The continuing growth in air travel has spawned major expansions in commercial airliner manufacture, not least by Airbus, the European partnership in which BAE Systems has a 20 percent shareholding and European Aeronautic Defence and Space Company (EADS) 80 percent. Airbus UK, which is responsible for the wings of all Airbus models, has made major investments to increase production and satisfy market demand as well as reduce costs and further improve quality. A significant proportion of this spend has been aimed at improving wing assembly by reducing reliance on manual methods and dedicated fixturing. Included in this agenda is research to develop and prove-out methods for automating wing box assembly, and the second phase of the Automated Wing Box Assembly (AWBA) project has recently been completed at Airbus UK’s Broughton plant with part funding under the UK government’s Civil Aviation Research and Demonstration (CARAD) programme.

Airbus UK, which employs over 9,500 – equally split between Filton in Bristol and Broughton in North Wales – is the UK’s national entity of the new Airbus Integrated Company (AIC), which began operation on 1 January 2001. AIC, which incorporates the “old” Airbus Industrie and all the major Airbus activities of BAE Systems and EADS, generated a turnover of $17.2 billion in 2000. Its “fleet” of 14 aircraft range in size from the new, single-aisle, 100-seater A318 to the recently launched, 550-seater, “double-decker” A380 that now has firm commitments from six airlines.

The UK headquarters of Airbus UK at Filton is also home to the main UK design and engineering facilities, while the principal manufacturing plant is at Broughton. The latter was established in 1938 by Armstrong Whitworth, and has a proud history in British aircraft manufacture. It built over half the Lancaster bombers that went into the second world war service and later the Comet jetliner. Its association with Airbus began in 1971 (then Hawker Siddeley Aviation), as sub-contractor for the wings of the first Airbus, the A300. Every wing of the 2544 aircraft so far delivered by Airbus was built at Broughton, as will the 1626, on order at the end of 2000. These are delivered to the final assembly lines at Airbus Deutschland (Bremen and Hamburg) and Airbus France (Toulouse).
The wing of a modern aircraft is made up of the main central wing box plus the leading and trailing edges (Figure 1). The completed wing box of an Airbus is a massive structure, measuring up to 32m long × 7.5m wide and 1.6m deep for the very long range A340-500/600 (Plate 1), which is claimed to have the world’s largest aircraft wings – the wing box of the A380 with a 36m span will be even larger.

A wing box is made up of three major components; the ribs (up to 41), the longitudinal spars (between four and seven) and the skin panels (up to four on the top and four on the bottom), which are strengthened with rows of stringers attached by thousands of rivets and bolts.

**Automatic riveting**

Over £400 million has been invested in wing box production at Broughton over the past four years. This includes £21 million on an Ingersoll spar milling machine, the only one of its type in the world, £6.6 million on a 41m long × 3.2m wide skin mill for machining A340-500/600 panels, and £21 million on two low voltage electromagnetic riveting machines (LVER), also for the A340 range. The latter automatically drills the holes and inserts the fasteners to attach stringers to the skin panels in a continuous operation – approximately 65,500 rivets and 32,000 bolts are used in assembling one A340-500/600 wing skin.

The wing box is built up in the assembly jigs (Plate 2) where the ribs and spars are loaded in a set sequence. The skin assemblies are then progressively located and drilled before being bolted to the supporting ribs and spars. Currently, this is a labour-intensive process using manual drilling and fastening methods with dedicated jigs and fixtures. Ideally, much of this process should be carried out automatically, but presents many difficulties, not least the sheer physical size of the components involved and the accuracies of alignment needed. It was to study potential solutions to these and other problems that Airbus UK initiated the AWBA research project.

AWBA has been carried out in two phases, each of two years’ duration: the £2 million AWBA 1 completed in 1997; and the recently concluded AWBA 11, which had a £5 million
budget. Both phases were 50 percent funded by the DTI under the CARAD programme. The first phase was to identify and acquire specific technologies for automated assembly of large wings while the prime objective of AWBA 11 was to demonstrate flexible manufacture within a single automated assembly cell at the same time as securing further enabling technologies and identifying technology gaps.

Both phases involved several partners. In phase two, these were AEA Technology (robotic fastening process control), automated handling and positioning systems (AMTRI), BAE Systems Advanced Technology Centre (ATC) – Sowerby (vision and sensor automated positioning systems), Leica (measuring systems), RTS Advanced Robotics (robotic technologies) and Tecnomatix (software and simulation) as well as Airbus UK who project managed the programme and provided the facilities and materials.

**AWBA demonstrator**

Set up in a converted hangar alongside the main Broughton wing production facility, the 8.5m high AWBA 11 cell demonstrator (Plate 3) is able to build a four-rib wing box section for Airbus’ largest aircraft, the A380, with the minimum of manual intervention. It undertakes all the elements needed in the assembly from the precise handling and positioning of the 6m high ribs to drilling and fastening the skins to the ribs. However, it is not a production cell and cannot build a complete full-length wing box.

The cell is of a gantry construction that allows the wing box to be assembled with the rib vertical, the concept for which was developed by AMTRI. The upper raft fixed below the gantry cross member holds the tooling for the leading edge spar, while tooling to locate the trailing edge spar is mounted on the lower raft close to floor level. With the two spars in position, the first operation is to place the ribs between the two spars, for which AMTRI developed the rib carrier robot.

