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Wing Manufacturing: Next Generation

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ABSTRACT

Due to the part size and technological limitations of the available assembly equipment, traditional wing manufacturing has consisted of a three stage process. Parts are first manually tacked together in an assembly jig, They are then removed from the jig, rotated horizontally and craned into an automated fastening machine. Finally they are removed from the fastening machines and craned to a third station where the manual tacks are removed and the parts are prepped for final wing box assembly.

With the advent of electromagnetic riveting (EMR) and the traveling yoke assembly machine this traditional approach has been replaced with single station processing. Wing panels and spars can now be automatically tacked together under continuous clamp up in their assembly jigs using EMR. This eliminates the requirement for disassembly, debur and cleaning required with the manual process. While the wing panels and spars remain rigidly held in their flying configuration by the assembly jig they are fastened with an articulated yoke. Tool tables are mounted to the bottom of a solid yoke to insure opposing head alignment. Assembly jigs are lined end to end to allow one machine to service multiple stations and further enhance productivity.

In addition to efficiency improvements this new process improves product quality. The elimination of multiple crane moves and the manual tracking process greatly reduces the potential in process damage to the components. Since the parts are held rigidly in their assembly jigs during the entire fastening process, final panel and spar definitions are improved. Further, the use of EMR riveting has been demonstrated to provide superior fatigue to conventional process.

Two recent case studies of this approach are presented. The E4000 assembly system went into production on the A320 program in early 1998. The E5000 spar assembly system, ASAT4, goes into production in mid 1998. These two system are evolutions of earlier systems introduced on the Airbus A340 and Boeing 767 programs respectively. These two systems include a number of new enhancements over past systems and demonstrate approaches to both high and low rate aircraft production.

1.0 INTRODUCTION-WING SPARS

The Automated Spar Assembly Tool or ASAT was originally developed for the Boeing 767 wing spar in the late 1970s. Since then this powerful concept has been further advanced and integrated into nearly all the current Boeing commercial wing lines. A fourth generation system, ASAT4, has been developed for the Boeing C-17 Globemaster III. ASAT4 provides an unprecedented level of flexibility in a minimum amount of floor space. Similar to ASAT3, ASAT4 consists of a vertical traveling yoke machine which straddles the spar fixtures. Two fixtures placed end to end form a system approximately 220 feet in length which is serviced by a single machine. This allows manual operations, e.g. load and unload, to be performed on one spar while the machine works in the adjacent cell. Each fixture can accept any of the six C-17 spars. Fixture reconfiguration between spars is completely automatic. The single three axis yoke machine, the E5000, travels the full system length. The yoke is simply supported on the side of a rigid gantry structure. The E5000 has completely redundant tool heads on both legs of the yoke. This permits drilling and fastener insertion from either side of the spar.

The wings of the Boeing C-17 Globemaster III are built around three wing spars, front, center and rear. During the initial production years these parts were completely manually assembled. Twelve different assembly jigs were used to assemble these six spars. Spar caps and stiffeners are located to the web in the first assembly jig (AJ1) with drill templates used to place fastener holes. Once fastened the spars are then transferred to a second assembly jig (AJ2) for precision location of critical components such as the wing rib attachment fittings. With thousands of fasteners per spar the entire process is highly labor intensive.

As part of a program wide effort Boeing engineers were challenged by the US Air Force to develop long term manufacturing cost reduction strategies for the C-17.

While automation is recognized as a means to significantly reduce labor costs and improve quality, large scale automation projects are typically difficult to justify on low rate sustaining programs such as the C-17. An additional hurdle common with many sustaining programs was the introduction of automation to an assembly designed without the benefit of Design For Manufacturing and Assembly (DFMA) initiatives. While the C-17 spars are flat in profile, there are offset fasteners with extremely tight clearances on both sides of the spar.

To prove cost effective in this environment the automation system must provide a high degree of flexibility in a minimum amount of floor space. The ASAT4, a fourth generation spar assembly system, was developed to meet these unique challenges of the C-17 program. ASAT4 is based on the concept of “in jig” assembly with a vertical yoke assembly machine. This ASAT configuration was initially implemented for the Boeing 737 and 757 programs. ASAT4 however offers an unprecedented level of flexibility along with many new features for improved process speed and control.

2.0 SYSTEM OVERVIEW-ASAT4

ASAT4 consists of a vertical traveling yoke assembly machine which straddles two CNC controlled flexible spar fixtures. The fixtures are placed end to end to form a system approximately 220 feet in length serviced by a single machine. This allows manual operations, e.g. load and unload, to be performed on one spar while the machine works on the adjacent fixture. Each fixture can accept any of the six C-17 spars. Reconfiguration between spars is completely automatic and requires under five minutes. The machine is designed with completely redundant tool heads which permits drilling and fastener installation from either side of the rigidly supported spar.

Since ASAT4 was introduced into a sustaining program the existing AJ1s remain in use for initial location of cap to web. This helped to reduce the over system cost and complexity. The spars are therefore loaded into the fixtures in a tacked condition. This is illustrated in Figure 6. The machine is used to install the bulk of the remaining fasteners. All fastener installation and fixture operation are CNC controlled. The high accuracy of the ASAT4 machines ultimately will allow elimination of the need for the AJ2s and reduce overall spar manufacturing floor space requirements. Components with critical position requirements will be located using machine drilled coordination holes.

3.0 AUTOMATED FASTENING MACHINE - E5000

The requirements being placed on next generation assembly systems demand that the assembly machine be stiffer, faster and significantly more accurate than older systems. These newer machines are actually being designed more as machine tools with the accompanying performance requirements. The ASAT4 automated fastening machine, the E5000, was designed to meet these challenges.

3.1 MAJOR MACHINE STRUCTURE-E5000

Figure 1: E5000 Machine with Redundant Operator Stations

The E5000 consists of a rigid yoke mounted to a gantry structure which straddles the spar fixture and rides on parallel sets of precision beds. The system is completely CNC controlled with fifteen servo axes all directly integrated into a single control, the Fanuc 15MBMA. Since the C-17 spars are flat no major rotary axes are required. The E5000 therefore operates as a three axes machine for fastener location.

