TRENDS IN MANUFACTURING AND ASSEMBLY TECHNOLOGIES FOR NEXT GENERATION COMBAT AIRCRAFT

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ABSTRACT

This paper covers the status on present manufacturing and assembly techniques and trends in new manufacturing technologies for the development of future combat aircraft. Aircraft building involves lot of challenges right from a detail component stage to the sub-assembly and assembly stage because of the complexity involved in the design and manufacturing of aerodynamic contour with weight control. The objective of this paper is to highlight the next generation manufacturing technologies which simplify the present production processes, improves the production rate and build quality. Advanced manufacturing techniques like CNC pipe bending for aircraft system pipelines, multi-pass Wire-EDM for cut-out brackets and actuator components, composite CNC machining for CFC panels, Multi-tasking machines for integrated machining of aircraft system parts, high speed machining to machine lengthy spars, etc., need to be adopted for series production. The various assembly techniques like modular assembly, manufacturing automation viz. Robotic arm for drilling, riveting, painting, inspection, etc., ensures repeatability and improved quality in series production. This paper brings out the emerging trends in manufacturing and assembly of next generation combat aircraft and the benefits derived in terms of cycle time and quality.

Keywords: combat aircraft, CNC pipe bending, CFC composite machining, multi-pass wire-EDM, high speed machining, modular assembly, manufacturing automation.

1. INTRODUCTION

Aircraft building involves lot of challenges right from detail component stage to the sub-assembly and assembly stage because of the complexity involved in the design and manufacturing of aerodynamic contour, each part is unique in geometry/shape requiring more tooling and low batch size/volume. Generally aircraft production is referred to as craft production because of the special skills required on the shop floor to achieve the acceptable level of aerodynamic contour and aircraft build quality. The next generation combat aircraft needs new manufacturing processes and assembly techniques to achieve improved build quality in terms of minimum number of joints/ fasteners, stealth requirements and interchangeability of system line replaceable units, pipelines, looms, doors and covers and increased rate of production. This paper elaboratively covers the present manufacturing methods, need for new manufacturing processes, description and benefits for various advanced manufacturing technologies.

These emerging new manufacturing processes simplify the present processes, improve the production rate through automation and production quality and reduced rejection. The next section covers in detail about the challenges with present manufacturing techniques and various advanced manufacturing and assembly techniques.

2. CHALLENGES WITH PRESENT MANUFACTURING PROCESSES

2.1. System pipelines

Presently, majority of the system pipelines for combat aircraft are fabricated through manual pipe bending and welding process resulting in poor quality. Also since the pipelines having multiple bends cannot be bend with a single pipe, the component is split up into multiple pieces and joined through Arc Welding (shown in Figure-1).

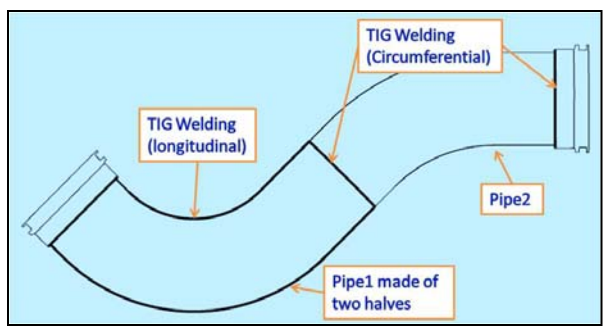

Figure-1. Pipeline Assembly welded with multiple parts.

These welded pipeline joints result in distortion of pipes, prone to crack at joint location and difficult to achieve interchangeability.

2.2. Complex profile actuator components

Generally, aircraft components are complex in shape, size and high strength as well as hard materials which are difficult to machine with conventional methods. Some of the materials were with Ti-6Al-4V, Inconel, etc and applications were long aspect ratio drilling, complex profile cutting, through cut grooves (as shown in Figure-2), etc. Presently, these applications are made through conventional machining which requires complex and expensive tooling, large cycle times for setting and machining finally resulting to an expensive process.

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Alternatively, these operations can be done through EDM/Wire EDM process.

