Lights Out Cell Automatic Tool Change Solution for Nut and Collar Anvils with Integrated Fastener Feed Hardware

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Abstract

Automated collar and nut installation requires complex hardware on the wet side of the spar or wing panel. Wet side automatic tool changers are becoming common but an operator is often required to connect electrical, pneumatic and fastener feed system components. This is unacceptable in a lights-out cell, and any fully automatic solution must be reliable while satisfying demanding design requirements.

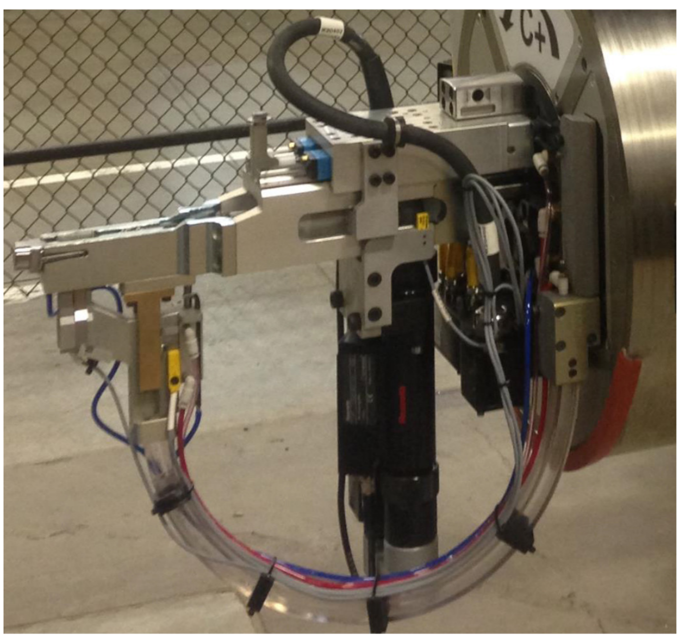

Figure 1. Wet side anvil for nut installation.

The 737 Spar Assembly Line (SAL) is a new lights-out machine cell at the Boeing factory in Renton, Washington. The SAL machines are equipped with a unique fully automatic tool changer (ATC). The wet side ATC interface is designed to automatically connect conventional as well as more unique services such as fastener feed. The fastener feed ATC module, called the “spinner,” rotates with the machine’s wet side rotary axis (C axis). It consists of a stack of rotors that rotate inside of a stationary annulus. Each rotor is designed for a size and type of fastener. Air conveys fasteners along the inner diameter of the annulus, requiring that each rotor is sealed from the others against the inner diameter of the stator. Nuts and collars are fed into their respective rotors, roll along the interior diameter of the annulus, and are redirected out of the annulus by a scoop fixed to the machine C axis. The scoop delivers the fastener to an anvil-mounted assembly which receives the fastener and blows it to the tool point for installation.

Introduction

Figure 2. SAL machine at Electroimpact.

The latest automation specifications demand compact equipment, space-efficient cells and emphasis on operator safety. One modern solution to such a specification is the 737 Spar Assembly Line (SAL) at Boeing in Renton, Washington. The SAL cell packs two assembly lines and four machines into a space which previously accommodated a single line with one machine. SAL is a lights-out cell surrounded by safety fences, light curtains and scanners. After the cell is cleared for the machine to run, no operator should need to enter the cell until the fastening program is complete.

The SAL machines install bolts, swage collars and torque nuts of four diameters. To process all of those fasteners, tool changes must occur quickly without operator involvement. Conventional machine tool holders can be outfitted with modules for electrical and pneumatic service connections, but inventive solutions are required to meet the unique fastener feed and packaging demands of the SAL cell.