High precision and stiffness is required along the X axis to allow for fast, stable and accurate positioning. The E5000 is driven in X by four motors in a synchronous tandem configuration, a unique feature provided by the Fanuc control. A Rennishaw RG2 tape scale is used for secondary feedback. This arrangement provides active electronic anti-backlash control which does not vary over time as is the case with most mechanical anti-backlash mechanisms. Active temperature compensation using macro calls within the Fanuc CNC is used to maintain absolute positional accuracy throughout the large thermal swings present in the Long Beach factory. These features insure the high accuracy required over the 100 foot working envelopes for precise CNC fastener and detail part location.

Servo positioned tool tables are mounted to the bottom of the yoke legs. See Figure 2. A rigid yoke provides the most reliable arrangement to maintain alignment between opposing heads. Precision alignment of the toolpoints is critical to the fastening process especially for the installation of collars onto interference bolts. The yoke is simply supported on the gantry legs with a minimal constraint design. This insures that in the event the machine beds should settle differentially the yoke will not see any torsional loading transmitted through the gantry which could cause the toolpoint to move out of alignment. These features provide the optimal configuration for long term process reliability.

The yoke is positioned vertically by one Y-axis motor which drives Y carriages on either yoke leg through a pair of right angle gear boxes. Secondary feedback for the Y axis is provided with a Heidenhain glass scale linear encoder which guarantees high precision over the 72 inch vertical working envelope. The entire Y-axis is counterbalanced with a 300 psi pneumatic counterbalance system. Air was chosen over more a more conventional nitrogen charged hydraulic system since pneumatic systems are less costly and more easily maintained. Functionally the pneumatic system has proven equal in performance to the older hydraulic systems.

3.2 PROCESS HEADS-E5000

While the C-17 spars are flat in profile, there are offset fasteners with extremely tight clearances on both sides of the spar. The E5000 was therefore designed with completely redundant tool heads mounted on both legs of the yoke. This permits drilling and fastener insertion from either side of the spar. The spar remains fixed throughout the assembly process. Redundant operator stations allow the operator to monitor the process from the most appropriate side with no loss of control. These are illustrated in Figure 1.

Two CNC controlled clamp tables are mounted to bottom of the yoke legs. Clamp up on a rigidly held part without part movement is critical to the success of the “in jig” assembly process. Clamping is accomplished without imparting a differential load to the spar by driving one table forward and actively sensing the spar surface with a non contact panel probe. The opposing table then drives into the part under load cell feedback to complete the clamping cycle. Clamping is maintained throughout the installation process by continual closing of the clamp table servoloops around the loadcell. This enabling operation is described in detail in Hartmann [1].

The fastener installation tools are mounted to redundant shuttle tables which ride on the underside of the clamp tables. See Figure 2. The tools consist of a servo driven spindle, a feedernose servo EMR, a “smart” pneumatic bolt inserter, a hole probe, a fastener ejection tool and a resynchonization camera. The shuttle table axis is the most critical axis to cycle rate. For each one inch machine move between fasteners the tool shuttle table must move approximately three feet between the various tools. Linear motors drive the shuttle tables with 1G acceleration to a maximum velocity of over 40 in/s. The integration of the linear motor shuttle table alone has reduced process cycle times by 15%-20%.

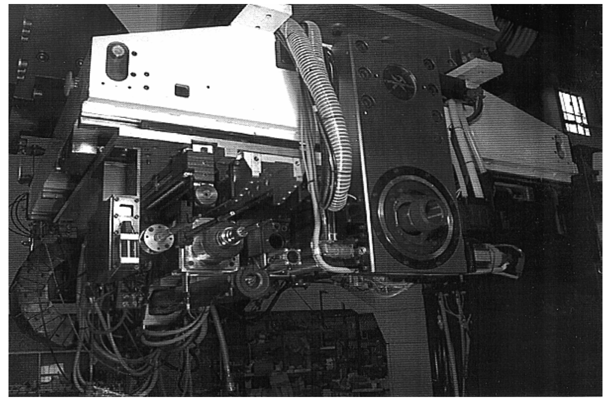

Figure 2: Clamp Table with Process Tools

A number of features have been integrated into the process tools to enhanced the speed and verification of the fastening process. These include:

1. The 15,000 RPM DC servo controlled spindle is provided with water cooling for increased heat dissipation required at higher power levels, The spindle is configured with an Ott Jacob powered drawbar which allows for quick change of the appropriate cutters. Cutters can be preset with their set up parameters stored in the CNC to reduce downtime during tool changes.
2. Past electromagnetic riveting heads (EMR) have been positioned using air cylinders. One disadvantage of this method is that since material stacks vary infinitely and slug rivets only come in 1/16” increments it is difficult to properly set the rivet protrusion height. Servo control of the EMR forming die’s axial position by the CNC however permits precise balancing of the slug rivet protrusion on both sides of the spar. The desired protrusion is calculated by the CNC using the stack thickness and selected rivet grip. The EMR is then servoed to the calculated position for exact protrusion balancing. This feature provides more repeatable and higher quality fastener installation results.
3. The axial position of the pneumatic bolt inserter is controlled by an air cylinder which has a linear encoder grating etched directly on its rod. This powerful feature allows continual monitoring and verification of the bolt insertion process. Bolt length, orientation, diameter, installation speed and bolt/hole interference levels all can be checked real time with this feedback device.
4. A servo driven hole probe based on precision ball gages is used to validate hole diameter in process and prior to fastener installation. Hole diameter is one parameter which cannot be measured after the fastener installation cycle is completed. A record of the hole diameter is critical to the long term goal of reduction or elimination of test coupons.
5. A fastener ejection tool allows automatic recovery in the event that a bad fastener is

detected prior to forming. This tool increases the efficiency and safety of the system as it eliminates the need for operator intervention to clear unwanted fasteners.

6. The resynchronization camera is used to reference the machine to the appropriate fixture. In additional it is used to verify the location of parts which were manually installed in the initial tacking stage. This tool thereby allows the E5000 to function as a very large CMM for verification of part and fastener locations.