In 1960's, EDM machines were Manual Ram EDMs that use DC spark generators with simple RC circuits and plunge the material in a single pass. As a result of this, the EDM process used to damage the surface of the components being machined. This damage was the outcome of the heat generated by the EDM process and consisted of recast layer, or white layer, or an annealed Heat Affect Zone (HAZ), which lay directly below the recast layer. The recast layer is made up of molten metal particles that have been re-deposited onto the surface of the work piece as referred in (Khan A. *et al*., 2006). Both the HAZ and recast layer could contain micro-cracks that causing stress failures of critical components. Since the present EDM process has limitations, it could not be used widely for machining complex profiles or hard materials, etc. in aircraft industry.

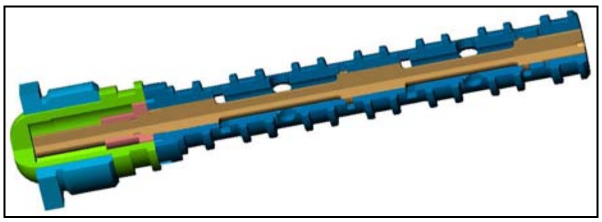

Figure-2. Actuator component having complex profile.

2.3. CFC composite parts

In present aircraft scenario, majority of skins and spars have been replaced with CFC composite parts with considerable reduction in part counts. The composite CFC parts are processed through manual Lay-ups/ Pre-Pregs and cured through autoclave process. With the existing manual process, the resin application is not uniform and the composite growth is not controlled, resulting to a thickness variation of even 14% on the contour non uniform and leading to interchangeability and repeatability issues. With this thickness variation on the contour of CFC parts, the assembly cycle time increases because of suit on assembly.

2.4. Sheet metal parts/ assemblies

As stated earlier that the aircraft is governed by aerodynamic contour, realization of the complex contour profile is a challenge. Some of the parts which are difficult to realize through machining is realized through sheet metal forming. Considering complexity of the contour and the sheet metal forming process, designers consider the split design philosophy (individually designed parts). This finally leads to increase in number of parts and tools as well as increased cost of manufacturing and time. Due to split, there will be more joints requiring more rivets and subsequently increase in weight. Presently, majority of complex shapes sheet metal parts are formed by using Rubber pad or drop hammer processes. These parts would be subjected to 100% inspection for wrinkles, thickness variation, crack detection, etc.

2.5. Longerons/spars machining

The recent trend in design of aircraft structures is to design and use large monolithic parts to reduce part counts thereby reducing setup time, cost and lead time in realizing the structure. Such large parts are designed with ribs to obtain high stiffness-to-weight ratio.

The structural components like spars, longerons, etc. are lengthy and having thin ribs (as shown in Figure-3). Since these components are highly stressed and at critical locations, these cannot be split into multiple parts with joints. Also these components demand the high precision quality with less distortion and good surface finish. These parts require relieve of the machining stresses as well as multiple settings to complete the machining.

A usual problem in the end milling of aluminium structures in conventional CNC is deflection of thin ribs under cutting pressure. The distortion will place a constraint on the achievable thickness of ribs at the desired surface quality.

Figure-3. Lengthy spar of typical aircraft.

2.6. System/ actuator components

System components like Manifold Blocks for Actuator require multiple operations like CNC Turning, CNC Milling, Drilling, Boring, Grinding, etc., with multiple work-piece settings on multiple machines. Since these components (as shown in Figure-4) are part of actuator assembly, it demands high precise quality

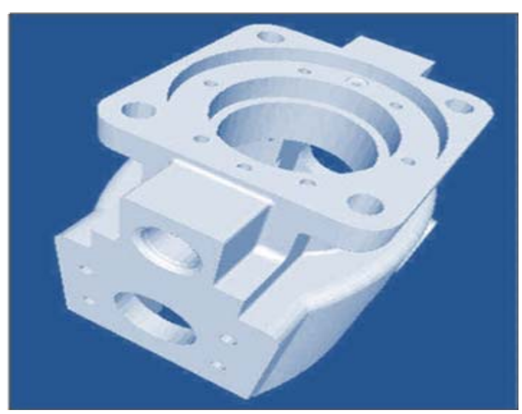

Figure-4. System manifold having multiple operations.

As these components require multiple settings within a machine as well as on multiple machines, the achieving of accuracies is a challenge.