The two spars have a series of pockets to accept the ribs and the robot has to manipulate a rib into these two sets of pockets. To accomplish this, the rail mounted rib carrier robot has a pivoting axis in addition to three linear XYZ axes. The sequence is to take a rib from the store, tilt it at approximately 45° to the vertical using the pivot axis, move it into position so that the bottom edge of the rib locates into the lower (trailing edge) spar and then bring the rib to the vertical so that the upper edge locates into the upper (leading edge) spar. The rib is then clamped hydraulically.

Locating the rib into the spars requires the robot to position to an accuracy of ±0.5mm, which for such a large structure is precise. This is accomplished with the aid of the Leica laser tracker system, which measures the position, in this case, of the upper and lower spar tooling and communicates any off-sets to the robot. The Leica system is used in industry, particularly in aerospace and automotive industries, for large-scale, 3D metrology, and is capable of measuring to accuracies of ±0.05mm over distances of up to 35m. The unit’s motorised head directs the laser beam over a 3D volume up to 70m diameter to locate and measure the 3D co-ordinates of target reflectors placed at the measurement positions. In the case of the AWBA demonstrator, the transmitting unit is located on one of the gantry legs but it is also portable.

**Skin wrapping**

After fixing a set of ribs in position, the next operation is skin wrapping, which was also the responsibility of AMTRI. Skins are taken from the store and simultaneously placed against pads on both sides of the ribs either
two or four at a time and then clamped by a series of programmable pneumatic clamps. Working from both sides balances the load when the clamps are applied and avoids having to construct a highly stiff supporting structure. The skin sets cover the trailing (lower) and leading (upper) part of the wing box, leaving the centre section open to allow access for internal fastening, and in production for manual assembly and inspection.

Fastening of the skins to the ribs in the demonstrator involves both external (to the wing box) and internal operations, for which two separate robot systems were developed. The external work of drilling the hole and inserting the fastener is done with a standard Kuka K350 six-axis robot rail mounted (seventh axis) and equipped with a sophisticated end-effector developed by BAE Systems ATC. The end-effector incorporates a vision sensor, high-speed spindle drilling head and stud inserter (Plate 4).

Before skin wrapping takes place, the robot uses the vision sensor, which consists of two cameras and four laser ranger finders, to locate the 3D position of each pad on the rib. This is memorised so that after the skin has been placed the Kuka robot knows exactly where to drill through the skin and the pad in one operation. Each hole four per pad is drilled and deburred and then a stud inserted in a cycle time of 15 seconds per hole. During these operations the robot’s six axes are locked in position; in effect the robot is merely an “end-effector positioner”. Responsibility for the drilling technology for these operations rested with AEA technology. It undertook tests to establish the optimum drilling parameters and cutting conditions to ensure maximum hole quality and minimum burr size. It also carried out modal analysis and vibration trials on the robot to study the effect of these factors on hole accuracy when drilling automatically.

Swaging of the fastening collar to the stud inserted during the latter operation is done by the internal robot, which was developed by RTS Advanced Robotics (formerly UK Robotics). Because of the restricted opening into the wing box – approximately $1 \times 1.5m$ – and the $5.5m$ reach to access the back of the fastener through the far side skin, RTS could not apply a standard, off-the-shelf robot and had to develop a “special”.

**Deployment robot**

The finished device is a 10 degrees-of-freedom robot with a reach of $6.5m$. It is made up of the deployment robot, a telescopic boom that swivels about a horizontal axis and is mounted on a linear track to allow access to the full length of the wing box, and a standard Fanuc six-axis parallel leg robot. The latter is fitted to the end of the boom arm and basically acts as its end effector. The ultimate tooling consisting of the swaging unit with collar feed and stereoscopic vision sensor (developed by BAE Systems ATC) is mounted on the end of the legged robot. The sensor guides the robot to find the stud end so that the tooling may dock with the stud. The collar then slides over the stud and is pulled tight before it is swaged onto the stud.

The internal robot is designed to behave like any other industrial robot, with the exception that positioning for set-up and programming is done by a teleoperator-type strategy. This is to avoid placing an operator or programmer in a potentially unsafe position within the confines of a wing box and also to overcome the problem of a large and heavy robot arm in a remote position. Using the teleoperator system, the end effector is positioned remotely using television cameras that form part of the tooling, to observe movement. As a further safety measure, the
robot arm is fitted with capacitance sensors to detect the onset of a collision, whether during teleoperational set-up or automatic operation.

Throughout the second phase of the AWBA project, extensive use has been made of software planning and simulation tools, for which Tecnomatix provided the solutions with its eMPower software products. RTS Advanced Robotics used these robotic simulation and off-line programming tools routinely for design of the internal robot, and BAE Systems ATC used them in the design of the external drilling and fastening robot. The whole cell was simulated in 3D to help the partners understand the interactions of the various sub-systems and to provide a visual tool for developing the optimum sequence of operations. It was also useful in supporting line-of-light studies during development of the laser tracking measurement system.

At the later stages of the project a final model of the whole cell was produced that enabled the cell’s entire build process to be viewed in 15 minutes, which in “real life” would have taken one-and-a-half days. Subsequently, the simulation model was scaled-up to the assembly of a full production wing box, allowing its physical feasibility to be assessed, the operational sequences and cycle times to be established and the likely cost of a full-scale production facility to be estimated.

Airbus UK states that the test work carried out in the cell has met all expectations and has already proved the concept of automatic wing skin panel wrapping. It is capable of handling and positioning a 6m high wing rib quickly and safely. It will continue to use the cell to assess the “scale-up” implications as well as the impact of the automatic methods on aerodynamics and systems and on health and safety. However, no decision has been made on which technologies used in the demonstrator will be implemented into full-scale production, nor have any time scales been laid down.