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HAWDE Five Axis Wing Surface Drilling Machine

Rick Calawa
Electroimpact, Inc.

Steve Smith, Ian Moore, and Tony Jackson
Airbus UK, Ltd.

ABSTRACT

The Horizontal Automated Wing Drilling Equipment (HAWDE) machine is an enabling technology for automated drilling of large aircraft parts. HAWDE is a five axis drilling machine that operates over the upper and lower surfaces of eight wings, each more than 40 meters long and four stories tall. The machine accesses the entire A380 wing using a combination of elevators and a machine transporter that carries the machine from surface to surface. HAWDE drills holes in spars, butt splices, and rib feet in the wing box final assembly jigs for A380.

INTRODUCTION

The new Airbus A380 is the largest commercial aircraft ever built. Airbus UK is responsible for providing the A380 wings, and for this they have constructed a new factory in Broughton, Wales.

In designing this new aircraft and new factory, Airbus was determined to push forward the use of automation wherever possible to reduce costs and improve quality. On the A320 and A340 programs, Airbus had realized reduced costs and improved quality due to automation of wing panel assembly. On A380, they wanted to extend the benefits of automation to wing box final assembly.

THE DEVELOPMENT OF HAWDE

Several machine and assembly jig concepts were proposed, but early discussions quickly concluded that full automation of wing box drilling could not be achieved in time for the first wing build. A scalable approach was needed. On day one, the machine would drill alongside workers with traditional hand drills and templates. Over time, more and more drilling would be automated.

As drilling is only one portion of the work of final wing box assembly, it is also imperative that a drilling machine not interfere with general access to the wing.

Production rate is always a consideration with automation. If the drilling time and re-work in the wing box were sufficiently reduced, Airbus concluded that they could reduce the number of assembly jigs required to meet production demand. This has huge impacts on factory space, capital equipment costs, staffing and maintenance costs for the program.

Lastly, considerations of machine utilization and work flow clearly pointed toward small, movable machines rather than large dedicated machines. The A380 wing box assembly facility consists of four, enormous four-story tall structures, each designed to hold one port and one starboard wing (see Figure 1). If a machine were restricted to a single floor of a jig, or even to a single wing surface, it would be idle (and probably in the way) during panel load and unload, sealing, bolting, and wing removal. It became clear that the HAWDE must move from floor to floor, surface to surface and jig to jig.

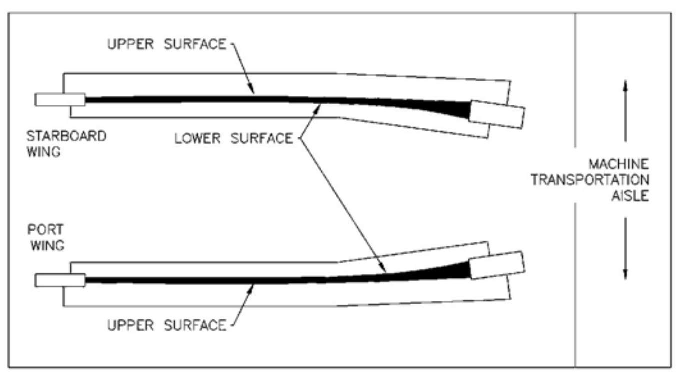

Figure 1a. A380 Wing Box as Oriented in Assembly Jig – Plan View

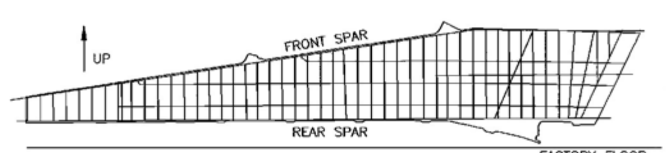

Figure 1b. A380 Wing Box as Oriented in Assembly Jig – Elevation

DESIGN CHALLENGES

The design goals of HAWDE presented several significant challenges:

1. Extremely large work envelope : 42m x 8m x 2m
2. Fitting the machine between floors (to minimize interference with manual operation) and yet accessing the entire wing surface.
3. Moving the machine between floors.
4. Moving the machine between wing surfaces and jigs.
5. Referencing the machine's location in the jig and to the wing.
6. Validating the cutting tool and drilling process.