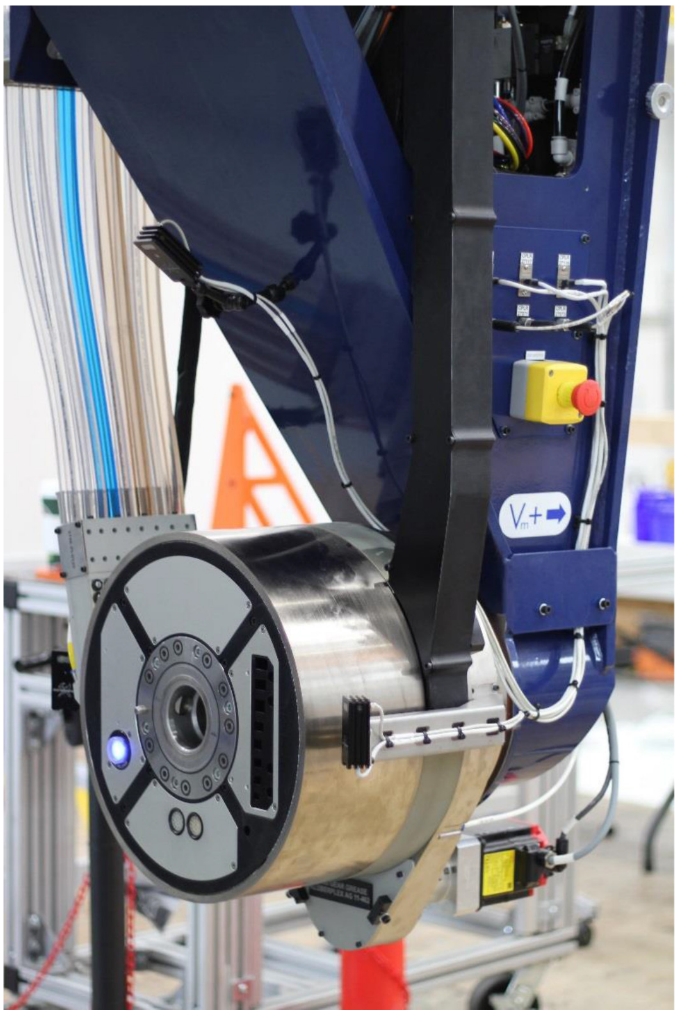

Figure 3. C Axis with spinner assembly.

The compact SAL wet-side tool interface with its integrated fastener feed module provides a distinct advantage in an industry where the demand for safe, fast, lights-out cells is growing. The safety benefits of keeping the operator out of the cell and therefore out of harm's way entirely is obvious but difficult to quantify. However, a measurable benefit of the SAL automatic tool changer as a whole is speed. The SAL ATC is capable of executing a full tool change more than 10 times faster than similar machines with partially automated tool change procedures. Part of what makes the tool change possible is SAL's custom wet side ATC interface.

Design Requirements

Single Touch Tool Holder Interface

Manipulation of the entire anvil as a package reduces the time required to complete an automatic tool change. This is a clear benefit for floor-to-floor rate. The tool holder centers and clocks the anvil, aligning anvil-mounted electrical, pneumatic and fastener feed hardware to their corresponding machine-mounted components.

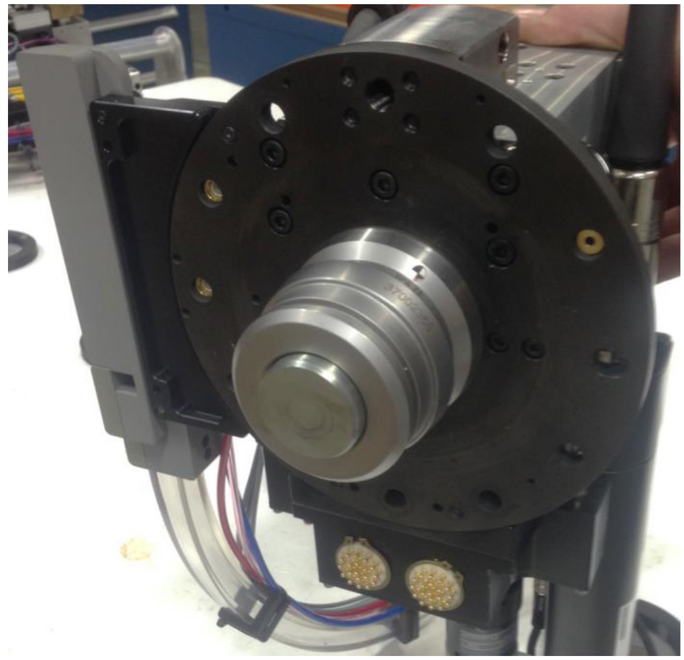

Figure 4. Tool interface with electrical, pneumatic, and fastener feed connectors.

The tool holder also applies 25 kN of holding force to the anvils, which is especially important for collar forming. After a collar is swaged onto an LGP bolt, the die must be stripped off of the formed collar. Tensile loads imparted on the collar anvil during the stripping of the die are resolved by the tool holder.