3. PRESENT ASSEMBLY TECHNIQUES

In conventional aircraft manufacturing, hard toolings are used. The present assembly jigs/tooling are product specific and any change in design needs fresh tooling as shown in Figure-6. This leads to long lead time, expensive and also large inventory. In addition to that, these tools need regular maintenance and calibration. Aircraft assembly tooling is employed for holding the parts in space during assembly. Tooling is divided into two different principal groups; fixtures and jigs. Fixtures position and hold parts during assembly, whereas jigs not only position and hold parts during assembly, but are also used to guide cutting tools. As aircraft parts have been attached to the fixture clamps, the assembly process is engaged. The assembly process is basically carried out by drilling holes followed by fastening through rivets. The typical aircraft assembly process can be structured majorly to drilling, riveting, fastening, shimming and sealing.

3.1. Drilling

In most traditional industries, precision holes can be successfully drilled with a drill press. However, since a significant number of aircraft structures are too large, complex and irregularly shaped, portable precision drill motors are brought to aircraft and used for drilling holes.

3.2. Sealant application

Some sections of the aircraft, such as the wings, fuel tank regions, etc., must be sealed. Other sections, such as cockpit must be air-tight. In some cases, sealant must be located between parts in the stack to avoid rubbing against each other. Sealant is either a liquid based resin, or something that can be taped on the parts. Sealant sticking to the drill, or hampering the chips from evacuation from the hole, are some of the typical issues. So applying sealant is a challenge with present process.

