus noted that damage tolerance in metal structures is improving. Another trend is to use less material. Machining a part usually removes 80 to 90 percent of the metal ingot from which the part is made. Although the removed material is recycled, there is clearly room for optimization. Some other processes are much more efficient in this regard: integrated stiffened panels, using an extrusion process, use less material.

However, Dellus asserted that metal technology has tended to plateau when viewed in light of the rapid advances in composites. Corrosion protection remains crucial with metals, but in a world that is growing more pollution conscious and more strictly regulated to reduce environmental damage, the chemicals used are increasingly seen as villainous. Despite the advantages of composite materials and the relatively stagnant technology of metals, business aircraft manufacturers choose to stay with metal for most of the airframe. They see composites as still being more expensive overall. Also, "metal alloys outperform them in traction and compression strains," Dellus said. ❑

Oil price impact?

How is the price of crude affecting composites, which are derived from oil? Promoters of composite material contend that the price of the raw material is only one figure in a big equation. They also point out that producing aluminum alloy requires a lot of energy, which is most often generated by burning oil-based products.

Moreover, the growing popularity of composite materials is seen as a favorable trend. Boeing and Airbus are quickly moving to almost all-composite airframes on their new designs, the 787 and A350. Business aircraft manufacturers expect this to translate into significant standardization. "We hope that increased production volumes will help material suppliers set up cheaper processes," Dassault's Serge Dellus told **AIN**. *–T.D.*

Business aircraft manufacturers see the airlines' acceptance of composite materials (here on a 787 wingbox) as portending less expensive materials through standardization.

Nano Future

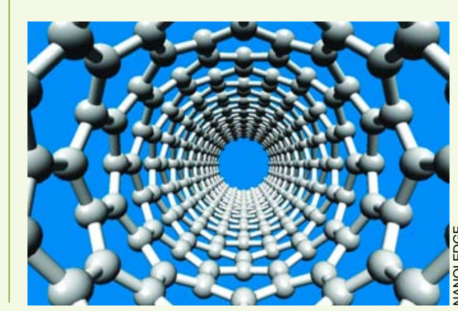
Carbon nanotubes have been proposed as the only material both light enough and strong enough to serve as the building blocks for a ribbon that would tether a space station to earth and serve as a ladder for an elevator to climb, and they might well spell the future of composites for airplanes too. According to Andy Upinie, Cessna's director for research and advanced technology, company experts are closely watching them for application in five to 10 years. Gulfstream structures staff scientist Frank Simmons told **AIN** that "nano composite technology has the potential to make a huge impact on the composite industry."

They are still in the laboratory phase and therefore extremely expensive. But major weight savings could come from replacing conventional reinforcement with carbon nanotubes. For a given stiffness, the composite's matrix has to be loaded with only one-tenth [this is just an order of magnitude] of the amount of conventional fibers. This would yield a major reduction in weight. Key will be the ability to disperse these nano structures. For the aerospace industry, nano technology researchers are considering carbon and silicon-carbon reinforcements. They could withstand the hot and corrosive environments found on aircraft.

In a recent research program, Rolls-Royce has studied the use of carbon nanotubes to reinforce syntactic foams. The idea is to use the combination as a filler for rotating fan blades in turbofan engines. Nano-reinforced foam can act as a strengthener and a damper.

In France, near Toulouse, the so-called Aerospace Valley competitive hub has launched a €13-million ($17 million) research program. Dubbed Nacomat, it involves 30 companies and laboratories. All are convinced that current materials are plateauing. They believe that a new generation of composite materials developed from the nanometric scale could provide the sought-after leap in the areas of airframe damage tolerance, weight, engine efficiency, brake wear, noise and cost of ownership.

Another benefit of nanocomposites could be built-in electrical conductivity. Currently, some metal has to be woven into composite subassemblies to ensure conductivity–in case of a lightning strike, for example–adding cost and weight. In future, conductive nanoloads could replace this technique. *–T.D.*



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