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Automatic Drilling and Fastening System for Large Aircraft Doors

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Abstract

Electroimpact has developed a system for drilling and fastening of cargo door structures which efficiently addresses many of the manufacturing challenges that such parts present. Challenges to door automation include 1) the presence of an inner skin that must be processed, in addition to the outer skin, and 2) a stiff frame structure, which makes the clamping and drilling processes that are typical to automated fastening machines very unforgiving of any errors in workpiece positioning. In this case, the manufacturing cell was to be installed in an existing facility with very limited ceiling height, further complicating the system and process design. New methods were devised to solve these problems, and the solutions found will likely have utility in future applications.

Introduction

Electroimpact was contracted to provide automation for the manufacture of commercial aircraft cargo doors. Drilling and fastening of the skins to the structure were the primary area of focus for automation.

There were several important parameters for the automation system, some of which are common to aircraft door structures, and some due to limitations of the facility in which the automation was to be placed:

1. The door structure consists of both inner and outer skins, which must be drilled and fastened. It is desirable to automate as much of both of those processes as possible.
2. The inner skin contains many openings, making normality control more difficult.
3. The system was to be built in an existing factory with no overhead crane.
4. The factory has a low ceiling, limiting material handling options and also constraining the machine height.

Design Approach

Several automation options were considered for the drilling and fastening system, including a drilling robot, and a C-frame riveter with robotic part positioning. Automated fastening of aircraft door structures using a c-frame riveter and robotic positioner has been accomplished successfully in the past, yielding good performance and accuracy [1]. However, the size and weight of the cargo door are great enough to cause concern for positioning with a single robot, particularly when the weight of a tooling frame is added. A machine design based on the E7000 series riveting machine

FIGURE 1 E7000 machine as implemented for cargo door manufacture.

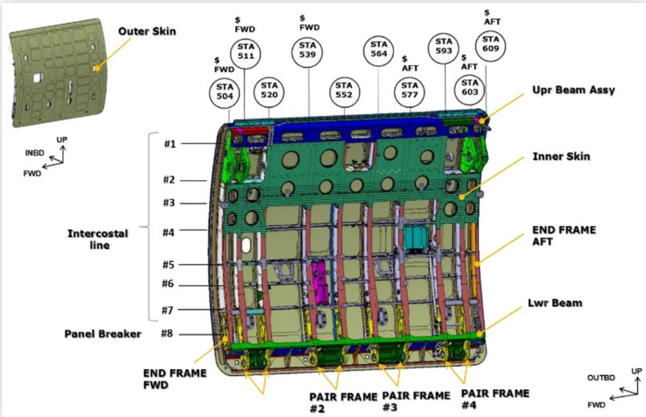
was therefore chosen. Important factors affecting that decision were double-sided clamping and fastening capability, which ruled out a standard robotic drilling system, and the fact that the E7000 part positioner could be designed to handle any realistic part and tooling weight.

Door Structure

The cargo door is an aluminum structure consisting of an egg crate assembly of frames and intercostals, upper and lower beams, the outer skin, and an inner skin (Figure 2).

The most obvious candidate operation for automation is the drilling and fastening of the outer skin to the frames.

FIGURE 2 Door construction.



Automation of these processes on a riveting machine removes the need for drill templates, and can reduce or eliminate disassembly and deburr, if access to both sides of the stack are accessible for all locations.

After careful study, it was determined that automated single-sided drilling of the inner skin on the same machine would also be possible. Although removal of the inner skin for deburr, and manual fastening would still be necessary due to the automated drilling being single-sided, the elimination of the two-step manual drilling operation provides an additional gain in efficiency.

Introduction of Automation

A revised build process was developed for the cargo door in order to incorporate automation. The inner skin blocks access to the inner side of the OML stack, and therefore the inner skin cannot be in place if two-sided access is to be achieved when fastening the outer skin. This fact makes it necessary that fastening of the door be done in multiple steps, with removal of the part from the machine for manual work in between steps.

Additionally, it became clear that there were some locations to be fastened on the outer skin where access on the IML side of the outer skin stack would be difficult or impossible, due to interferences with the structure. Therefore some drilling with only single-sided clamping and subsequent disassembly and deburring would still be necessary.

