2004-01-2832

Determinate Assembly of Tooling Allows Concurrent Design of Airbus Wings and Major Assembly Fixtures

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ABSTRACT

Most new aircraft programs encounter the challenge of balancing the time required for design optimization with product delivery constraints. The high cost and long lead times of traditional tooling makes it difficult for aircraft manufactures to efficiently meet ever-changing market demands. The large size, low relative stiffness and high positional tolerances required for aircraft components drive the requirement for rigid fixed tooling to maintain the precision part relationships over time. Use of today's advance 3-Dimensional CAD systems coupled with the high accuracy of CNC machines enables the success of the determinate assembly approach for aircraft tooling. This approach provides the aircraft manufacturer significant lead-time reductions while at the same time it supports enhanced system flexibility. Determinate assembly for aircraft tooling has proven to be highly successful for tooling manufacture on large-scale system such as the A380 and A340-600 wing assembly projects.

INTRODUCTION

The Airbus A380 is the largest commercial aircraft to enter production. The size of this new aircraft required Airbus to develop new facilities and new methods to manufacture and assemble its components. AirbusUK is responsible for the design and manufacture of the A380 wings. A new factory was constructed in Broughton, Wales, for the purpose of assembling and equipping the A380 wings. This new factory and the wings, which leave it, are a shining example of the confluence of cutting-edge aerospace design and state-of-the-art manufacturing technology (Figure 1).

Most new aircraft programs encounter the challenge of balancing the time required for design optimization with product delivery constraints. This issue is further exacerbated by today's demands for shorter and shorter product lead times. Historically, tooling is used to set precision relationships required on large aircraft assemblies such as wings. Typically, in order to maintain the high positional tolerances, detail locators are manually set using precision metrology equipment. As a result, tooling requirements have created large hurdles to lead time reduction and product flexibility.

Figure 1: Airbus UK A380 Factory in Broughton, N.Wales, UK

The large size, low relative stiffness and high positional tolerances required for aircraft components drive the requirement for tooling to maintain the precision part relationships over time. The use of "Determinate Assembly" for the tooling itself can provide the desired flexibility and lead time reduction. Use of today's advanced 3-Dimensional CAD systems coupled with the high accuracy of CNC machines enables the success of the determinate assembly approach for aircraft tooling. The A380 and A340-600 wing panel systems provide illustrations of how this method supports concurrent aircraft and tooling design. This presented approach provides the aircraft manufacturer significant lead-time reductions while at the same time it results in enhanced system flexibility.

DRIVERS FOR USE OF DETERMINATE ASSEMBLY

The world of aerospace manufacturing is becoming more and more aggressive every day. Customers want aircraft, which are more efficient and carry more load than ever before. They expect these aircraft to be right around the corner, not ten years in the making. In order to meet these high standards, aircraft designers have turned to new tools and methods, which allow them to quickly evaluate their designs and readily communicate part geometry to manufacturers. The advent of computational tools such as Finite Element Analysis (FEA) and Intelligent Computer Aided Design (ICAD) has accelerated the pace of design optimization and allows refinement of component designs to a level, which was unheard of until recently. (3)

In order to sell aircraft in today's market, new aircraft programs must hit the ground running. Production ramp up rates must meet new more aggressive targets to satisfy market demands. Typically, precision tooling and assembly equipment are used to set the relationships between and fasten or bond together the myriad of parts, which make up the aircraft frame. In order to enable production rates to rise, it is necessary for the assembly equipment to be ready for production as soon as the aircraft components are ready for assembly. However, major assembly tools are typically larger than the aircraft parts themselves. Since the tooling design is dependent upon the design of the aircraft, tooling manufacture and configuration typically presents a rate-limiting step in new aircraft implementation cycles. Further, as the aircraft designs evolve and variants are introduced, we again find the required tooling modifications on the critical path to delivery. The increasing demand for lead-time reduction requires a new approach to tooling design and implementation.

