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Process Development for Use of AERAC

Authors: Peter Vogeli and Peter Zieve
Electroimpact, Inc.

Terry Hopkins, Steve Howard, and Jim Bratten
Textron Aerostructures

ABSTRACT

Two Automated Electromagnetic Riveting Assembly Cells (AERAC) were manufactured for Textron Aerostructures by Electroimpact, Inc. The AERAC installs the final rivets in the A330/A340 upper wing panel in the floor assembly jig. At Textron for each wing the corresponding floor assembly jigs are lined up end to end in a line.

An operating procedure, in which the formboards are removed in bays, allows efficient operation of an in-the-jig riveter such as the AERAC. Specialized machine codes developed for the AERAC allow quick fully programmed stringer-to-stringer jumps of the stringer side offset tooling.

The AERAC is programmed entirely from a CATIA drawing of the part. Of the 5 axes of rivet data available only two are retained for use by the AERAC.

INTRODUCTION

Two Automated Electromagnetic Riveting Assembly Cells (AERAC) were manufactured for Textron Aerostructures by Electroimpact, Inc. The first has been in production since January and the second since March of 1991 making the upper wing skins of the Airbus A330/A340 widebody jet aircraft. Photo 1 is of the AERAC mounted on the FAJ at Textron. Photo 2 shows the stringer side workhead deployed on a stringer.

The two AERAC machines at Textron are the first of their kind. AERAC is the only automatic riveter which installs final wing rivets in the floor assembly jig (FAJ). These wing skins are the first to be assembled using the Low Voltage Electromagnetic Riveter (EMR) [1, 2]. The A330/340 upper wing skins are each built up from four panels as shown in Figure 1. At Textron for each wing the corresponding floor assembly jigs are lined up end to end in a line. The FAJs for panels one and two are each about seventy-five feet long, with a total length for the four jigs of two hundred and fifty-five (255) feet. Each AERAC machine, left and right, has an X-axis which runs this entire two hundred and fifty-five floor length and permits each machine to work on all four panels.

The total rivet count on the upper skin is 34,000 per side. About 28,000 of these are ¼ inch rivets ranging from #13 thru #29 grip length. The ¼" rivets are unusually long with a length to diameter ratio of up to 5:1. About 6000 are 3/16 inch rivets ranging from #9 thru #16 grip length. The base material is 7150 aluminum.

The stringers all have a J shape with a line of fasteners along each side of the web. The rivets on one side are offset, the other side not.

AERAC CONCEPT

The original AERAC concepts remain unchanged [3]. AERAC runs on the FAJs saving floor space and foundation costs. Rather than a hydraulically actuated stringer side workhead the AERAC has a CNC controlled W-axis. This is in addition to the skin side Z-axis. As a result the AERAC is a six-axis machine in contrast to other CNC riveters which have five CNC axes. The axes of the AERAC machine are shown in Figure 2. The W-axis can be run off of tracer or can be commanded to a calculated position. This sixth axis adds considerable versatility for stringer-to-stringer moves.

The AERAC yoke reaches over the jig from the skin to the stringer side to clamp up with eight hundred pounds. Skin side tools deployed through the continuous clamp up are a drill, feeder nose EMR riveter and shaver. On the stringer side an offset riveter is deployed. The pitch and yaw of the yoke are controlled by normality sensors on the skin side. Proper edge distance is maintained by an edge margin (or Y) tracer on the web of the stringer.

The flying height of the stringer side workhead is maintained by a second unique tracer axis. This axis, the W-tracer, shares a single tracing stylus with the edge distance tracer and is combined with it in a unit called the two-axis tracer. The two-axis tracer mounts on the offset clamp arms and rotates with the offset clamp foot to allow tracing both above and below the stringer.

The W-tracer permits the lower head to be advanced toward the wing panel with confidence. With the W-tracer the flying height of the lower head is automatically adjusted as the panel thins from inboard to outboard. If required the tracer controlled W flying height can be offset by a pot on the operator panel.