The requirement to fasten six different spars with one machine is by itself not a significant challenge in today's DFMA design environment. The C-17 however was not designed with this philosophy and therefore access to the fasteners varies considerably across the different spars and even with a single spar. The E5000 system is designed to install two diameters of slug rivets as well as three diameters and two types of interference bolts. There are a assortment of different clearance requirements for each fastener size and type. To meet these requirements a variety of front end or clampnose configurations were developed. One offset configuration is illustrated in Figure 3. To avoid collisions and potential damage to the spars it is imperative that the correct clampnose is installed for the appropriate part program. Each nosepiece assembly has therefore been provided with an identification tag realized through a series of dip switches and a D shell connector. This connector and all other utility connections are fully integrated into the headstone and the appropriate nosepiece for quick change convenience. This greatly simplifies the tool change process for the operators.

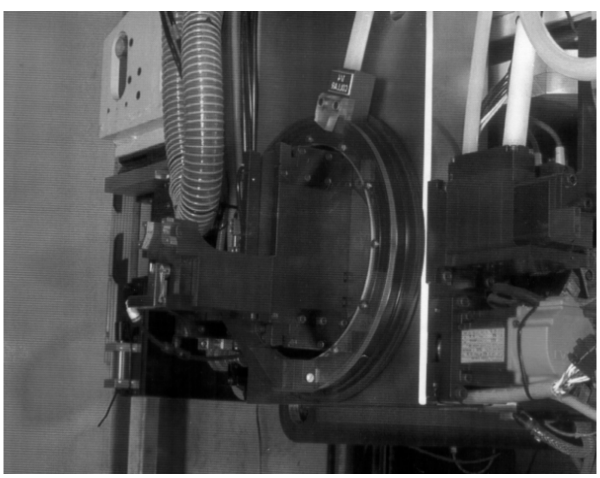

Figure 3: Offset Clampnose

The large number of fasteners which must be supported requires a compact fastener feed system. Fasteners are stored in coiled tube cartridges which are approximately the size of a small briefcase. Each cartridge holds around five hundred fasteners. The narrow cartridge cross section permits a large number of cartridges to be carried on the gantry in a relatively small area. The sixty point system easily fits onto one side of the gantry. (Figure 4), The individual escapements are pneumatically controlled through a PLC which resides on the Fanuc fiber optic ring. The cartridges are multiplexed through a series of laterals located below the main storage racks. A second routing station located on top of the gantry directs the requested fastener to the appropriate side of the machine. For low fastener counts drops tubes are provided at the operator stations upstream of the main fastener feed station to permit manually feeding. The cartridges are automatically loaded off line with vibratory bowl feeders. This removes all inherent problems of dealing with bulk fasteners off line and away from the production environment. For a further discussion of these feed systems see, Rink [2].

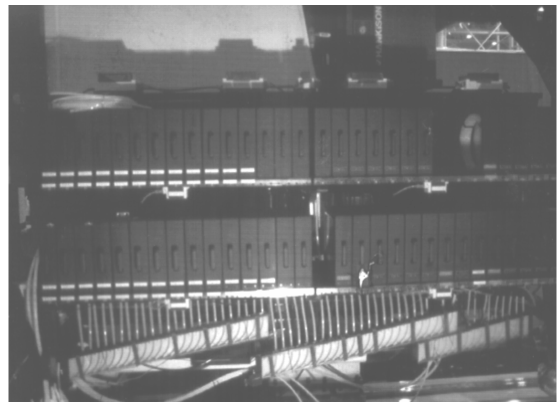

Figure 4: Fastener Feed System

4.0 FLEXIBLE FIXTURES-ASAT4

Jigs are typically used in the aircraft industry to provide faster, simpler and more repeatable location of detail parts than could be accomplished by repeated manual layouts. In the past large component jigs have been designed for high rigidity and precision to meet the tight tolerances required for integration with other aircraft components in final assembly. Drill blankets are used to locate holes and locating jigs index subcomponents relative to the nearest available reference. Over the first few shipsets jigs are typically modified to correct unforeseen problems encountered in the downstream assembly process.

The result is typically the development of dedicated inflexible fixtures for each major aircraft component. For lower rate programs this inflexibility can prove costly. The large number of jigs are expensive to maintain and routine. Floor space requirements are high and cannot be as easily amortized over low production rates. The lack of jig flexibility can also hamper the design of derivative aircraft modifications. With conventional jigs changeover time between variants can significantly reduce efficiency and drive up costs. Assembly jig flexibility is therefore key to the commercial success of low rate programs.

The ASAT4 system contains two flexible fixtures which are situated end to end to form one automated cell. The two fixtures are identical and each can accept any of the six C-17 wing spars. Since the C-17 is a relatively low rate program the decision was made to keep the original dedicated AJ1s for use as tack fixtures only. Unlike previous ASATs the spar is therefore provided to the ASAT4 cell in the tacked configuration. ASAT4 is then utilized to install the bulk of the fasteners and to ultimately locate and install critical components such as the rib attachments. This revised job description allowed a significant reduction in the number of indices required relative to previous ASATs and thereby reduced the overall system cost. Despite the reduced number of indices the fixtures still must maintain the spars in precise and repeatable locations relative to the machine coordinate system since all fastening is performed under complete CNC control.