TECHNICAL BACKGROUND OF DETERMINATE ASSEMBLY

To attack this problem, many companies have been evaluating the use of "Determinate Assembly." Determinate Assembly is a term used to describe the practice of designing parts, which fit together at a pre-defined interface, and do not require setting gauges or other complex measurements and adjustments. It is part of the more general practice of "Design for Manufacture and Assembly" (DFMA). The potential benefit of determinate assembly is a reduction in tooling, which thereby reduces both cost and lead-time. Conceptually, the component parts are manufactured to a high degree of accuracy, which allow the parts to "snap together" and still maintain their required positional tolerance. Much has been written about the promise of determinate assembly and similar practices (4,5). However, the benefits have yet to be realized on a large scale for production parts such as wings due to the part size and flexibility, thermal issues and the high positional tolerances required. Therefore, assembly fixtures are typically still required. Determinant assembly has however proven itself in the manufacturing processes by greatly simplifying tooling design and manufacture.

An initial implementation of determinate assembly in tooling arena came on the A340-600 panel-build cell. This assembly cell is used to locate and fasten aluminum stringers to machined aluminum skin panels (2). These are very large assemblies on the order of a few meter high and over thirty meters long. The original fixtures used to locate the stringers and wing skins followed a conventional design. Individual details for stringer locations were designed and field set using laser trackers. Over two thousand individual points had to be aligned in the field. This was a difficult, labor intensive and time-consuming process.

Subsequent to the initial production implementation of the A340-600 system, the panel-build fixtures had to support a unique test wing configuration. In order to accommodate this test part, the fixtures had to be altered and the process had to be integrated into an already tight build program. The solution therefore demanded that the alterations resulted in minimal downtime for the one time change and restoration to the original build configuration. To address this requirement, the concept of a "pegboard" formboard was developed. Formboards are used to mount the stringer location indexes. With this approach, high accuracy holes were machined into the formboard. Precision locating dowels were pressed into these holes. This resulted in a series of "pegs" with high positional tolerances. Stringer nests were then manufactured again to a very high tolerance. These nests however were relatively small and can be reliably machined on readily available commodity CNC machines. The stringer nests are then located onto the formboard pegs though precision bushings. The total tolerance stack-up between the sets of parts is less than the required aircraft build tolerance.

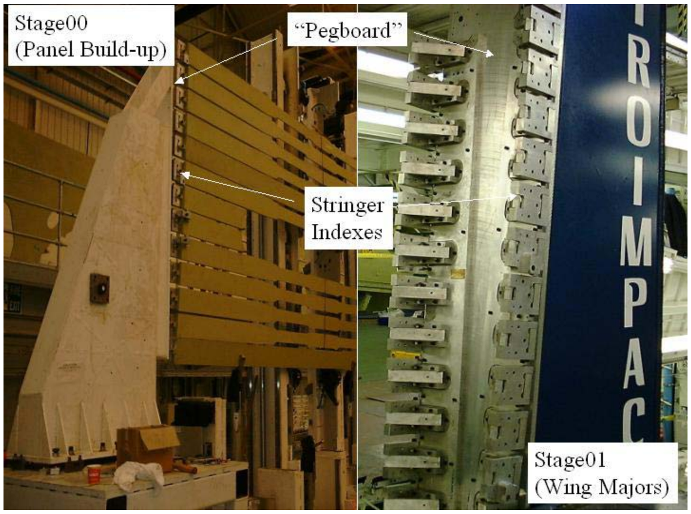

Figure 2:Determinate Assembly on A340-600 test-panel tooling modifications

In the field, only the formboard must be located as opposed to the up to twenty individual details per board. This saves significant field time. Further, the peg locations can be determined early on in the aircraft design process, since the final precision stringer locations are set by the stringer nest. (See Figure 2) This allows the majority of the tooling to be designed and manufactured very early in the wing design program.

CONCURRENT BUILD ON A380

The A380 signifies a step change in aircraft size. This wholly new aircraft presented the designers with significant challenges to design a wing, which can handle the required loads and maintain optimal aerodynamic efficiency. As with all new programs, while the aircraft design had many hurdles to overcome, it was imperative that the program milestones be maintained. In order to meet these requirements, a fundamentally new approach to the assembly tooling was required. The tool design and manufacture needed to progress completely in parallel with the aircraft design. The experience of determinate assembly on the A340-600 static-wing test panels provided the foundation for the implementation of this new process.

By using the determinant assembly concept, thousands of stringer index points could be incorporated into a couple hundred formboards with "pegs" (locating pins). (See Figure 3) All of the structure, which supported and roughly located these formboards could be designed, built, and installed ahead of the final aircraft-component design release. The formboards themselves could be manufactured from very preliminary aircraft data. Once the aircraft-component data was final-released, only the individual groups of indexes ("index plates") had to be manufactured. These were then essentially dropped into place on the formboard pegs.