CHALLENGE #1: WORK ENVELOPE

The A380 wing is huge. The lower surface, with it's high curvature, sweeps out a particularly large volume: 42m long, 8m high and 2m deep. A conventional machine with 8m of Y travel would be enormous. This approach was quickly discarded in favor of a small machine which rides on the structure of the assembly jig to reach high up on the wing.

In order to maintain accurate tooling locations and minimize the foot print of the jig, it's critical to place the fixed structure of the jig as close as possible to the wing. This leaves a narrow corridor with a bend or 'kick' in it between the wing and the jig columns. With this envelope, straight X rails became impractical . Two options were considered:

- Design a machine which uses a small X/Y frame and re-position the frame several times
- Design a machine that can drive around a corner.

The first option was dismissed due the number of times a frame would have to be re-positioned. The jig columns are on 3m spacing. This means that a machine using an X/Y frame would have to be re-positioned at least 15 times to drill the rear spar for example.

Instead, the HAWDE X drive was designed to negotiate a curved section of rail. The HAWDE is cantilevered out from upper and lower hardened and ground square rails at the column line of the jig. The curve in the rail is approximately 8 degrees on the lower surface and 2 degrees on the upper. The rails are not continuously curved. They are straight except for a short, 300mm section with a radius of roughly 2m.

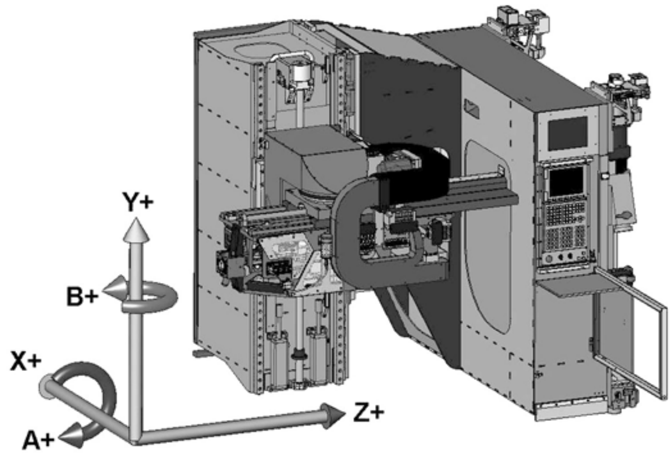

Figure 2. HAWDE Machine Axes

The complex kinematics required to position the toolpoint of the machine are performed within the Fanuc 15i machine control. This means that an entire wing surface can be programmed from a single Cartesian coordinate reference without the need for sophisticated mathematics in the post processor.

HAWDE transitions from straight rail to curved and back to straight without interruption. The machine maintains full toolpoint accuracy around the kicked rail without adjustment or pause. The HAWDE toolpoint accuracy is +/- 300um in X, +/- 200um in Y, and Z over 20m of X axis travel.

CHALLENGE #2 FITTING BETWEEN FLOORS AND REACHING ENTIRE WING SURFACE.

While the HAWDE machine must be able to reach any point on the wing surface, it's highly desirable that the machine be able to traverse without requiring the access floors above it to be raised.