OPERATING SEQUENCE

In developing an operating sequence for AERAC engineers faced the primary difficulty with riveting in the jig – The formboards. The formboards on the A330/340 jigs are located at every rib station, or about every 30 inches. A 12-inch wide riveting head maneuvered between the formboards would miss half the rivets.

There were three methods proposed for the AERAC operation. Of the two methods that were ultimately not adopted, one method was to run an entire line of rivets along the length of the stringer, dropping formboards as you go. The second proposed procedure was to rivet between the formboards on the first pass and remove the formboards one at a time in a second pass to install the missing rivets.

The operating procedure eventually developed for AERAC to install the rivets in a series of "bays". Several formboards are removed from the jig allowing the AERAC access to rivets along up to five rib stations. The AERAC installs all the rivets in this bay on one side of the stringer webs (either above or below). The offset clamp foot is then rotated and the rivets on the other side of the stringer webs are installed. This minimizes the time required for rotation of the anvil.

Although with the J stringer only half of the rivets are hidden behind the outer flange AERAC employs the same offset clamp foot and anvil to install all the rivets. This minimizes tooling changes.

Figure 3 illustrates how the bay operating procedure is implemented. Typically the operator removes 3 to 6 formboards at the inboard end of the wing to open up the first bay. The AERAC installs either all the upper or all the lower rivets in the bay. The offset head is then rotated, and the opposite side of the stringers is riveted to finish out the bay.

After completing this first bay the operator replaces formboards as needed in the first bay to stabilize the wing. Often none or only one is required. Formboards are removed to open up a second bay. The second bay is riveted similar to the first. This sequence of opening bays and replacing formboards as needed to stabilize the panel is repeated along the length of the part. The longest panels are riveted in no more than four (4) bays. The part is removed from the FAJ with all rivets installed.

SPECIAL M-CODES

This "bay" operating procedure puts a premium on speed in jumping from stringer-to-stringer. Jumps must be automatic and they must be quite reliable. Special functionality is required to run the AERAC efficiently with this operating sequence.

The AERAC PAL supports the standard machine M-codes. For example, running a machine cycle, turning tracers on and off and the like. These M-codes are virtually identical to those available on conventional automatic riveters.

In addition, special M-codes were developed to control the motion of the skin side (Z) and the stringer side (W) workheads. These special M-codes take full advantage of the CNC capability of the stringer side workhead using the PAL axis mover feature of the controller. These M-codes facilitate efficient stringer-to-stringer moves. These special M-codes are listed below:

M42 – "Jig Clear"
Retracts the Z and W axes to their deep drop position and then rotates the yoke to be square to the jig in preparation for an extended move down the length of the jig or to jump a formboard. Also available as a pushbutton. All tracers and sensors must be off. The final positions of the axes are set in a table.

M44 – "W Standby"
Moves the W side pressure foot to six (6) inches from the Z side pressure foot to six (6) inches from any W position. The normality sensors must be on and the Y and W tracers off. The six (6) inch distance may be changed in a table. This M-code is used to retract the offset riveting head back from the current stringer in preparation for a Y jump to the next stringer. Conversely the M-code can be used for rapid approach from the deep drop position after stepping around a formboard.

M45 – "Y Flange Clear"
Moves the Y-axis one (1) inch in a direction dependent on the rotation of the offset clamp arms. The offset clamp arms are moved one (1) inch away from the web. This M-code is used to lift or drop the offset clamp foot away from a stringer to clear the outer flange. The Y and W tracers must be off. The one (1) inch distance may be changed in a table.

M52 – "W to Enter Stringer"
Turns on the W tracer, approaches the panel till it nulls out, turns off the tracer and backs up the W axis 3/16 inch. This M-code is used to position the offset clamp foot so that it may safely enter the stringer without getting hung on the edge of the stringer flange. To enter the stringer, the Y tracer is turned on (M55) after an M52. The 3/16-inch distance may be changed in a table.

M53 – "W Deep Drop"
Retracts the W table to its fully retracted position. The retracted position may be set in a table. Used to step around a formboard and to provide clearance for the operator to rotate the head.

M54 – "Z Deep Drop"
Retracts the Z table to its fully retracted position. The retracted position may be set in a table. Used to clear the machine from the skin for a drill change.

