The long wait is nearly at an end. Final assembly of the first Airbus (Toulouse, France) A350 XWB midsize passenger jet, an A350-900, is expected to begin by the end of this year and be completed by the fourth quarter of 2012, in time for its scheduled first flight. Assembly of its major fuselage and wing components is underway. The forward and center sections will ship from the Airbus facility in Saint-Nazaire, France, and the rear fuselage will come from the Airbus plant in Hamburg, Germany. For each aircraft produced, the new final-assembly line in Kinston, N.C., will receive the three sections produced, the new final-assembly line in Hamburg, Germany. For each aircraft fuselage will come from the Airbus plant in Saint-Nazaire, France, and the rear sections will ship from the Airbus facility in Hamburg, Germany.

The center fuselage (denoted section 15 by Airbus) is the longest of the three, at 65 ft/20 m. Section 15 is built up from six sizeable composite panels made by Spirit Aerosystems (Wichita, Kan.). Manufactured at Spirit's 640,000-ft²/63,360-m² facility, which opened last July in the U.S. (Kinston, N.C.), these components exemplify a distinct design approach adopted by Airbus in pursuit of not only the weight and performance benefits of composites, but also ways to address potential issues, such as lack of electrical conductivity, without increased cost (see “Panelized option attested early on,” on p. 97).

Also part of Spirit Kinston's scope of work for the A350 are the three-piece, all-composite 102-ft/31 m front spars for the wings. The three-part forward spar aids in assembly at the Airbus Broughton wing plant and avoids bottlenecks. And it will accommodate new processes in the future. The ability to adapt to the changing production needs of its customer, Airbus, is a key focus for Spirit. The 574 orders currently on the Airbus books for the A350 XWB “is a large number of planes,” points out Dan Wheeler, a Spirit VP and the general manager of the Kinston facility. He adds, “We have set up production here to be able to meet Airbus' schedule as production ramps up.”

**Intelligent design: Fuselage**

A notable characteristic of the A350 design is that the main fuselage comprises modules, as necessary, to relieve bottlenecks. And it will accommodate new processes in the future. The ability to adapt to the changing production needs of its customer, Airbus, is a key focus for Spirit. The 574 orders currently on the Airbus books for the A350 XWB “is a large number of planes,” points out Dan Wheeler, a Spirit VP and the general manager of the Kinston facility. He adds, “We have set up production here to be able to meet Airbus' schedule as production ramps up.”

**Spirit AeroSystems actualizes Airbus’ intelligent design for the A350’s center fuselage and front wing spar in Kinston, N.C.**

BY GINGER GARDINER

The Airbus A350-900, is underway. Major fuselage and wing components will flow from Spirit Aerosystems’ Kinston, N.C., plant to Europe, toward final assembly in Toulouse, France, near the end of next year.

The A350 XWB Update: Smart Manufacturing

**Fuselage section demonstrator**

This panelized A350 fuselage section, at 18m/59 ft long and more than 6m/19.7 ft in diameter was the second ever made, and closely reflects the A350 XWB fuselage’s final design. Although it was constructed of 12 panels, the panels used in production sections will run the length of the barrel. — including aluminum seat rails and a mix of aluminum, aluminum/titanium alloy and titanium for lower frames and passenger cabin structural floor grid structures, the current from a lightning strike will seek any metal paths available, such as fasteners. For this reason, both the 787 and the A350 make strategic use of metal parts. Selections were made based on the parts’ ability to provide necessary structural reinforcement in some highly loaded regions while facilitating an electrical return path for the internal electrical systems and equipment. All of the A350’s metal parts are said to be better placed for load and weight optimization. This design is expected to avoid the fit issues Boeing had when it joined the first 787 barrels made with totally different tooling approaches, and it facilitates manufacture and assembly via easier parts handling, less complex and lighter tooling, and less expensive second section production.