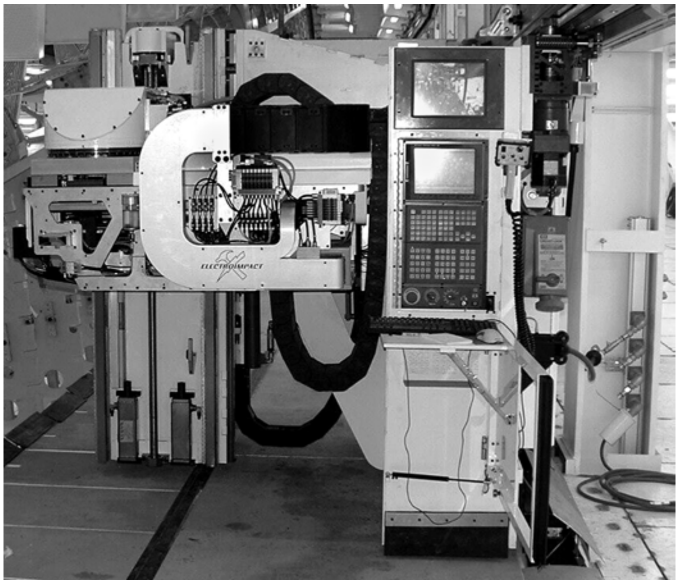

Figure 3. Y-Shift in the Lowered Position

The HAWDE uses a hydraulically actuated secondary Y axis to achieve this. The 'Y-Shift' axis rests on a steel index block in either an up or down position. With Y-Shift down, the machine can move or drill without the access floor above being raised. This minimized the disturbance the machine causes to workers above.

The Y-shift only needs to be extended in order to reach hole positions near, at, or slightly above the level of the flip floor overhead. The head of the machine can reach down to approximately 300mm above the current floor level and up to 500mm above the floor level above. The 200mm overlap allows Airbus NC programmers some flexibility in programming fasteners in this region.

Figure 4. Y-Shift in the Raised Position

CHALLENGE #3: MOVING BETWEEN FLOORS

Moving the HAWDE between floors required the design of a custom machine elevator. One elevator is required for each wing surface to be visited by HAWDE. The elevators carry lengths of upper and lower HAWDE rail and rack, exactly matching the rest of the jig. The rail is accurately positioned to mate up with the rail in the jig when the elevator reaches a floor level.

The HAWDE elevator consists of two nested frames, lifted by a telescoping hydraulic cylinder. The main frame is rigidly attached to the cylinder and rides in guide ways similar to a standard elevator. The sub-frame hangs on the main frame and is lifted by it. When the elevator approaches a floor level, pins are extended outward from the sub-frame. These pins rest in V-blocks which are precisely aligned for each floor. The main frame then continues downward a small distance so that the sub-frame is completely held by the V-blocks. This arrangement provides sufficient rail alignment and rigidity to drive the HAWDE machine smoothly between the jig mounted rail and that carried by the elevator. On the ground floor, the elevator has a door on either end; one passing into the jig and one passing out to the machine transportation aisle.

CHALLENGE #4: MOVING BETWEEN SURFACES AND BETWEEN JIGS

One of the chief design requirements for the machine transport system was that it must be simple and fool-proof enough to be safely run by the HAWDE machine operators, who have not had any special crane training. This precluded standard rigging techniques and introduced a crane designed solely for transporting machine tools.

Transport of the machine among wing surfaces and jigs is accomplished by means of a large transportation frame and a custom-designed stacker crane. There is a transportation aisle on the inboard end of all of the jigs, used for moving the HAWDE and GRAWDE machines. In order to leave a jig, the HAWDE takes the elevator to the ground floor and passes to the transportation aisle.

The transportation frame has an upper and lower HAWDE rail and rack, just as the elevators do. Special alignment features below the factory floor allow a machine operator to easily drop the transportation frame down at the line where it is needed. The frame locks in place and engages the HAWDE rail in the jig. The machine can then smoothly drive onto the frame.

A stacker crane is an electrically powered high-rail gantry with an hydraulically actuated mast instead of a traditional wire rope and hook. The mast allows the stacker crane to take a moment load. This limits uncontrolled load swings.

Figure 5. HAWDE Machine Transported Between Jigs

The interface between the stacker crane and the HAWDE transportation frame is a series of four steel mushrooms. The mushrooms hang down from the crane into holes in the top of the frame. To lock, keyhole plates slide over and engage the heads of the mushrooms. Sensors on the crane indicate proper locking of the keyhole plates. A safe lifting condition is indicated by a green 'OK to Lift' lamp on the enunciator panel of the stacker crane. Lifting is prohibited until a safe condition is achieved.