Figure 5: Flexible Fixture Unloaded

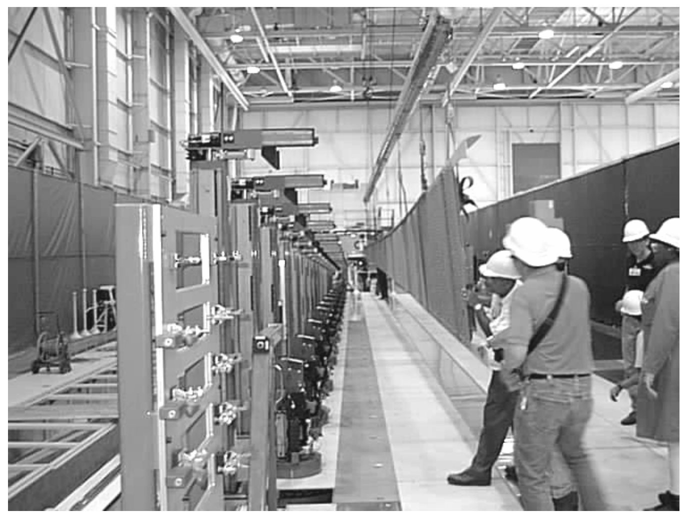

Figure 6: Loading Spar into Fixture

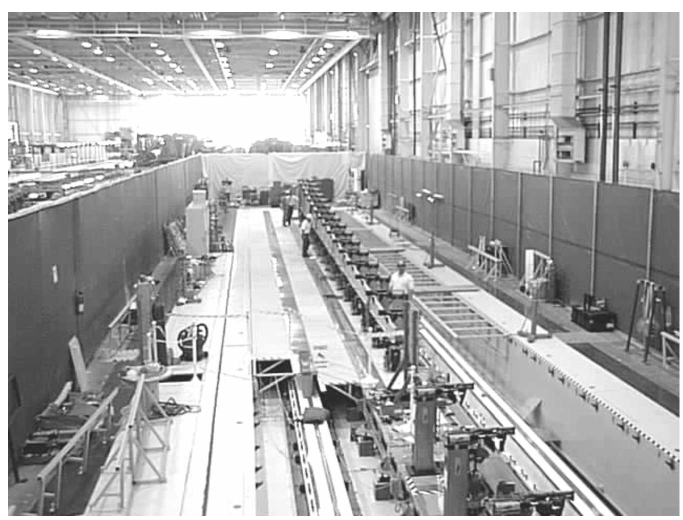

Figure 7: Spar Loaded in Fixture

Each fixture consists of sixteen upper index assemblies, sixteen lower index assemblies and one primary index assembly. These assemblies are mounted to a series of rigid steel based modules which are placed between the two X-axis machine beds. The sixteen lower index assemblies provide the anchor for the spar fixture and are used to clock the spars' X-axis parallel to that of the machine. Each lower index consists of three unique index nests which correspond to the cap geometry of the front, center and rear spars at that particular station value. The nests are spaced 120 degrees apart on a pneumatic rotary indexer as shown in Figure 8. The indexer operates using a Geneva mechanism which provides .001 in. true position repeatability. Pneumatically controlled toggle clamps retain the spar in the lower nests. The clamps move on a vertical slide and index off each individual nest to insure proper orientation of the clamp body to the respective spar cap as the spar heights vary between the three spars. Belleville washer stacks provide the clamp arms with sufficient compliance to accommodate the gage changes between the three spars at each station.

The entire lower index assembly is mounted to the fixture base modules though a second pneumatically controlled rotary indexer. This second indexer provides 180 degrees of motion. By placing the center of the indexer's rotation coincident with the spar datum plane the same assembly is able to locate an opposite hand spar by reversing the orientation of the nest. The second indexer and all required utilities are mounted in a covered trench.

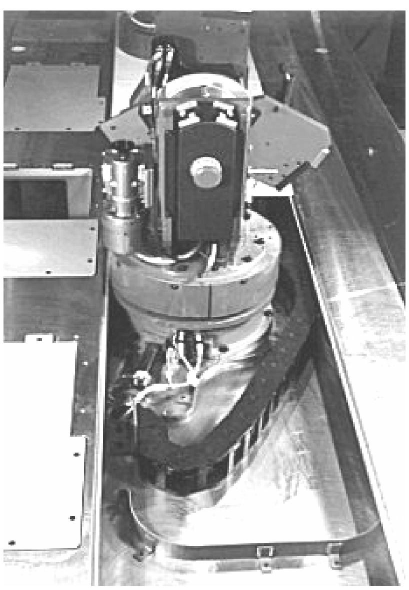

Figure 8: Lower Index Assembly

The upper index assemblies hold the spar vertical by grabbing onto the upper spar cap and thereby maintain the spar plane perpendicular to the machine drill axis. These components are mounted to vertical posts which are provided with sufficient vertical motion to sink into the floor and completely out of the machine path. Servomotors are used to position the upper index both vertically and horizontally under CNC control. Upper index positions are therefore all programmed positions which are easily changed in software. A swing clamp with ample compliance to accommodate the different cap widths draws the upper cap into the index.

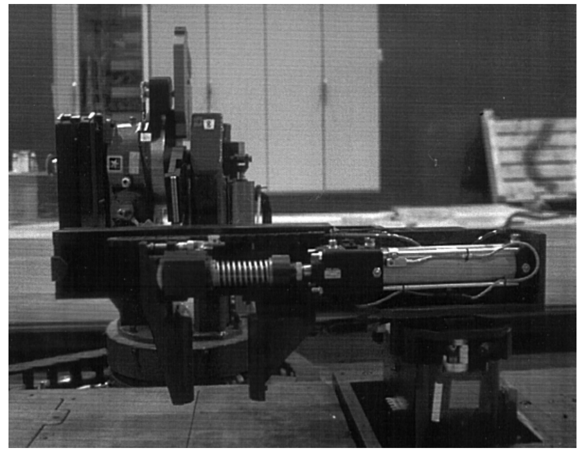

Figure 9: Upper Index Assembly with Post Fully Down

The spars are indexed in the X-axis through a single tooling hole in the web designated as the primary index. The primary index is shown in Figure 10. The tooling holes in the spars webs have been placed such that a single index location can be used for all six spars. The AJ bases sit on conventional jig feet and are fixated to the foundation in X at one point which coincides with the primary index. This insures that all growth due to temperature for both the fixture and the spar originate from the same point. A single primary index provides a fixed origin point to which the machine can synchronize. This is important to insure proper functioning of the machine temperature compensation which is critical to provide the accuracy required for precision jigless component location.