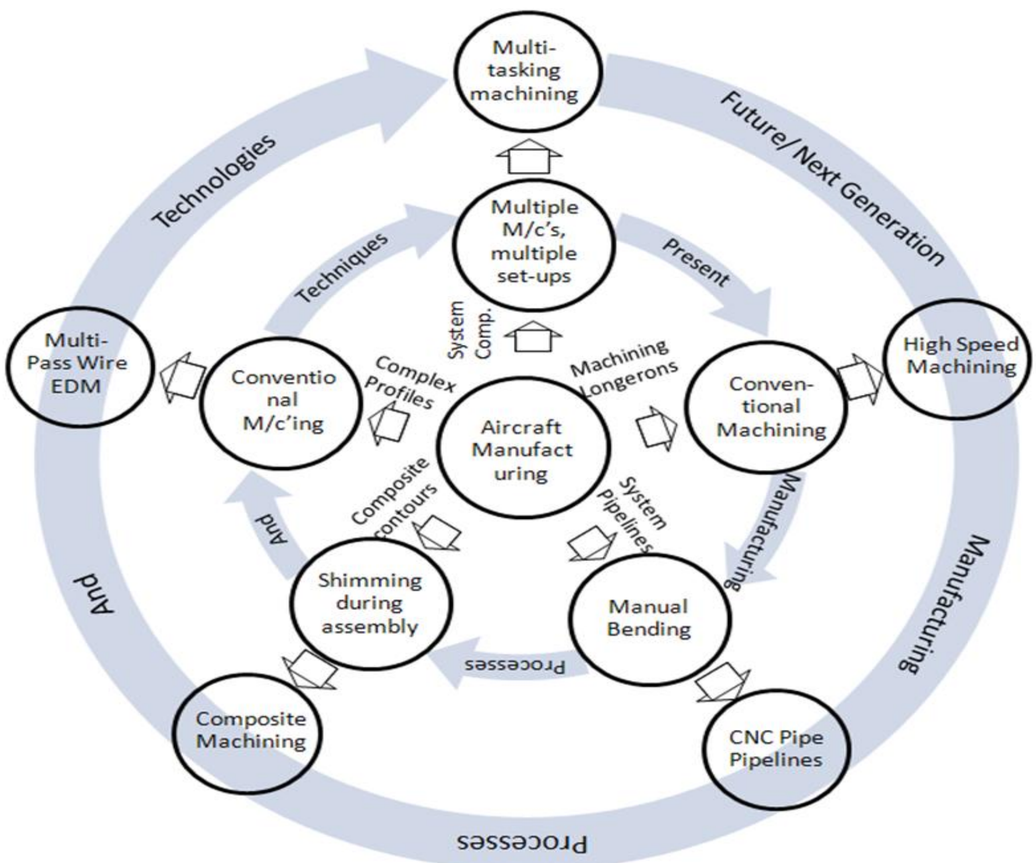

Fig.5: Present and Next Generation Aircraft Manufacturing Processes

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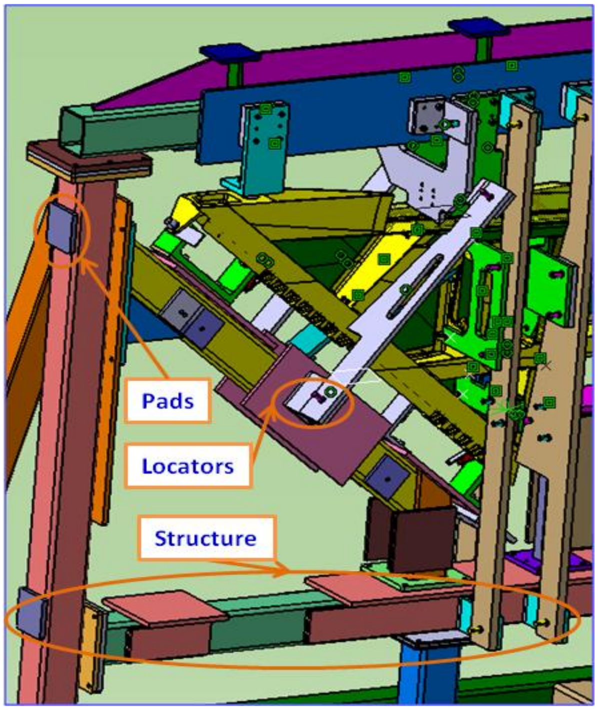

Figure-6. Typical product specific jig for aircraft.

3.3. Fastening

Fastening is the last step in the assembly process before removing the finished product from the fixture. Fasteners used are rivets, screws or bolts. The most commonly used fastener is the solid rivet that is either hammered or squeezed into place. The aircraft assembly process requires rivets at various stages of assembly.

The cost for the assembly of an aircraft consumes upto 40% of the total airframe manufacturing cost (Bullen, 1997). The manufacturing process of typical combat aircraft Wings requires drilling of over 10000 holes. The majority of these holes, approximately 80% of the total, were drilled manually. The manual drilling is accomplished by highly skilled and trained operators using expensive tools and equipment in order to retain the necessarily high levels of quality. So carrying all these assembly operations manually and with present philosophy is a challenge.

4. NEED FOR ADVANCED MANUFACTURING TECHNOLOGIES

Advanced Manufacturing technologies like CNC pipe bending for aircraft system for repeatability, multi-pass Wire-EDM for cut-out brackets and actuator components to realize complex shapes with reduced cycle time, Composite CNC machining for CFC panels to achieve uniform thickness, Multi-tasking machines for integrated machining of aircraft system parts, High speed machining of lengthy spars to avoid warpage, etc., need to be adopted both for prototype development as well as series production as briefed in Figure-5.

5. OVERVIEW ON VARIOUS ADVANCED MANUFACTURING PROCESSES

5.1. CNC pipe bending for system pipelines

Pipe Bending as a process starts with loading a pipe into a pipe bender and clamping it into place between two dies, the clamping block and the forming die. The pipe is also loosely held by two other dies: the wiper die and pressure die.

Evolution of DMU technologies through CAD packages enable to validate the design in digital mode. In aircraft industry, the routings of system pipelines are finalized in DMU keeping requirements such as pipelines spacing, standardization of bend radii etc. The data required for CNC pipe bending are generated using CAD/ DMU.

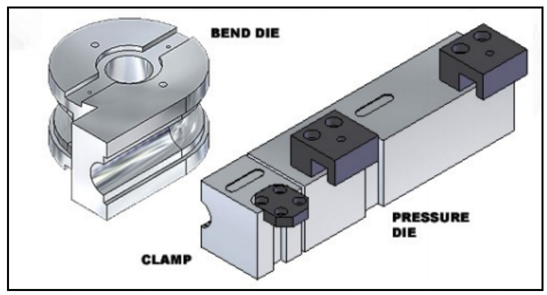

Figure-7. Typical tooling for CNC pipe bending.

The process of tube bending involves using mechanical force to push stock material pipe against the die, forcing the pipe to conform to the shape of the die. Generally, the stock pipe is held firmly in place and the end is rotated and rolled around the die and in certain pipe bending processing, a mandrel is placed inside the pipe to prevent from collapsing. Much of the tooling is made of hardened steel to maintain the better tools life as shown in Figure-7.