Rotation

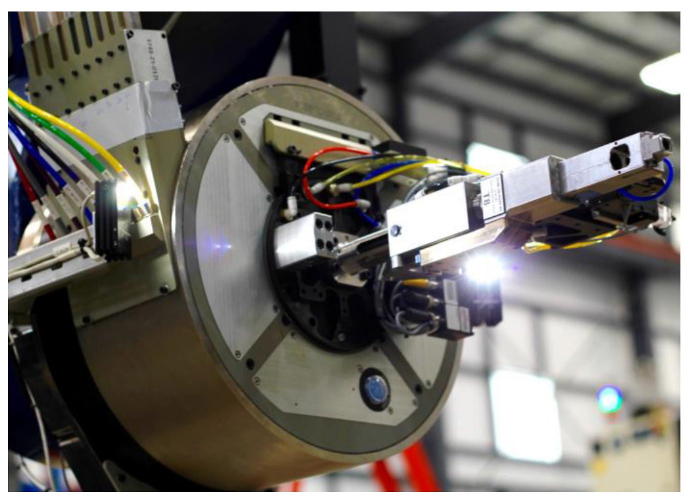

Figure 5. Nonzero C axis position.

The machine C axis has close to 360 degrees of rotation so that wet side anvils can access all fastener locations on a spar. Any electrical and pneumatic services required by the anvils pass through a rotational cable carrier before they reach the ATC interface. The fastener feed module, or "spinner," enables the fastener feed system to blow nuts and collars to the anvil at any C axis rotational position.

Reliability and Marking

Materials and feed system pneumatic flow rates must be selected such as to prevent cosmetic damage to aluminum collars and ensure long machine component life. Early prototyping results showed that the use of plastics in certain locations reduces marking and wear.

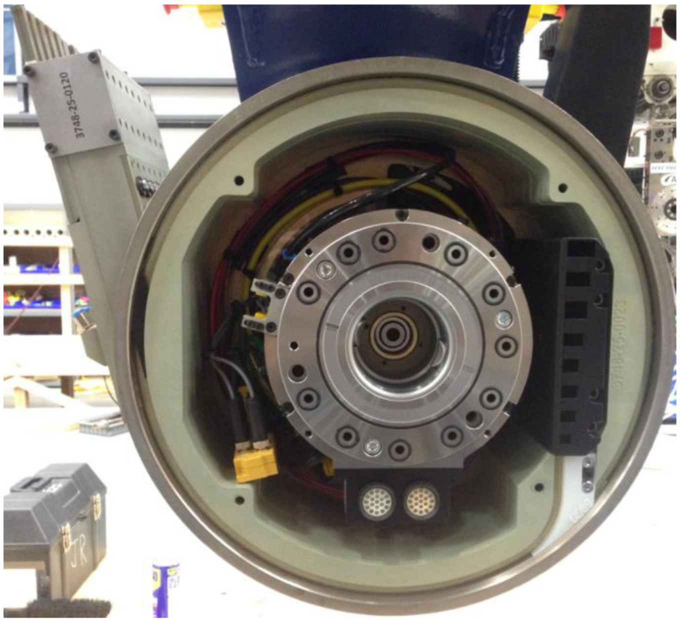

Figure 6. Partially disassembled rotor with plastic components.

Minimum Size and Weight

It is necessary to limit the size of the SAL machine wet side hardware due to machine weight implications and material handling clearance.