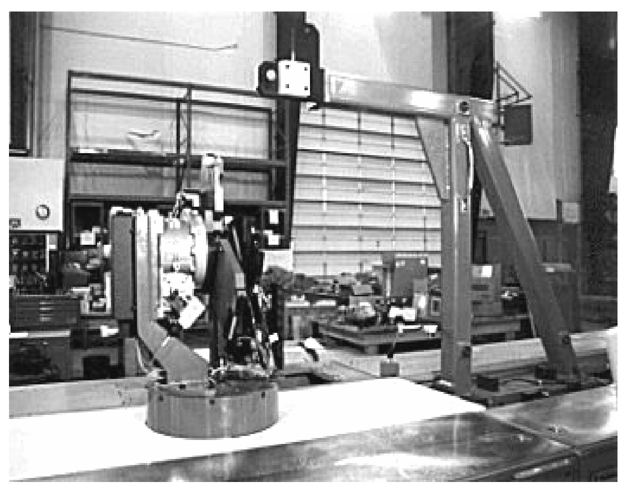

Figure 10: Primary Index with First Lower Index Assembly

The two flexible fixtures are completely automated for both their set up and operation. The fixtures are directly controlled by GE PLCs which reside on the fiber optic ring of main system brain, the Fanuc 15MBMA CNC.

Each fixture has thirty two servo motors in addition to pneumatically controlled actuators. Changeover between one spar configuration to another requires under five minutes and is controlled either from the machine button panel or remotely from the fixture junction boxes. No manual intervention is required. Once running under part program control all operation of the fixture is controlled through M-codes for complete CNC operation.

5.0 INTRODUCTION: WING PANELS-E4000

The first application of the E4000 yoke assembly machine cell is on the A319/A320/A321 upper wing panels. The machine has built a pair of A320 upper wing panels. A second set is nearly completed as of this writing.

In the E4000 assembly cell detailed parts are loaded into the cell. These detailed parts include seventeen stringers, two skins, a buttstrap and a pylon reinforcement. These parts load into the clamping details of the wing panel holding fixtures, both port and starboard. The E4000 machine then runs across the fixtures, drills critical holes and installs all of the permanent fasteners. When the wing panel is removed from the fixture all of the assembly work is complete.

6.0 E4000 FACILITY

a. The machines and fixtures sit on a dedicated foundation provided by BAe. The foundation is sixty-six meters long with features for mounting the machine rails and the two fixtures (port and starboard).

b. The facility includes two upper wing panel fixtures, a port and a starboard.

c. There are two parallel sixty meters runs of levelable precision bedrail, fifty-six meters of continuous Renishaw RG2 scale on each bed, IKO precision recirculating roller bearing and ground rack. The bedrails straddle and run along both sides of the fixtures.

d. The E4000 riveting machine runs on the bedrail.

e. There are floor plates surrounding the machine and fixture.

f. There is an offline fastener feed system.

7.0 E4000 ASSEMBLY MACHINE KINEMATICS

The E4000 machine is designed to access the entire surface of the wing panel for drilling holes and installing rivets and lockbolts. Each wing panel is fifteen meters long and three meters in width. The width of the panel is the vertical height that the machine must traverse since the panel is placed vertically in the fixture.

The E4000 machine is capable of accurate positioning of the toolpoint. On the E4000 machine the toolpoint is the point where the drill first touches when entering the skin. The E4000 is designed to locate this point within .008" over the work envelope of the machine.

The E4000 machine utilizes a solid yoke that is articulated in five axes. By rotating the solid yoke the alignment between the opposing heads is maintained. Correspondingly, the work axis of the yoke is horizontal. The E4000 machine can rotate the yoke +/-15 degrees in A and B to keep the drilling axis normal to the wing panel surface. Rotation of a solid yoke provides precision alignment between the opposite heads. Alignment within .007" is required for reliable collar loading, and it is achieved. The yoke is employed as the engine of alignment and clampup.

The yoke is connected by two trunnions that attach near to the extreme points of the yoke. By attaching the trunnions near to the extreme points the stability of the yoke is enhanced. Each trunnion features two perpendicular passive rotary axes. One of the rotary axes is for the A axis, the second is for the B axis. The trunnions are supported by the gantry. In addition the trunnion on the stringer side features a passive length change slide.

The gantry has two independent X axes, one on each side of the wing panel. In addition, the gantry features two separate Y saddles that also straddle the wing panel. When the two gantry X axes move in unison the yoke translates in X. When the two gantry X axes move differentially the yoke rotates in B.

The motion is similar for the two Y axes. Parallel motion causes a Y translation of the yoke. Differential motion causes the yoke to rotate in A. A figure is enclosed which illustrates the resulting kinematics.

The servo axes of the E4000 machine are as follows:

AXIS	SIDE	DESCRIPTION	FEEDBACK
Xm	skin	gantry rack tandem master	RG2
Xs	skin	gantry rack tandem slave	tandem
Im	stringer	gantry rack tandem master	RG2
Is	stringer	gantry rack tandem slave	tandem
Ym	skin	vertical ballscrew master	Heidenhein
Ys	skin	vertical ballscrew slave	Heidenhein
Jm	stringer	vertical ballscrew master	Heidenhein
Js	stringer	vertical ballscrew slave	Heidenhein
U	skin	head in/out for 2000 lbs of	Heidenhein and load cell

		clampup	
V	stringer	head in/out for 2000 lbs of clampup	Heidenhein and load cell
C	stringer	anvil rotation	motor encoder
K1	skin	EMR in/out	motor encoder
K2	skin	hole probe in/out	motor encoder
E	skin	shuttle table linear motor, 2m/sec transfer speed	Heidenhein
W1	skin	spindle #1 feed	Heidenhein
W2	skin	spindle #2 feed	Heidenhein

In addition to the above listed real axes, the E4000 also features three virtual axes. These axes respond to motion commands and are displayed on the CNC but are actually the result of calculation.

Table 2: E4000 machine virtual axes

A	yoke A rotation, ARCTAN[(Y-J)/192"]
B	yoke B rotation, ARCTAN[(X-I)/192"]
Z	Z plane of workpoint from yoke center

Table 3: E4000 spindle drives

S1	spindle 1, 13,500 RPM, HSK 50 hydraulic collet with Ott-Jacobs power drawbar
S2	spindle 2, 13,500 RPM, HSK 50 hydraulic collet with Ott-Jacobs power drawbar

As already mentioned, the X axis is 55 meters long. The Y axis is 3.55 meters, although some of this height is sacrificed to allow for A axis rotation.