The usage of CNC pipe bending process over conventional manual bending results in

a. Better accuracy and repeatability
b. Complex bend radii and angles
c. High degree of control
d. Flexible and quick change-over
e. Less human intervention/ low skill set

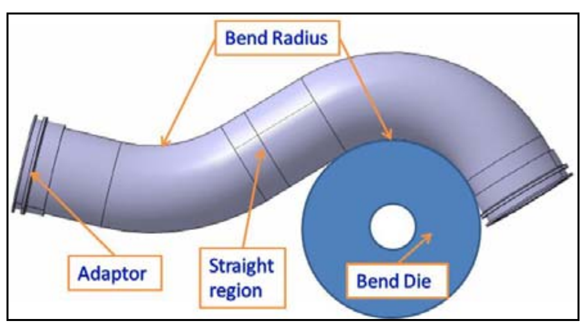

Figure-8. Pipeline Assembly simulated for CNC pipe bending.

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The CNC pipe bending process results in avoids welding of seams, improves the quality at bend kink location and better control on geometrical and dimensional accuracies. By eliminating the connection parts, potential danger zones in the pipeline system are reduced/ eliminated. This results in a longer service life of the pipeline assembly as shown in Figure-8.

5.2. Multi-pass wire EDM process for complex actuator components

Next generation Wire EDM machines are designed with advanced circuits to filter noise, control of spark generation, monitoring of spark gaps and automatic adjustment to the burn conditions. This gives a stable more predictable process. In addition, improvements to wire, graphite, and dielectric oils eliminate recast, HAZ and fatigue/ micro-cracking. These improvements bring the process back to aircraft industry especially for complex profile cutting, long aspect ratio drilling, etc.

5.3. CFC composite parts machining

The demand for carbon fiber-reinforced composite has grown considerably in recent years especially for aircraft industries. Fiber-reinforced plastic has high specific strength, high stiffness or modulus, and good dimensional stability. This combination of properties is unusual and not easily obtained in alloys. FRP composites are usually fabricated by moulding. However, certain machining procedures, such as milling and drilling are needed to obtain close fits and tolerances, as well as to achieve near-net shapes in classical production processes. Machining of CFC panels provides better control on the thickness and sizes, avoiding the solid shimming further improving the aircraft build.

5.4. Hydroforming process for sheet metal parts

Hydroforming is a specialized type of die forming that uses a high pressure hydraulic fluid to press room temperature working material into a die. It is a cost-effective way of shaping ductile metals like Aluminium, stainless steel, etc., into light weight structural stiff parts. Generally hydroforming is classified into sheet hydroforming and tube hydroforming processes. Sheet hydroforming uses one die and a sheet of metal; the blank sheet is driven into the die by high pressure water on one side of the sheet forming the desired shape (as shown in Figure-9. Tube hydroforming is a expansion of metal tubes into a shape using two die halves, which contain the raw tube. Hydroforming replaces the older process of stamping two part halves and welding them together. It allows complex shapes with concavities to be formed, which would be difficult or impossible with standard forming processes.

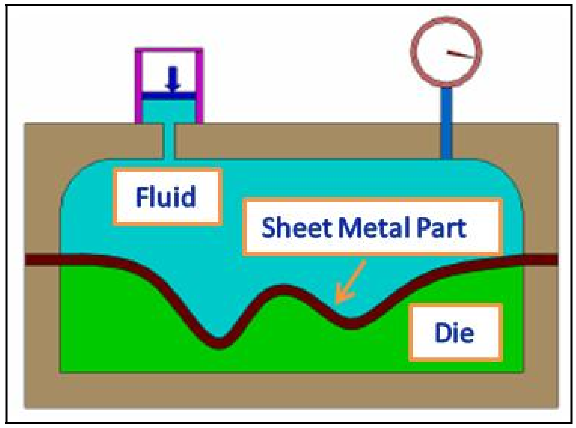

Figure-9. Typical hydroforming process.

Hydroforming is capable of producing parts with stringent tolerance requirements where a common tolerance for sheet metal parts is within 0.76mm. It also allows for a smoother finish as draw marks produced by the traditional method of pressing a male and female die together are eliminated.

5.5. High speed machining for longerons

High speed machining is very much suited for thin wall machining. High speed machining not only increases metal removal rates but also results in improved surface finish, burr-free edges, dimensional accuracy and a virtually stress-free component after machining as well as reduced warpage.