AERAC PART PROGRAMMING OF STRINGER JUMPS

In addition to position and federate data the part program contains M and G codes to perform specialized machine functions. Many of these functions are standardized in the control. But the AERAC is provided with a number of unique M-codes that allow simple part programming of stringer-to-stringer jumps. The post processor inserts these sequences of unique machine-readable codes into the part program in response to calls from the CL file.

Each line of the part program begins with a five (5) character line number N^^^^. The words X^^^^ and Y^^^^ are the X and Y position data in 1/1000's of an inch. The program format is leading zero suppress so that zeros on the left are unwritten. The Y data is ignored by AERAC when the edge distance tracer is active.

The word F^^^^ is the commanded federate of the AERAC in 1/1000's of an inch per minute. The program changes the federate for various moves throughout the part program as needed. G98 instructs the control to reset the CAR register to the X-Y location indicated by the data on that line. The post processor inserts an M00 program halt before each G98 to allow the operator to line AERAC up to a hard fastener using the nosepiece miniature video camera equipped with crosshairs as shown in Figure 4.

Figure 5 is divided into four segments which illustrate the sequence of leaving a stringer. Figure 6 has four segments which depict entering a stringer. The corresponding part program from the #4 panel of the left wing is listed in table 1. This part program fragment illustrates the CNC programming required for a stringer-to-stringer move. The part program is divided into the corresponding segments which correlate with figures 5 and 6. The comments are added for clarity.

As is seen in the part program a typical stringer jump involves rising or lowering in Y to clear the stringer flange before pulling out. An M45 incremental 1" Y flange clears all the A330/340 stringer flanges and simplifies the programming.

The next step in the sequence, pulling the offset workhead out away from the stringer is accomplished by the use of an M44, "W six inch standby", where the stringer side axis moves six inches back from the skin side tool point. This M-code uses the overall span of the yoke and the Z-axis position to computer the target position for the W axis.

After making a programmed Y move to the next stringer an M52 is run to position the offset workhead to enter the stringer. This M-code turns on the W tracer, allows the W axis to move toward the wing until the W tracer has been nulled out, turns the tracer back off, and then backs up the W workhead 3/16 inch. This positions the offset workhead to safely reenter the stringer.

The edge distance (Y) tracer is then turned on (M55) and allowed to null. The W tracer is again turned on (M40) to maintain a constant flying height inside the stringer. After relocating in X on a hard fastener (G98) the row of rivets is run.

CATIA DOWNLOAD

The wing design of the A330/340 is completely on CATIA including all of the rivet locations. In addition, Textron has also designed the FAJs on CATIA. This allows a clear path to be established from the CATIA database straight through to the AERAC part program.

A CATIA drawing of the part provides five (5) axes of rivet position data in aircraft geometry. This CATIA part drawing is rotated to present the part to the CNC programmer as it is mounted in the jig. This rotation transforms the rivet location data from aircraft geometry to the jig geometry needed for programming of the AERAC.

Of the five (5) axes of rivet data available only X and Y is retained for use by the AERAC. And the Y data is only employed for stringer-to-stringer jumps. During normal operation the AERAC runs under the control of five (5) sensors and the X program data. The yoke pitch and roll, the extension of the two workheads and the machine Y-axis are all controlled by tracers.

To produce a part program for the AERAC the CNC programmer must first create a cutter location (CL) file. On the CATIA screen he uses a pointer to pick rivets in the desired order form the combined jig and part drawing. The programmer must coordinate with the manufacturing engineer since his program dictates the operating sequence of the machine.

The programmer inserts auxiliary functions into the CL file to indicate stringer jumps, messages and other actions. The CL file is then processed by a post processor to produce a machine readable part program. The auxiliary functions become M codes and the messages are displayed on the operator screen as required. For example, one of the screen messages instructs the operator to rotate the offset anvil. The part program is executed line-by-line by the machine tool to produce the part.