Machine automation on the panel was broken into three distinct operations:

Operation 1:. Single-sided drilling of outer skin locations not accessible for double-sided drilling and fastening.

Operation 2:. Two-sided drilling and fastening of the outer skin.

Operation 3:. Single-sided drilling of the inner skin.

With the introduction of automation, the new overall build process is:

1. Frames, upper and lower beams, and intercostals are loaded into assembly jig. Outer skin is positioned over frames, and secured with temporary tack fasteners. Inner skin is positioned on inside of frames and held in place with temporary fasteners.
2. Door with tacked inner and outer skins is loaded into riveting machine. Locations on outer skin with limited IML accessibility are drilled with single-sided clamping.
3. Positioner is inverted. Inner skin drilled by machine.
4. Door unloaded from riveting machine. Inner and outer skins are removed and deburred. Sealant is applied and outer skin reinstalled with temporary tack fasteners.
5. Door is loaded into riveting machine. Majority of outer skin rivets and bolts are machine-installed.
6. Door is unloaded from riveting machine. Inner skin is replaced and manually fastened.

Tooling and Part Handling

Because the build process requires the part to be loaded into the machine and unloaded again multiple times, with manual operations in between, transferring the part between an assembly jig and part-holding tooling in the machine part positioner would consume considerable time. Instead, it was preferable to make an assembly jig with all of the necessary tooling features for part build-up that could also be loaded directly into the riveting machine.

Electroimpact designed a Riveting Assembly Jig (RAJ) to support the panel during all steps of the new build process outlined above. In addition to facilitating build-up of the cargo door, the RAJ integrates with the riveting machine to hold the panel during automatic processing, and also interfaces with a cart that facilitates movement of the door through the factory. Rollers on the cart combined with a rail system installed in the factory floor guide the motion of the RAJ between work stations. This system allows manual movement of the door, RAJ, and cart by a single person.

Loading of Riveting Machine

Because there is no overhead crane in the factory, it was necessary to devise a floor-based method to load the cargo door and RAJ into the machine. The vertical motion of the riveting machine's part positioner is used to lift the RAJ from its cart. After the RAJ is lifted clear, an A-axis rotation of the machine positioner brings the RAJ fully into contact. Pneumatic clamps then engage, locking the RAJ into place on the machine positioner.

The rail arrangement in the factory floor guide the motion of the cart, enabling the cart and RAJ to be placed at a repeatable location in the machine cell. After positioning the cart and RAJ at the designated position, the operator runs a scripted machine loading routine to lift and engage the RAJ. The entire load process can thus be accomplished in around five minutes, which is substantially faster than machine loading can typically done with an overhead crane. Furthermore, because all of the movements are pre-defined and fully constrained, there is less room for human errors that could result in damage or unsafe conditions.

FIGURE 3 Cart presents RAJ with door to machine positioner. Positioner motion is used to lift RAJ from cart.

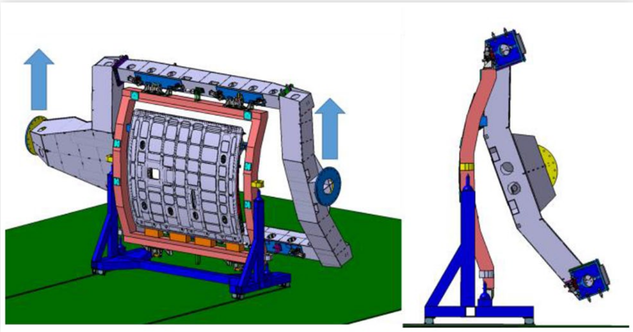
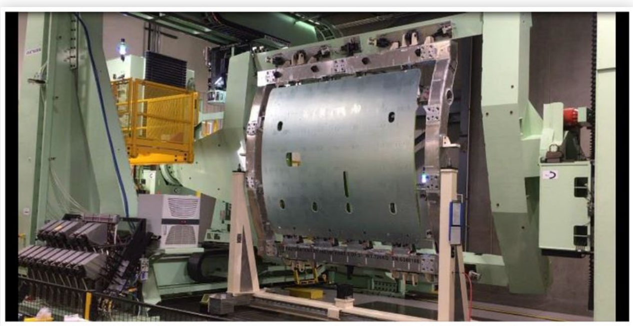


FIGURE 4 RAJ with door after being lifted from cart by machine positioner.