The aircraft structural components are usually machined from billets and machining involves removal of considerable amount of material. High spindle speed, feed with low depth of cut ensures high material removal rate, better heat dissipation because of faster chip removal, less deflection of thin walls due to reduced cutting force, reduced warpage and reduced machining time with better finished parts.

5.6. Multi-tasking machining for system components

Multi-tasking machine tools have been developed to have both functions of turning (the same as turning centers) and machining (the same as 5axis simultaneously controlled machining centers which perform milling, end milling, boring, tapping, etc.). Machining processes requiring multiple turning centers and/or machining centers can be integrated and run on a single multi-tasking machine(as shown in Figure-10).

Multi-tasking machines also known as 'combi-machines' enables to integrate different family of operations viz. turning, milling, grinding, inspection in a single set-up without manual intervention. There are many advantages to multitasking, the biggest of which is the improvement in process and cycle time to produce a complete part.

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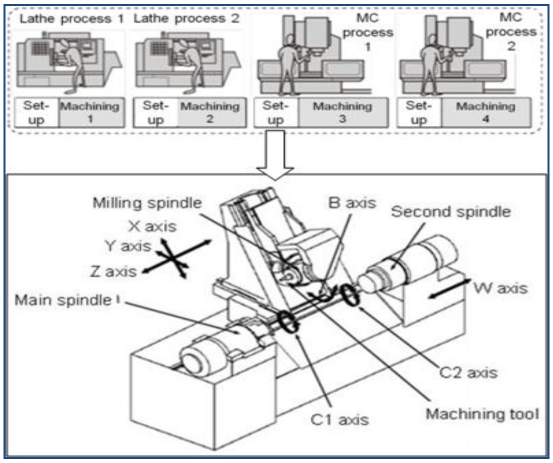

Figure-10. Multiple machines leading to multi-tasking machine.

6. NEXT GENERATION ASSEMBLY TECHNIQUES

The various assembly techniques like modular assembly, jig-less assembly, automation viz. Robotic arm for drilling, riveting, painting; inspection ensures repeatability and improved quality during prototype development as well as series production.

6.1. Modular assembly

The most common tooling technology for aircraft assembly used today is conventional tooling consisting of steel beams that are welded together. These tooling are tailored for a specific tooling operation. Since conventional tooling is designed to a specific application, each assembly has its own dedicated tooling and is product specific tooling. In addition, when building a complex product like an aircraft, the final design is forced by changes that immediately affect the tooling design. This necessitates modifying the tooling/ locating holes or shimmed pick-ups to new locations. Hence it is recommended to opt for Modular tooling.

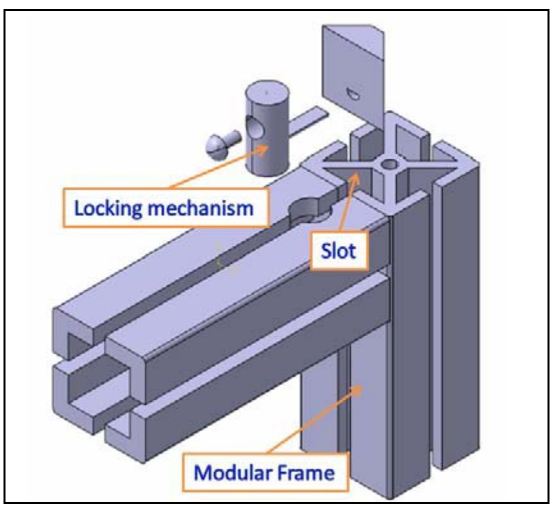

Figure-11. Typical frame designed for modularity.

Modular tooling is a tooling solution that is built for a dedicated purpose as well, but the surrounding system, and distance supports are designed from a toolbox of modular components. The framework of modular tooling is screwed together. This is possible by using the slots shown in Figure-11. Modular Tooling helps in reducing the cycle time of assembly enhancing the production rate. Modular tooling also helps to design jigs/ fixtures which will meet a group of components.

6.2. Jig-less assembly

Jig-less assembly is aimed at reducing or eliminating the need for product specific jigs during assembly by developing new assembly concepts, models, tools and procedures.