Because the fuselage sections’ carbon fiber composites do not conduct electricity as well as aluminum alloy structures, the current from a lightning strike will seek any metal paths available, such as fasteners. For this reason, both the 787 and the A350 make strategic use of metal parts. Selections were made based on the parts’ ability to provide necessary structural reinforcement in some highly loaded regions while facilitating an electrical return path for the internal electrical systems and equipment. All of the A350’s metal parts are said to be better placed for load and weight optimization. This design is expected to avoid the fit issues Boeing had when it joined the first 787 barrels made with totally different tooling approaches, and it facilitates manufacture and assembly via easier parts handling, less complex and lighter tooling, and less expensive second section production.

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avoids added structure associated with dedicated ESN components and the resulting weight penalty that would offset the lightweight advantage of a CFRP fuselage. As a result, the six assembled sections of the center fuselage, at 64.6 ft/19.7m long and 22 ft/6.7m in diameter, will weigh a mere 9,000 lbs/4,082 kg.

Intelligent design: Wing
The A350 wing design also benefits from topology optimization, a finite-element-based analysis that determines the most efficient material layout for a structure (see "Topology optimization," below). This technique was used, and its benefits were proven, for a variety of structures that make up the A380 wing, including the leading-edge stiffening ribs. For the A350, topology optimization was employed earlier and more extensively as Airbus sought higher performance within a more efficient design process with less cost.

In addition to the all-composite front spar, advanced composite materials enable passive and active load-control mechanisms that improve the A350 wing aerodynamic and structural performance. Passive adaptivity is achieved using aerostatic trailing, a design technique for aerodynamic surfaces in which trailing edges and cilia are matched with the likely aerodynamic loads that may be imposed on them. The A350 composite wing also takes advantage of maneuver load alleviation (MLA), which provides active load control. MLA is a system for reducing wing bending moment load during aircraft maneuvers. The digital flight control system automatically adjusts the control surface deflections along the span of the wing to optimize and evenly manage the loads, from the wing root all the way to the wingtip.

Another aspect of this design is variable camber. The A350 will be the first Airbus aircraft capable of this function, which will rely on a wing flap system that allows for differential inner and outer flap settings. A gearbox and motor are mounted between the outer and inner flap, enabling differential control of each flap’s angle after they have been retracted.

The center of lift position also can be changed for load management. For example, the inner flap can be set slightly down, shifting the center of lift inbound for heavy weight situations. It is also possible to move both flaps together up or down a small amount, which improves wing performance by tuning the peak lift-over-drag ratio. During cruise, the flap functions will be controlled automatically by the flight control computer, which continuously sense data from the flight management system.

The overall result is an extremely efficient wing that produces more lift with less weight and is capable of advanced handling performance that also helps to reduce the aircraft’s fuel burn.

Manufacturing: Center fuselage
Section 15 is not only the largest fuselage section, but also the most complex. Four of its panels have constant-curvature surfaces, but because it is adjacent to the wing, the two lateral junction panels (see dark blue parts in “Center Fuselage Section 15,” on p. 59) have both convex and concave curves, which provide an aerodynamic fairing and structural connection to the all-composite wingbox.

The section 15 begins with an Electrolaprm (Mülkiteo, Wash.) SI-15 dual-head automated fiber placement (AFP) machine that was specifically designed for these large structures. Electrolaprm engineered the S-15 to perform on-the-fly feeding and cutting and fully bidirectional lay-up over ranged, complex surfaces within customer place- ment tolerances and with full operator control over the feed rate at speeds up to 2,000 inches/min (50.8/mm/min). Necessary for the large fuselage panels, the high speed was achieved by re-engineering the guillotine-cutting system and optimizing the feed, tow path and creel and machine-control systems.