8.0 WING PANEL HOLDING FIXTURES- E4000

Elements of the fixtures include:

a. Fixture bases which can be precision leveled

b. Upper beam on each fixture

c. 14 rotating headers on each fixture

d. Stringer clamps and buttstrap grippers are mounted on the headers

e. Slider for the inboard end

f. Stringer inboard locators are mounted on the slider

g. Slider moves out of the way to permit unloading

h. Skin straps to pull in panels, air motors pull in straps

The fixture is designed so that every location on the panel can be accessed. This is achieved by the rotating headers. As illustrated the stringer side head is 14” wide. The dimension to the inside surface of the rotating header is eight inches. Therefore, coming from either direction the stringer side head can rivet up to the centerline of each rotating header.

9.0 PROCESS TOOLS - E4000

As shown in the attached photo the shuttle table on the skin side carries seven tools. All of the tools on the skin side remain permanently attached with the shuttle table, which uses a high speed linear motor to transfer from tool to tool. The shuttle table positions on the skin side are as follows:

a. EMR

b. bolt inserter

c. sealant applicator

d. spindle 1

e. spindle 2

f. hole probe

g. resynch camera

The stringer side has multiple anvil setups. The anvil setups have side tooling to perform the necessary functions. Stringer side tooling is shown in the photo. The various stringer side tools are listed in Table 4. The stringer side anvils attach to a spring loaded crash base which freezes machine motion if the anvils are deflected to the side or outward.

Table 4 E4000 stringer side tooling

ANVIL	FUNCTIONS	SIDE TOOLING
drill only	drill only	V tracer
shallow offset	rivets, 5/16 collars	Y/V tracer, double hit, collar feed
deep offset	1/4 collars	Y/V tracer, collar feed
straight	1/4 and 5/16 collars	Y/V tracer, collar feed

The sequence for installing a rivet is as follows:

a. clampup

b. drill and countersink

c. feed, measure rivet and upset rivet with EMR

d. double hit if required

e. shave

The sequence for installing a lockbolt is as follows:

a. clampup

b. drill and countersink

c. probe hole

d. apply sealant to hole

e. feed and measure bolt

f. feed collar

g. drive bolt

h. swage collar with EMR

10 MANUFACTURING PROCESS - E4000

a. Stringers, buttstrap and pylon reinforcing are loaded into the clamps. All rotating supports are initially closed.

b. Sealant is applied at the rib bays and at the stringer ends.

c. Two skins are loaded in. The lower skin sits on the trailing edge locators and is pushed in by removable pushers. The upper skin is attached to lugs and is slid in and the gap then adjusted. Skin straps press the skins up against the stringers.

d. The E4000 machine runs over the panel and installs rivets and lockbolts to stabilize and hold firm all of the sealed areas. This includes fastening of the buttstrap.

e. Precision 5 axis drilling is performed on the inboard end. Only the U side head is engaged for the inboard

hole drilling. The U side head presses the panel up against the fixture. The inboard pattern is employed when the wing panel is attached to the center wing box.

f. After the seal pass is complete the skin straps are removed and the production pass begins. Headers are rotated out of position to create 48" wide bays. The bulk of the rivets and lockbolts are installed.

Some of the fastener locations utilize sensors (there are six sensors, four skin side normality sensors and a two axis stringer side tracer). Some are located under CNC control.

CONCLUSION

The ASAT4 system has been designed to meet the specified requirements of low rate production requirements of the Boeing C-17. A high degree of flexibility has been integrated into the spar fixtures and the E5000 automated assembly machine to allow one system to meet the production requirements for all six C-17 wing spars.

The E4000 Wing Riveting System has provided British Aerospace with a flexible automated assembly method which assists in meeting ramped-up Airbus production schedules. Its centerpiece, the five axis solid yoke with workheads on each end of the yoke, accurately and effectively installs both rivets and lockbolts over the entire wing panel surface including offset areas.

Both these systems represent the transition to the next generation of the automated wing assemblly process which involves in jig riveting. The in jig process saves floor space and improves control of the build process

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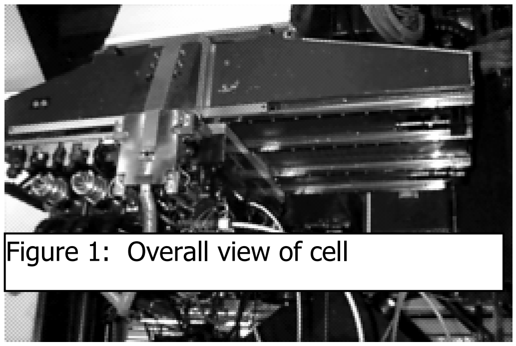