In the current application of AERAC hard fasteners are hand installed at the rib stations. To insure an even spacing between rivets and hard fasteners the program calls for the operator to align the machine on a hard fastener at the beginning of each row. The pressure foot contains a miniature camera with an adjustable crosshairs as shown in figure 4. Before the row is begun an M00 stops program execution. Watching the CRT the operator jogs the machine into alignment with jog buttons on the hand pendant. Once aligned the operator presses cycle start. The next line of code executed contains a G98 which resets the CAR register to the hard fastener location. As rivets installed by AERAC are implemented to replace hard fasteners this realignment procedure will become unnecessary.

REFERENCES

[1] "Low Voltage Electromagnetic Riveter," Zieve, P., SME paper AD86-680, Fastec 10/86

[2] "Rivet Quality in Robotic Installation," Hartmann, J., Zieve, P., SME Paper AD89-640, Fastec 10/89

[3] "Design of the Automatic Electromagnetic Riveting Assembly Cell," Zieve, P., Hartmann, J., Howard, S., and Hermann, K., SAE paper #902045, Aerofast 10/90

APPENDIX

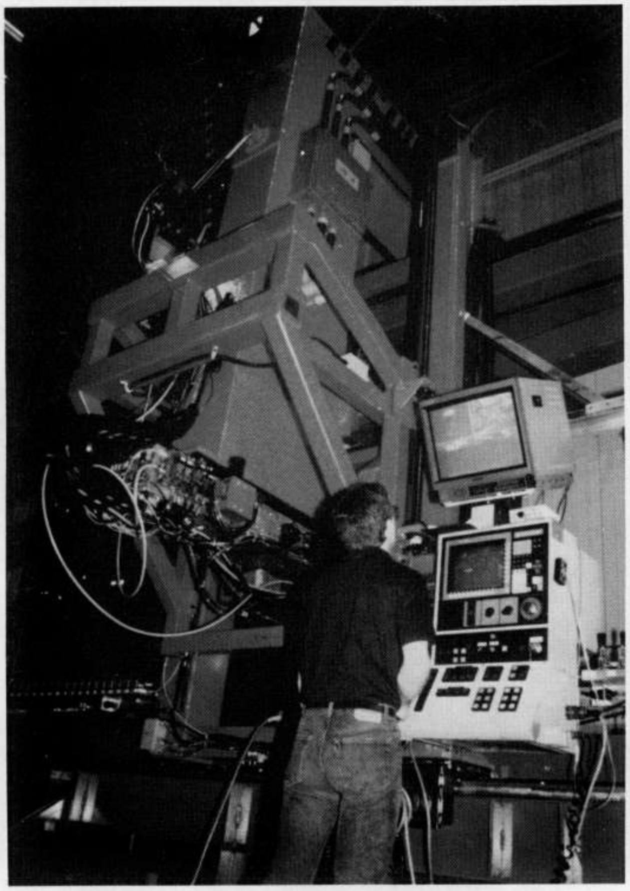


PHOTO 1: AERAC ON FAJ AT TEXTRON

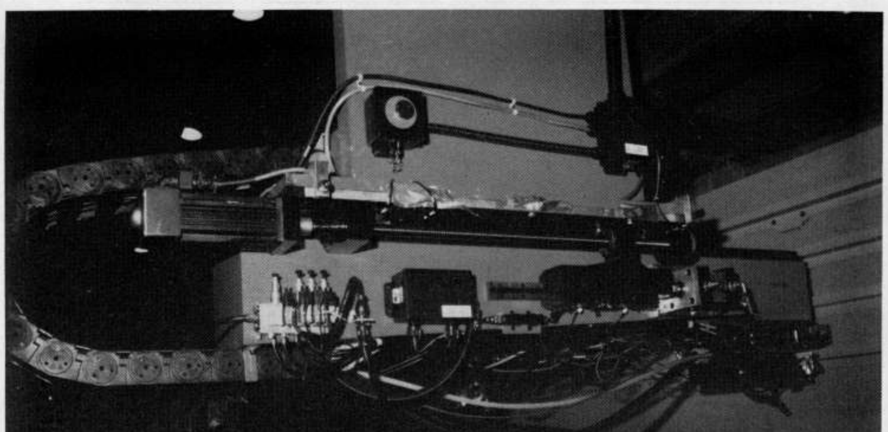


PHOTO 2: W TABLE DEPLOYED ON STRINGER

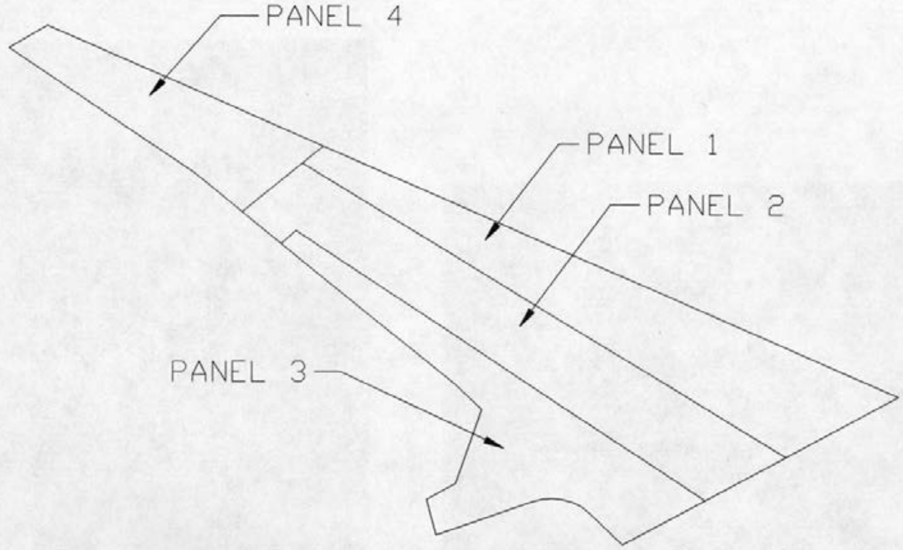


FIGURE 1: A330/A340 WING PANELS

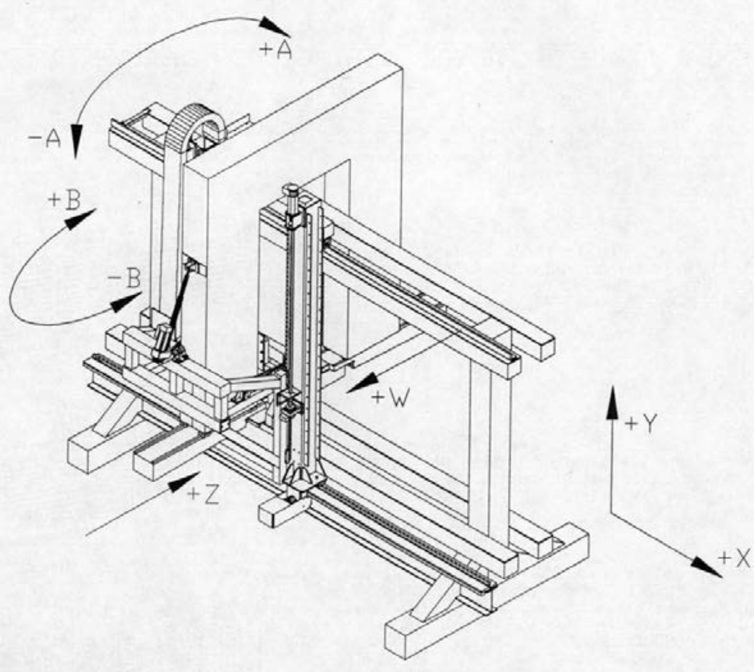
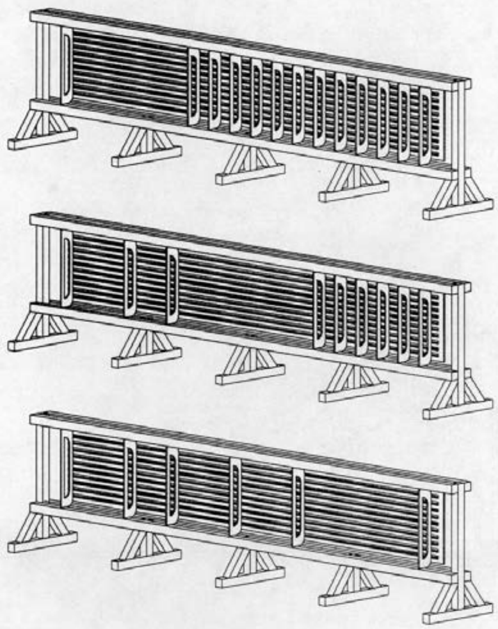