The machine lays up Hexply M-21E carbon fiber/toughened epoxy prepreg from Hexcel ( Stamford, Conn.) onto a male in- vat tool. The first section 15 crown panel was completed in November 2010. All of section 15’s panels incorporate integrat- ed CFRP stringers, which are produced using a cantilever-type AFP machine built for high-speed 2-D laminating by M’Tors (Torres de Elotz, Spain). The stringers then are placed onto the composite panel layups and cocured under vacuum in one of two 88-ft/24-m long by 22-ft/6.7m diameter autoclaves. (The first has been installed; the second will be added as production increases.)

Panelized option attested early on
Although it was developed independently by Airbus (Toulouse, France), this approach to constructing the A350 XWB’s fuselage sec- tions — the use of large composite panels attached to frames — is comparable to the optimal design conclusion reached by the Advanced Technology Composite Aircraft Structures (ATCAS) program back in the late 1990s. ATCAS was part of the National Aeronautics and Space Admin. (NASA) Advanced Composites Technologies (ACT) initiative in the U.S. Under the ACT mandate, the development of an all-composite com- mercial transport aircraft was split between two parallel programs: McDonnell Douglas Aerospace Co. (Long Beach, Calif.) was tasked with the design and development of a full-scale all-composite wing, and the ATCAS program, conducted by Boeing Commercial Airplanes (Seattle, Wash.), was to do the same for a composite fuselage. According to publicly released reports in 1997 and 1998 by ATCAS’s technical leader Peter Smith and principal investigator/structural engineer Dr. Larry Iwczewicz (currently the Federal Aviation Admin. National Research Council specialist for advanced composite materials) each area of a composite fuselage (crown, sides and keel) presents unique structural design challenges. The crown panel is primarily governed by tension loading, the sides are dominated by shear and pressure load redistribution around windows and doors, and the keel is subject to complex loading dominated by axial com- pression and load redistribution from the keel beam. The reports also note that the panel- and-frame approach reduces panel assembly costs because it requires fewer longitudinal splices and leverages the size efficiencies of automated fiber placement (AFP) manufactur- ing while maintaining design flexibility within each uniquely loaded area.

Side Story
Although the company’s Web site gives the example of a nature does in bones, trees, and bird wings, for optimization as a finite element analysis (FEA) that have been employed in the aircraft design process.

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As one of the pioneers in the use of topology optimization in aircraft design, Toulouse, France-based Airbus used OptiStruct software by Altair Engineering (Troy, Mich.) for design optimization on the A350 XWB to support weight reduction, including the fuselage tail (Section 19), wingbox and wing flap support structure. Common results include 30 percent weight reduction, 30 percent improved performance (e.g., stiffness, strength) and 50 percent cost savings. A-E-S Europe (Hanover, Germany), a computer-aided engineer- ing (CAE) firm that specializes in simulation and structural optimization, describes topology optimization as a finite element analysis (FEA) algorithm that evolves the optimal lightweight shape for a structural design, similar to what nature does in bones, trees, and bird wings, for example, but in a week vs. hundreds of years.

The company’s Web site gives the example of a 5-MW wind turbine for which the manufacturer needed to significantly reduce, within a tight time line, both weight and plausibility mass without increasing structural stress or reducing stiffness. A-E-S Europe used topology optimization to derive a completely new shape within one week. The result cut the mass of the two components by 35 percent without increasing the maximum stress. This was accomplished by removing dead mass (mass where it does not support functionality), adding mass to the structure along key load paths and making a homogeneous stress distribution, that is, stress distributed uniformly throughout the structure without peak stress points.

For Airbus, topology optimization is just one of many computer-aided optimization techniques that have been employed in the aircraft design process — and employed early on — to reduce time and cost. In fact, these techniques have become absolutely necessary to success- fully optimize the complex composite structures of modern aircraft. For example, one of the optimization models for the A350's fuselage skin is 820,000 differ- ent design variables, including ply thicknesses, fiber orientations and stringer cross-sections, as well as 300,000 constraints, such as skin buckling, minimum strength and manufacturability parameters. Scoring optimization for the A350 composite forward fuselage required that Airbus engineers address 14,000 design variables, including ply thickness, etc.) and more than 1 million constraints. This forced the team to break the structural optimiza- tion model down into smaller components to reduce the variables and, thus, successfully size the components for initial design.