Figure 1: Overall view of cell

Figure 2: Stringer side workhead and shuttle table

Figure 3: Operator Platform

Figure 4: View of completed panel

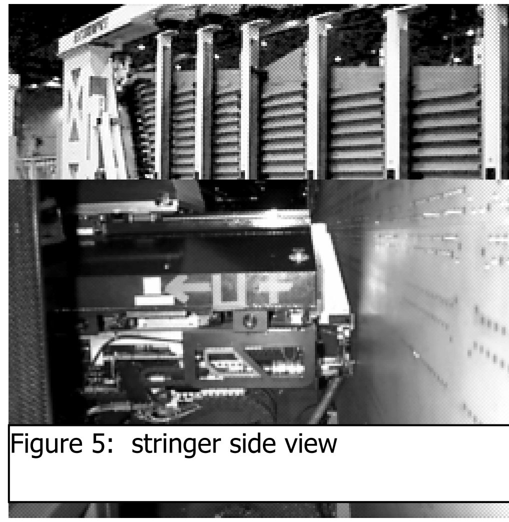

Figure 5: stringer side view

Figure 6: skin side workhead

Figure 7:   stringer side anvils

Figure 8: E4000 installs offset fasteners

Figure 8: Skin side panel in fixture at root

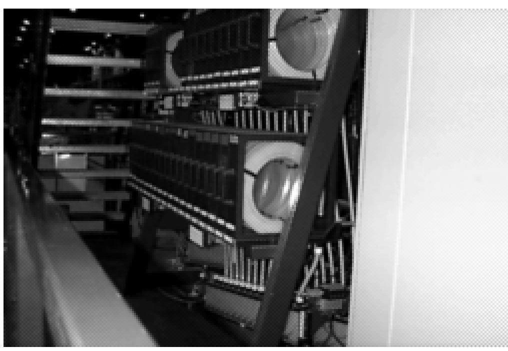

Figure 9: Cartridge fastener feed system

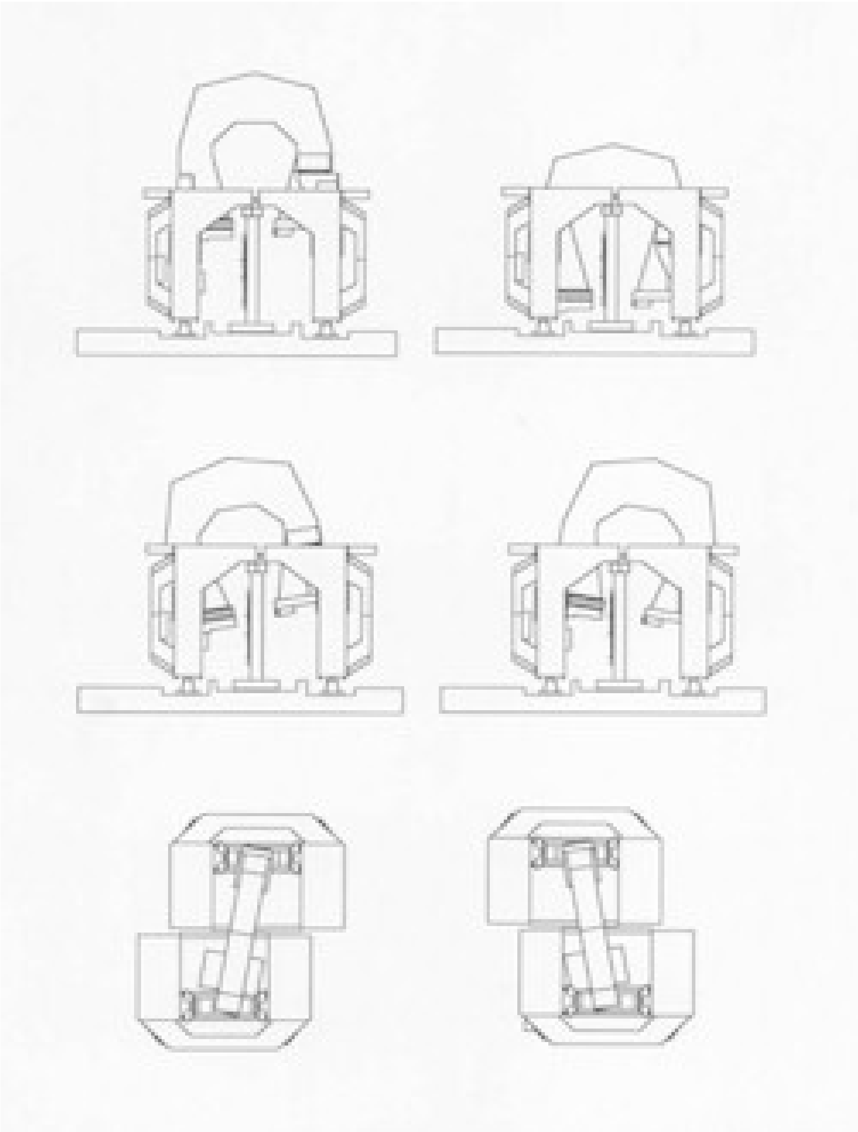