Automation of Inner Skin

Machine drilling of the inner skin requires the part positioner and RAJ to be flipped 180° from the orientation used for outer skin drilling and fastening. Consideration was given to this requirement to invert the part in the design of the machine positioner, and the RAJ itself. The system of pins and clamps that locates and retains the RAJ to the machine positioner was analyzed at all possible orientations, and designed for suitable redundancy and factors of safety.

Concave Shape of Inverted Door

In addition to the mechanical challenges associated with inverting the part, the geometry of the inner door introduced another set of challenges that had to be addressed. Because the shape of the door when inverted is concave, access by the machine fastening head is difficult. As illustrated below, the width of a standard E7000 head would limit its ability to access the inner skin.

Theoretically, the length of the nosepiece could be increased until all locations on the inner skin could be drilled without interferences between the head and the positioner, but an excessively long nosepiece leads to a correspondingly long gauge length and long drills, which would be expected to adversely affect machine speed and drilling performance. A solution was found in rotating the machine's upper head 90° from its standard orientation, so that the wide direction of the head falls along the long direction of the part. This change permits the head to approach the inner skin more closely. A longer-than-normal nosepiece is still necessary, but its length is significantly shorter than would have been required without the rotation.

FIGURE 5 Because of its width, a standard E7000 head cannot get close to the panel due to the concave shape of the inverted cargo door. A long standoff distance with a correspondingly long nosepiece would be necessary to allow access.

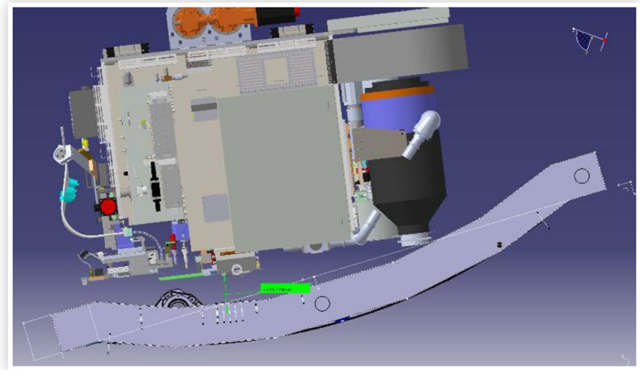
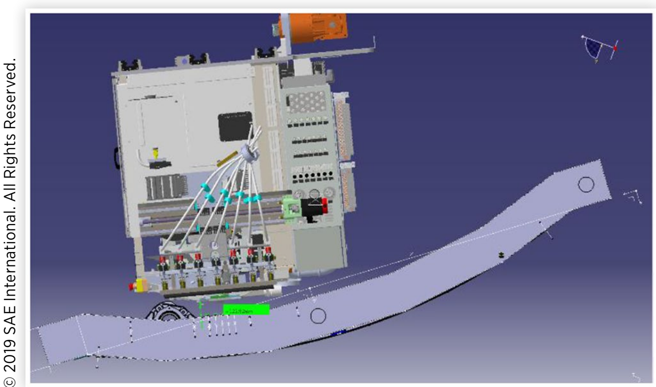


FIGURE 6 E7000 head rotated 90° so that the narrower dimension is in the direction of panel curvature.



Effect of Rotated Head on Machine Performance

The E7000 uses a linear motor for high-speed shuttling between process tools, and rotating the head places the high thrust loads perpendicular to the long direction of the machine's upper beam. This force takes the form of torsion loading on the beam cross section. Finite element analysis showed that redesign of the upper beam structure was needed to prevent excessive deflection or oscillation while shuttling with the maximum thrust output of the motor.