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An automated TORRESMILL router removes the window and door cutouts from the large side panels. MTorres also supplied Spirit’s two 5m/16.4-ft tall columnar UT inspection machines, each with a separate array of UT scanners, to achieve simultaneous inspection of inner and outer skins for each fuselage panel. After inspection, the finished composite panels are attached to the fuselage frames. Most of the frames are composite, but a few are aluminum to support the ESN. Additionally, the door surrounds are titanium. The frames and surrounds are attached with automated equipment.

After they are completed, the Section 15 panels will be nested into a 70-ft/21m container. They will be transported by road to Morehead City, N.C., or another port in that state, and then by ship to the Spirit AeroSystems facility in Saint-Nazaire, which is located near Airbus’ Aerolia facility in northwest France. Spirit’s 60,000-ft²/5,574m² plant in Saint-Nazaire is an assembly-only facility officially opened July 23, 2010 and operational later that year. Where the three upper shell panels are joined together with the forward and aft passenger floor. The remaining three panels are shipped loose and installed by Airbus Saint-Nazaire on the section 15 unit. Afterwards, the section will be mated with the center wingbox, which will arrive from Airbus Nantes (located 50 miles/80 km to the east), and equipped with piping and other systems. Then the center fuselage/wingbox unit will ship by air to Toulouse for final aircraft assembly.

### Producing forward wing spars

The A350’s forward wing spar, a 102-ft/31.2m long structure, is the largest spar Spirit has ever made, and it is Spirit’s first all-composite spar. The structure comprises three parts from root to tip: a 7m/23-ft long inner spar, a 12.7m/42-ft long middle spar and an 11.5m/38-ft long outer spar.

The spar parts are made with up to 160 plies of CFRP, tapering from a width of 6 ft/1.8m at the root of the inner spar to, roughly, a width of 1 ft/3.3m at the tip of the outer spar.

MTorres has been a key partner in developing Spirit’s spar production capability. Two of the company’s TORRESFIBLEAFP systems were specially designed to provide greater flexibility and productivity than would be available with either conventional gantry or column-type machines. Reportedly, these AFP systems are capable of layup rates as high as 2,360 inches/min (60m/min), an order of magnitude greater.
er than previously possible and key to making the spar production process in Kinston economically viable. MTorres has delivered similar equipment to GKN Aerospace’s (Redditch, Worcestershire, U.K.) new facility near Filton, U.K., for production of the A350’s rear wing spar. These machines were developed to achieve the tight U-shaped geometry along the spar components’ edges — where many issues arise when 45° material is applied over 90° corners. The machine heads also deliver the higher temperature and greater compaction pressure required to successfully process the relatively low-viscosity Hexply material — the same M-21E toughened epoxy prepreg that is used to layup the fuselage panels. Each of the MTorres machines can lay two spars simultaneously on 15m/49-ft Invar mandrels, which are then transferred to the autoclave for curing.

The cured spar components are checked for quality, using an automated gantry-based TORRESONIC UT inspection machine, measuring 15m/49.2 ft long and 2m/6.6 ft wide. MTorres built the frame and attached a commercially available robot by Kuka Roboter GmbH (Augsburg, Germany), with electronics supplied by Tecnomat SA (Madrid, Spain). The finished spar sections are shipped to Spirit’s Prestwick, Scotland, facility, where they are joined together, mated with the fixed leading edge and other fixtures, then delivered as a complete leading edge assembly to Airbus’ Broughton facility for final assembly with the A350 wing. The first complete outer spar was shipped Dec. 10, 2010.

**Inner spar demonstrator**

This early version of the A350 wing’s inner spar was produced using a TORRESLAYUP AFP system, built by MTorres (Torres de Elorz, Spain).