Figure 10: E4000 Machine Kinematics

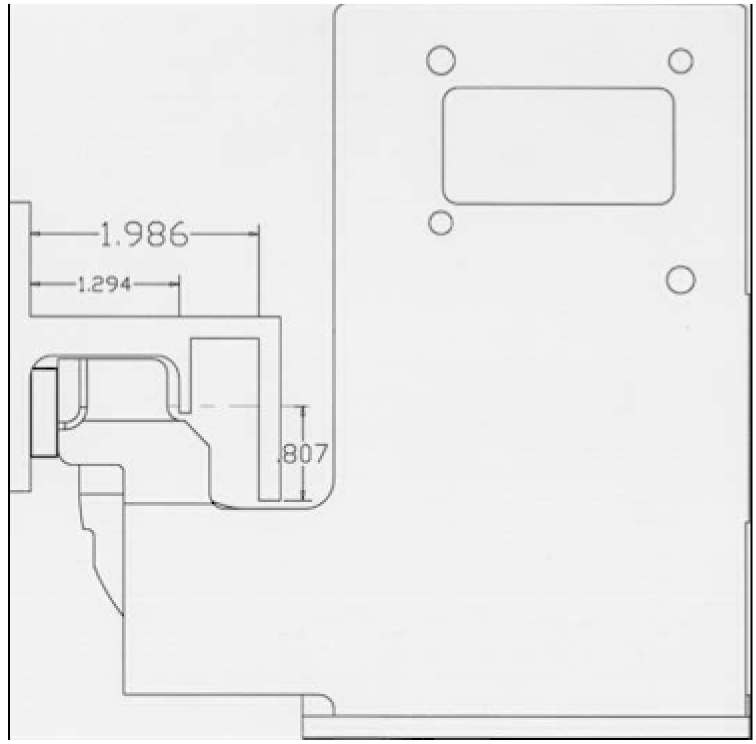

Figure 11: offset anvil

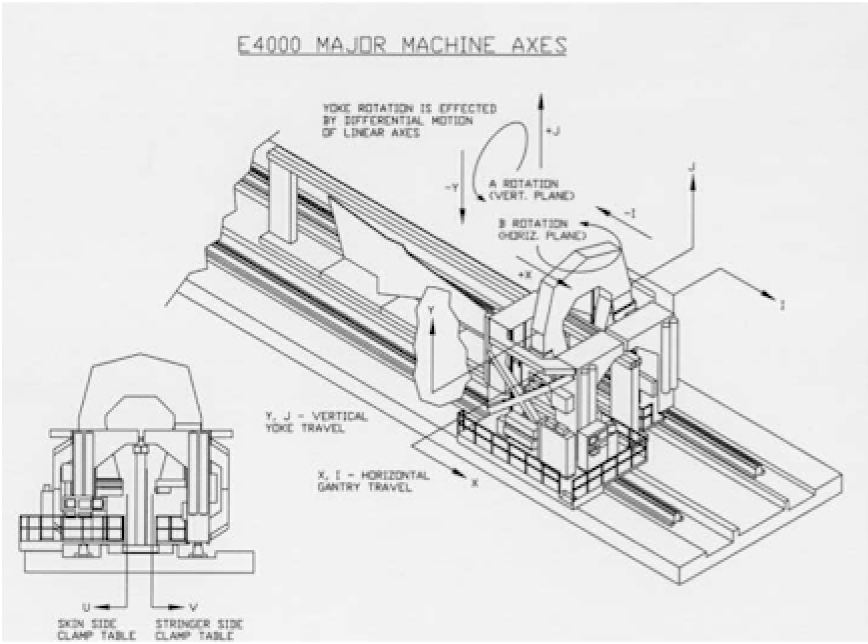

Figure 12: E4000 Machine View

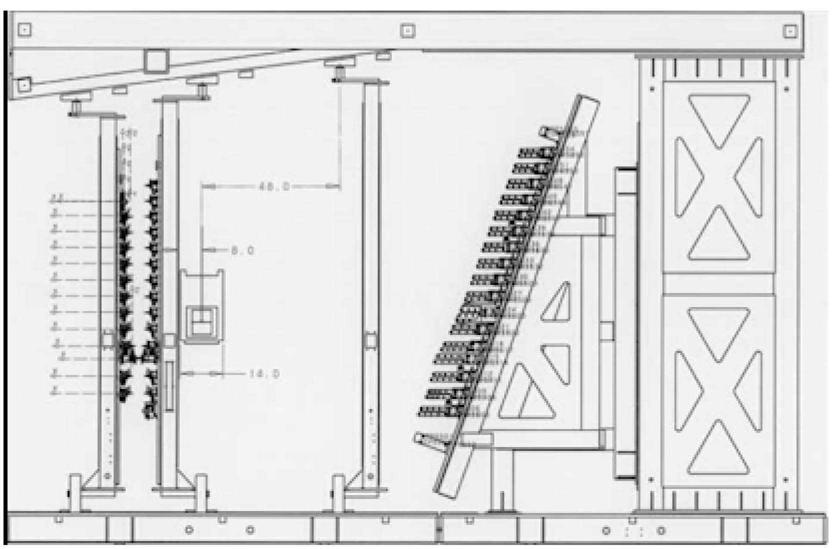

Figure 13: String side head clears the rotating support. Rotating supports provide a 48” wide workbay.

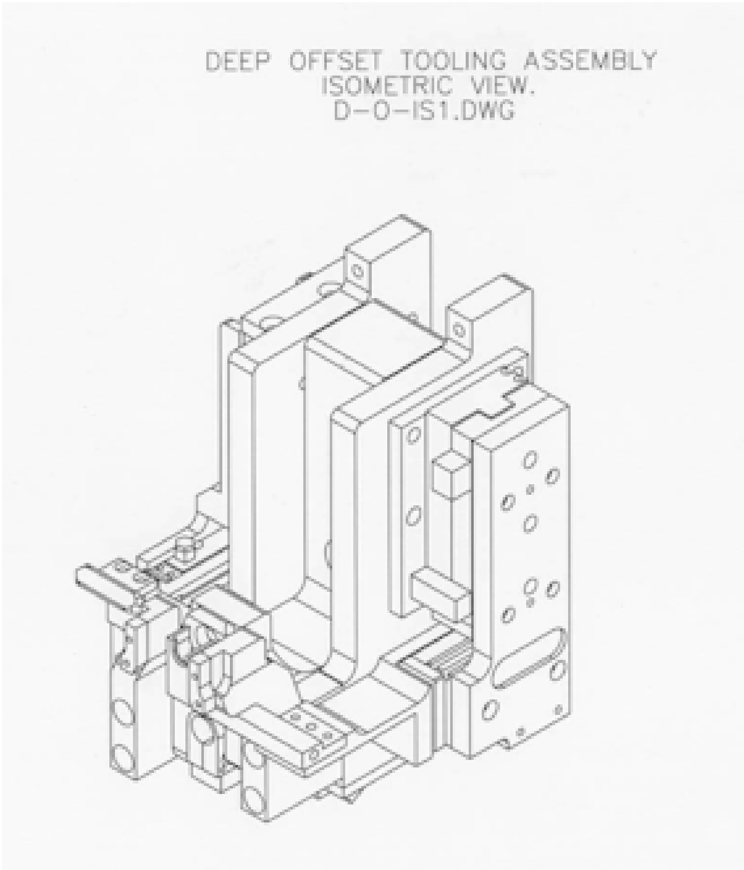

Figure 14: Offset anvil

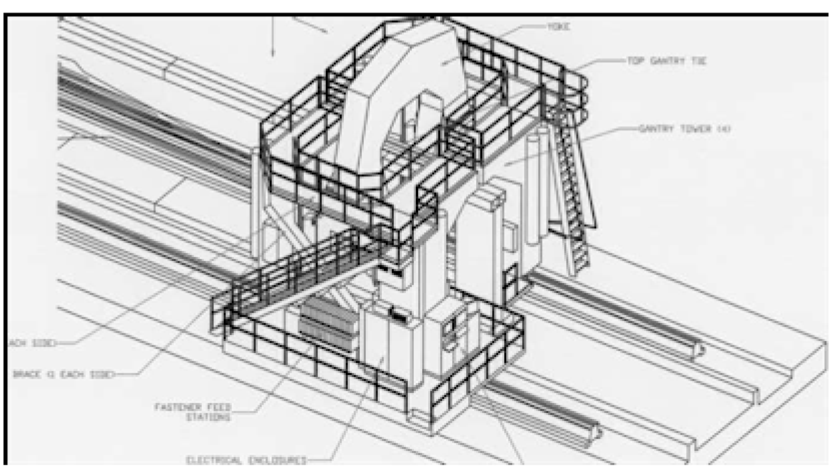

Figure 15: E4000 machine view