As a result, the upper beam was redesigned with an eye toward maximizing the torsional rigidity of the structure. Additional constraints on the new cross section were 1) low ceiling height of the factory, which prevented the beam from being made significantly taller, and 2) the desire to keep the overall mass of the upper beam low, since increased mass at such a high position on the machine has the effect of driving

FIGURE 7 Acceleration of the shuttle table (yellow arrow) induces a torque on the machine's upper beam.

up the machine's natural frequency, which could limit performance during pitch moves. Given these constraints, a new upper beam design was developed which was very nearly square in proportions, and includes a fully enclosed lower face, as these two changes yield a structure that is more torsionally efficient. Additional changes were made to the internal structure of the beam, driven by finite element analysis. The result was a machine that could accommodate shuttle moves with the rotated head, with no sacrifice of performance.

Normalizing on Inner Skin

The E7000 machine typically uses an array of four laser distance sensors on the upper head to control fly height and maintain normality to the panel [2]. The sensors are arranged in a rectangular pattern around the tool point. This arrangement works well for typical aircraft skin panels, since all four sensors will generally land on the panel and therefore give useable readings. The inner skin of the cargo door is different, with many large openings that the machine must navigate around while maintaining normality.

With the standard square sensor pattern, a sensor would fall into a hole at many inner skin fastener locations, potentially compromising normality. Therefore a new four-sensor pattern was added that would better dodge the panel openings. A "cross" pattern was used, as it fits much better between holes and openings while the tool point moves along rows of fasteners. In combination with the legacy rectangular pattern, the result was an array of eight sensors, with good normalizing capabilities on both the inner and outer skin.

FIGURE 8 View of machine headstone from underneath. Legacy normality sensors are indicated by red arrows, while new sensors added for the inner skin are indicated with yellow arrows.

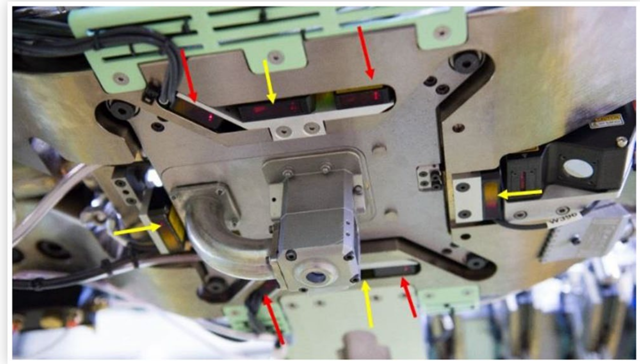
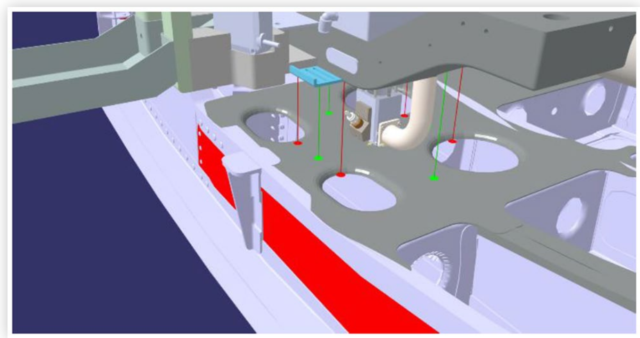


FIGURE 9 Machine head in position to drill typical fastener location on inner skin. Red dots indicate positions of sensors in original design, and it can be seen that two sensors fall into holes at this location. Green dots show new sensor locations, all of which fall on the panel.



Summary/Conclusions

There is a large potential market for automation of drilling and fastening of aircraft door structures. Systems have been developed previously for automation of passenger doors and other smaller structures of similar construction; this project led to a method for automation of larger cargo doors. Most significantly, methods developed here allow for automated processing of both sides of a two-sided part, as well as fast and efficient part loading and unloading without the use of an overhead crane. These methods should have application in future systems for processing of similar parts.

References

1. Barton, E. and Wolf, R., "Drivmatic® Automatic Fastening System with Single Robot Positioner," SAE Technical Paper 2017-01-2078, 2017, doi:10.4271/2017-01-2078.

2. Stansbury, E., Bigoney, B., and Allen, R., "E7000 High-Speed CNC Fuselage Riveting Cell," *SAE Int. J. Mater. Manf.* 7(1):37-44, 2014, doi:10.4271/2013-01-2150.

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Definitions/Abbreviations

OML - Outer Mold Line

RAJ - Riveting Assembly Jig

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