CHALLENGE #5: WHERE AM I?

There are over 2 kilometers of HAWDE rail installed in the A380 wing factory. This presents a challenge shared by all mobile equipment. How does the machine know where it is?

The HAWDE machine uses a two-stage process to locate itself for drilling on the wing. The first step is very similar to a traditional axis homing routine. It provides rough alignment to the wing and provides global location information to check against programmed move commands. The second step is a close-tolerance alignment to an existing hole on the wing using an automated vision system.

Every time the HAWDE is transported to a new location, it must run an X-axis homing routine before it is allowed to drill in the wing. The HAWDE moves along its X rail until two switches are triggered by one of several special plates. The steel plates contain a pattern of holes that the switches read as a 16-bit number. The number is an index into a table from which the HAWDE reads the current jig number, port or starboard wing, upper or lower wing surface, floor level, and an X and Y offset.

Once the HAWDE has been homed in X, the machine is globally located in the jig within 6mm. This rough positioning serves two purposes. First, it severely limits the part programs which can be run. Only programs written for the current location of the machine will execute. All others raise an alarm to alert the operator of a conflict or programming error. Secondly, the rough alignment provides a starting point for the next phase, an automated vision system.

The HAWDE uses a Cognex CDC-100 digital video camera and MVS 8100D frame grabber with a custom machine vision application to accurately locate datum features on the wing. The re-synchronization function is called from the part program and requires no operator intervention.

Commonly, the machine datum target is a custom slave / dowel bolt. The head of this bolt includes features designed to provide an extremely high contrast image for automated recognition. The HAWDE vision system can identify this target with a very high degree of certainty and find its center within +/-7um. The vision system can also locate straight or countersunk holes with slightly less accuracy.

CHALLENGE #6 VALIDATING THE MACHINE AND THE CUTTING TOOL

As with any cutting process in a part as expensive as a wing box assembly, it is common practice to validate the machine and the cutting tools before drilling. Typically this is done by drilling a test piece. However, the HAWDE machine is often working in areas in the center of the wing surface where moving it away from the wing to a specific location for validation and then back again would be difficult and impractical.

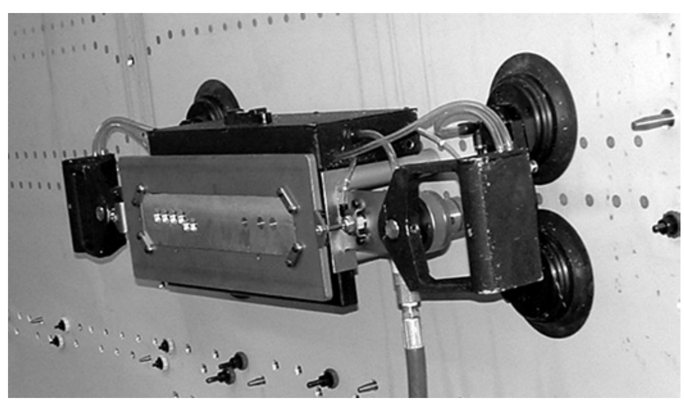

Figure 6. HAWDE Coupon Stand

Therefore, a coupon stand was designed to allow for validation without the need to move the HAWDE machine. Weighing less than 25 pounds, the stand is easily transported and positioned by a single operator. Vacuum cups then hold the pneumatically actuated stand securely to the wing surface while the HAWDE pressure foot normalizes and clamps onto the test coupon. All the clamping force is transferred through the stand to the wing surface.

CONCLUSION

The HAWDE machine has met all of the design challenges laid out during the early development of the A380 wing box assembly plan. Due to their ability to move the machine freely among the jigs, A380 production staff are achieving a high degree of machine utilization. Airbus UK is actively working to expand the work load for the existing HAWDE machine and investigating optimizations for future models.

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CONTACT

Rick Calawa is a Mechanical Engineering Lead at Electroimpact, Inc.. Mr. Calawa holds a Masters Degree in Mechanical Engineering from University of Washington. He can be reached at rickc@electroimpact.com.