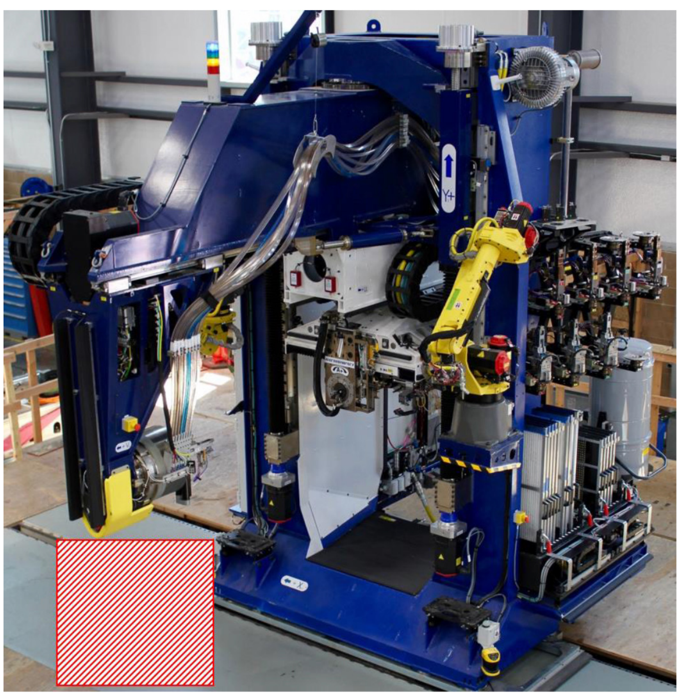

Figure 7. Area under the wet side must remain clear.

Components are designed to be as small and light as is practical because clearance is required below the machine on the wet side for material handling carts to enter and exit the cell.

Wet side hardware is located far from the machine X and B bearings due to overall machine size constraints. Thus, lighter weight components increase the machine natural frequency and allow for improved B axis controllability by limiting the mass furthest from the center of gravity. Additionally, a light machine helps keep the overall weight below the overhead crane capacity which is relatively low.

Theory of Operation

The tool holder has integrated pneumatic ports along its outer diameter that provide pressurized air to the collar and nut anvils. The air is used to pressurize pneumatic cylinders that deliver fasteners to the tool point. The spring-loaded electrical connector provides power and signal service to anvil mounted components. One of its two circular connectors is dedicated to low-voltage inputs and discreet signals. These signals are used to give feedback to the machine such as tool identification and fastener feed confirmation. The other circular connector is used for nut runner spindle communications and power.

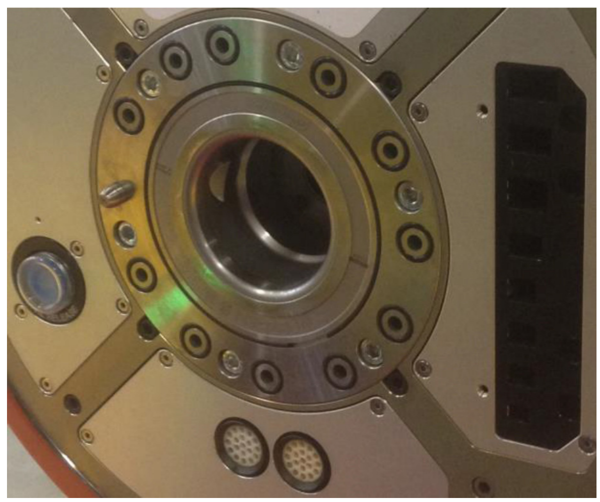

Figure 8. Automatic tool changer interface.

The spinner assembly is designed into the outer diameter of the wet side process head. It has eight internal paths, one for each size and type of fastener. The paths are machined into a stack of rotor plates which turn with the C axis inside of a cylindrical stator. Each internal path is pneumatically sealed from the others by means of a strip of felt cording which is energized against the inner diameter of the stator with urethane foam.

Fasteners are pneumatically conveyed from the fastener selector to the spinner inlet through flexible tubing. After entering the spinner, the collar or nut rolls along the inner diameter of the stator until it reaches a plastic scoop that rotates with the C axis. Additional airflow is provided at the spinner inlet to ensure fasteners do not get stuck at the low point of the stator.

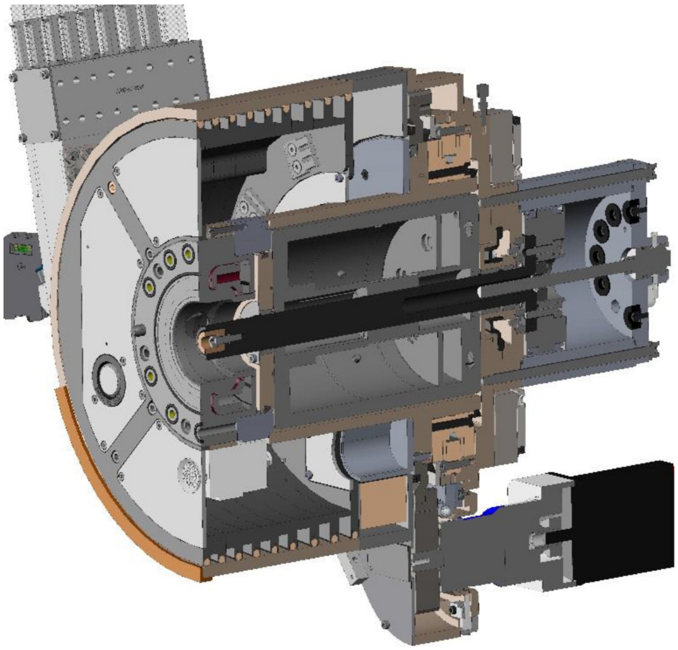

Figure 9. Spinner cutaway with rotor/stator configuration shown.