FIGURE 2: AERAC AXES



THE OPERATOR REMOVES THE FIRST SEVERAL FORMBOARDS TO OPEN UP A BAY. THE AERAC INSTALLS RIVETS ONE ONE SIDE OF THE ALL STRINGERS BEFORE THE OFFSET TOOLING IS ROTATED AND RIVETS ARE INSTALLED ON THE OPPOSITE SIDE OF THE STRINGERS. THE END FORMBOARDS ARE NOT REMOVED ON THE AERAC SINCE THEY DO NOT OBSTRUCT ACCESS TO ANY RIVETS.

AFTER COMPLETING THE FIRST BAY, THE OPERATOR REPLACES FORMBOARDS IN THE FIRST BAY AS NEEDED AND REMOVES FORMBOARDS TO OPEN A SECOND BAY.

THE OPERATOR OPENS A FINAL BAY AFTER FORMBOARDS IN THE SECOND BAY ARE REPLACED. THE PANEL IS REMOVED FROM THE JIG AS A COMPLETED PART AFTER THE RIVETS IN THE FINAL BAY ARE INSTALLED

FIGURE 3: FORMBOARD REMOVAL ORDER FOR BAY RIVETING

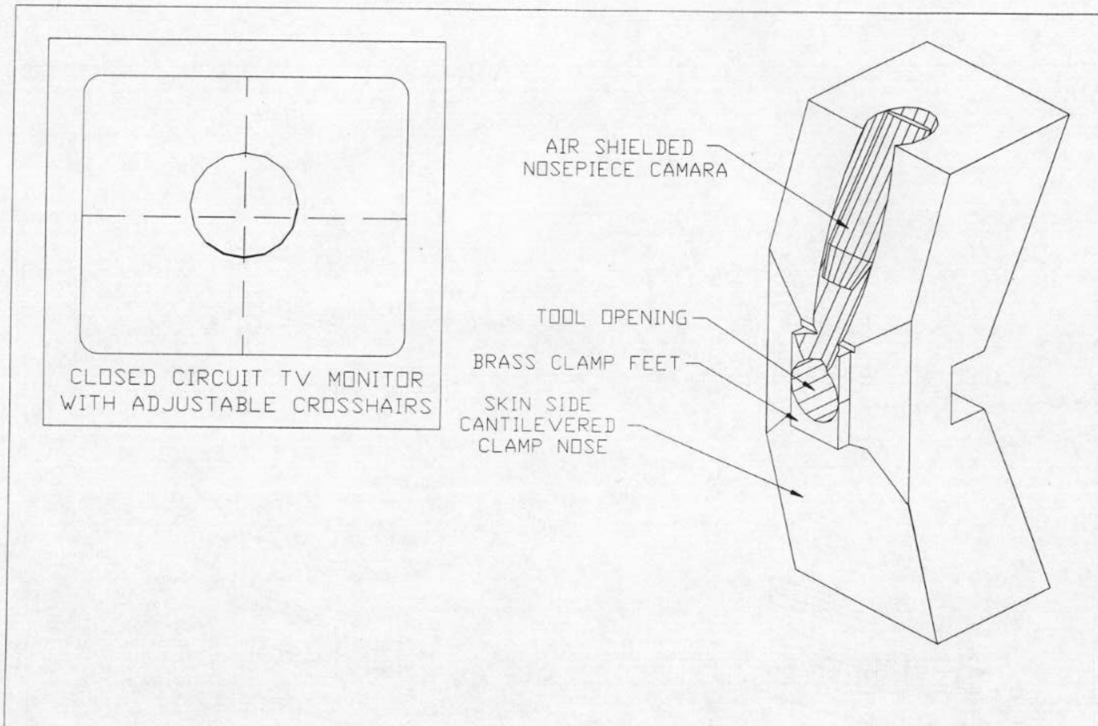


FIGURE 4: AERAC RELOCATION ALIGNMENT CAMARA

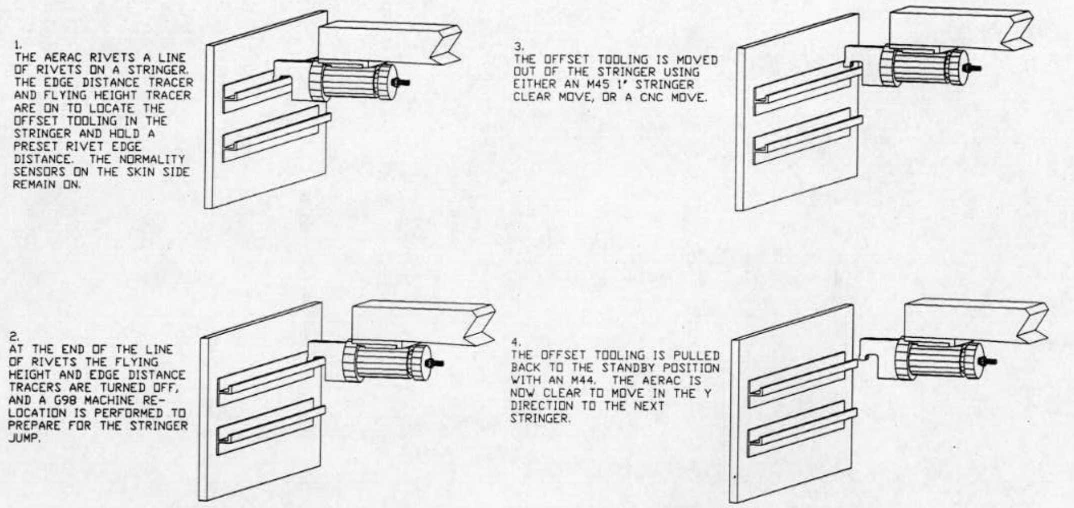


FIGURE 5: AERAC STRINGER TO STRINGER MOVE (#1)

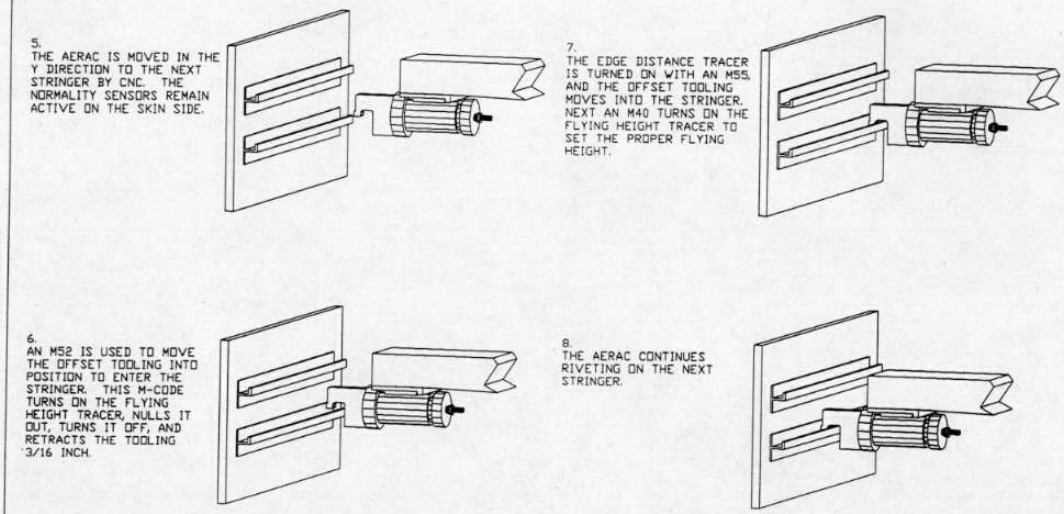


FIGURE 6: AERAC STRINGER TO STRINGER MOVES (#2)