In the new concept of jig-less aircraft assembly, the end locators are replaced by transferring the holes directly on to the part. These holes are made by high precision machines. In this approach, all the parts will have atleast two holes so that the part can be assembled with the adjacent part. These holes are termed as 'key holes'. In this method, the tooling elements (end locators) are eliminated and only the jig is used as the main assembly structure (as shown in Figure-12). This approach reduces the tool manufacturing time, reduces the product dependent fixture and also increases the accuracy of the assembled product. This approach results in reduction in number of tools and joints (rivets) and subsequently weight also.

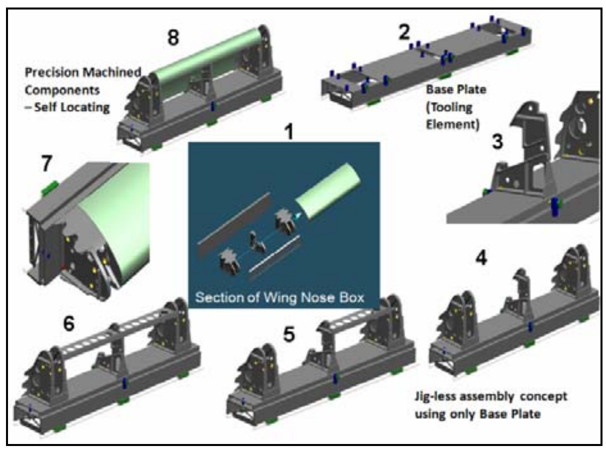

Figure-12. Aircraft sub-assembly with Jig-less philosophy.

6.3. Assembly automation

6.3.1. Robots in integrated drilling and riveting

Each sub assembly in the aircraft has its own jig, which is designed to be suitable only to assemble that particular structure. When there is change in the structure, the jig requires major modification or it becomes un-use and discarded. These jigs are expensive and take long lead time to build. High temperature variations require tool calibration. Any tooling realignment is time-consuming, and can often be achieved by the fettling and shimming.

A fuselage/wing assembly needs thousands of holes drilled and drilling them manually is time consuming and error prone. Manual drilling requires multiple steps, such as drilling a pilot hole, drill to the final diameter, then reaming it while robotic drilling can be accomplished in a single setup. Robots drill the hole to its full diameter and depth, including the countersink, in a single pass.

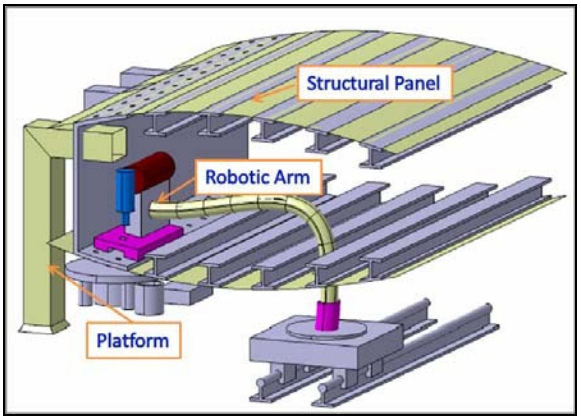

Figure-13. Robotic arm for automation drilling.

The role of automation in the manufacture of aircraft is important although not as pervasive as in the automotive industry. Robot's ability to repeatedly position very large aircraft components with a high degree of precision ensures that flexible automation has potential growth in aircraft industry (as shown in Figure-13).

6.3.2. Robots in painting

Using robots to paint airframes remove people from the hazardous environments associated with painting and ensures uniform thickness of paint coating, reduced cycle time. When done manually, extensive scaffolding that must be put into place before the painting begins.

Automation provides improved environmental conditions for employees working in the assembly of aircraft and other large complex structures. Automation with Robotic arm accommodates flexibility in the design changes through offline robotic programming/ track mode and reduces the human errors and significantly improves the lead time.

7. CONCLUSIONS

This paper highlighted existing aircraft manufacturing and assembly operations and the challenges involved in achieving the aircraft build quality and cycle time. The need for going to advanced manufacturing technologies has also been explained. Certain manufacturing/ assembly processes viz., CNC pipe bending, Multi-pass Wire-EDM process, CFC Composite machining, High Speed Machining, Multi-tasking Machining, Modular assembly, Jig-less assembly, robots in assembly have been highlighted touching upon the benefits which could be derived.

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