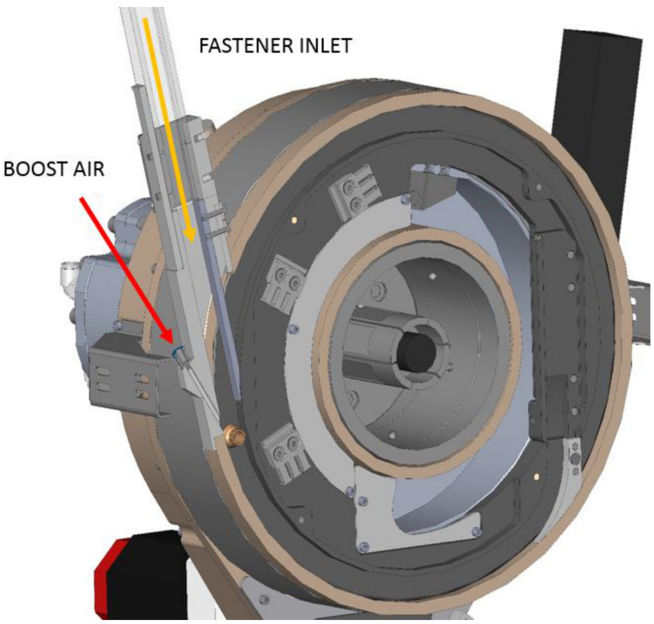

Figure 10. Fastener and airflow inlet.

The rotating scoop is mounted to the rotor stack. It functions as a ramp which redirects the fastener from the inner diameter of the stator toward the exit ramp.

The rotors of the spinner rotate with the C axis as it positions the anvil for spar geometry access. The interior plastic scoop and exit ramp also rotate so that fasteners can be delivered to the anvil at any angular position.

The exit path is another scoop which changes the trajectory of the fastener, orienting it in the Z direction toward the anvil.

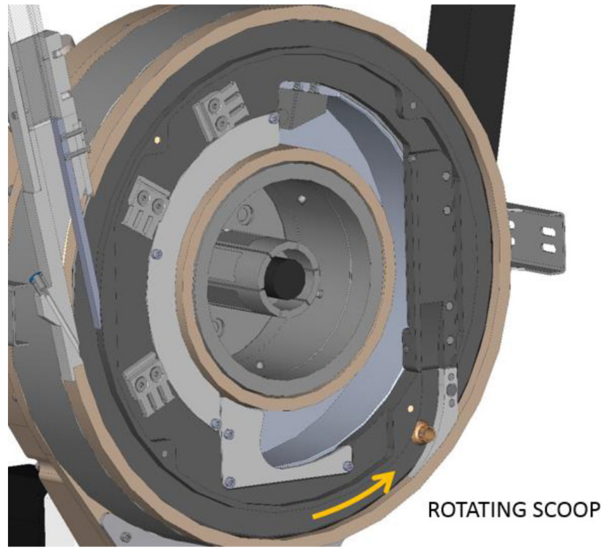

Figure 11. Fastener redirected by scoop into exit ramp.

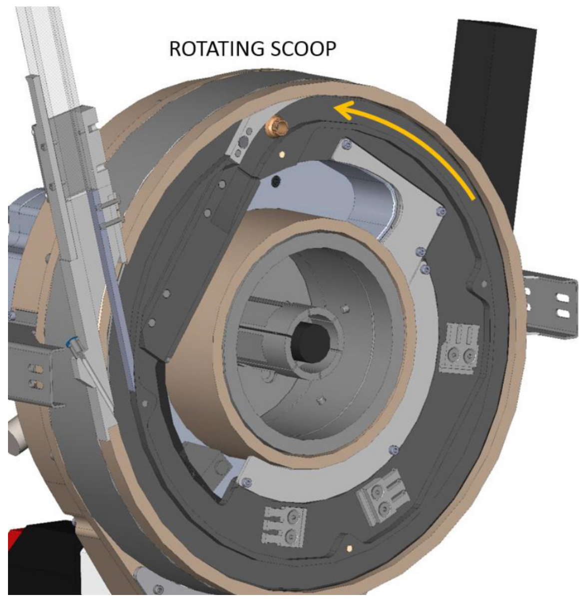

Figure 12. Rotating scoop at alternative feed position.

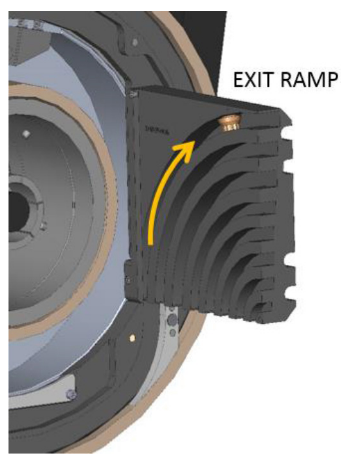

Figure 13. Fastener exiting spinner.

A receiver assembly mounted on each anvil has an opening which is aligned to the spinner exit scoop. Fasteners are passed from the spinner to the receiver and given another boost of air to propel them through a section of soft tubing to the anvil loader where they are picked up by the socket or die and installed.

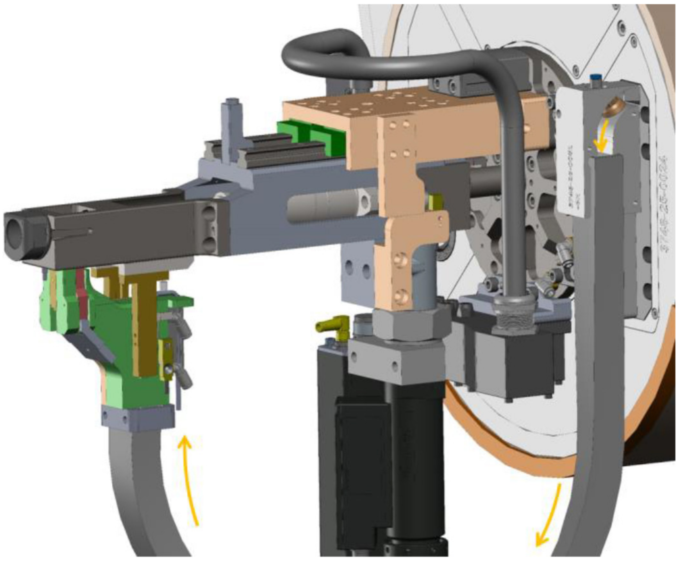

Figure 14. Fastener received by anvil and conveyed to tool point.

All of the hardware mounted on the wet side anvil is manipulated at once by a robot during the automatic tool change procedure. Single touch tool change helps reduce the time required to complete a full change of process tools to just over a minute including automatic calibration. Similar machines with partially automatic tool change procedures can require fifteen minutes to complete a tool change due to design factors and operator efficiency.

Conclusions

Lights out machine cells offer discernible safety and productivity benefits. Fastening machines often require complicated tool change procedures well suited for the dexterity and adaptability of an operator. On the 737 Spar Assembly Line, the wet side anvil interface is just one of many inventive design solutions that have been implemented to fully automate the cell. A clear benefit of these efforts is a tool change procedure that is safer for the operator and at least ten times faster than manual and partially-automated alternatives.

Contact Information

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Definitions/Abbreviations

ATC - Automatic Tool Changer

B axis - Machine axis which rotates about the vertical axis of the machine. Used to allow machine to navigate bends or kicks in parts.

C axis - Machine axis which rotates about the Z axis. Used to rotate the wet side nosepieces and anvils to access complex spar geometry.

LGP bolt - Lightweight groove proportioned lockbolts. LGP bolts have grooves that collars swage onto.

SAL - 737 Spar Assembly Line.

Wet side - Interior of the wing or spar where fuel is stored.

X axis - Longest machine axis. Navigates spar length.

Z Axis - Drilling and fastening machine axis.

The Engineering Meetings Board has approved this paper for publication. It has successfully completed SAE's peer review process under the supervision of the session organizer. The process requires a minimum of three (3) reviews by industry experts.

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