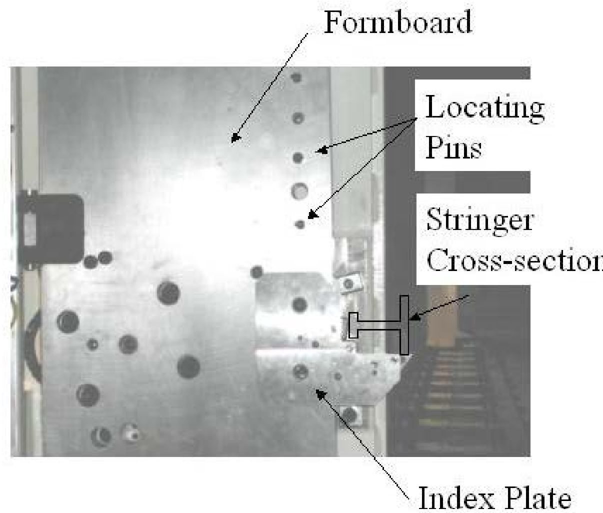

Figure 3: Prototype A380 pegboard ("formboard") and one index-plate

While the approach seemed sound, it was by no means an easy solution. The geometry of the aircraft components and their location indexes restricted the amount of flexibility, which could be incorporated with this approach. The sheer size of the A380 panels and the large number of index points meant that any systemic problem with the method carried large risk. Design envelopes and change criteria had to be rigorously negotiated between tooling and aircraft designers. While not overly restricting aircraft component design, tooling requirements were embedded into the aircraft design system (see Figure 4).

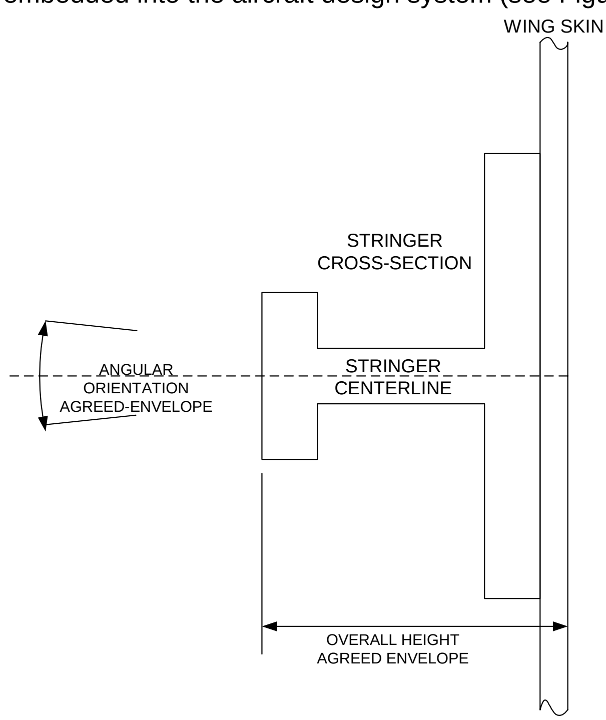

Figure 4: Typical envelopes of allowable stringer cross-section changes, agreed between design and tooling

This allowed the AirbusUK designers the freedom of making changes within predetermined envelopes without worrying about tooling impact. It allowed the tooling engineers to progress the design and build of nearly all the tooling components, minus the specific indexing components (e.g. index plates) at the onset of the program. For this approach to be successful, it required close communication between the aircraft and tooling engineers. By agreeing on boundaries, which were respected by both sides, each could achieve their goals and meet the aggressive production program.

In the wing majors fixture, the use of determinate assembly methods allowed the manufacture and installation of all the major index assembly features significantly ahead of the release of the final wing data. The final data was released approximately one month before first wing load. Index features used to set hinge line geometry were designed and installed using final "index flags". The flags were located on the previously installed structure using the determinate assembly features. The optimization of the DA features allowed for a fully integrated concurrent program, reducing the timeline required from engineering concept to release for manufacture. The use of the determinate methods for tooling allows for the quick reconfiguration of the fixture for future A380 aircraft models. The index flags can be replaced for future variant configurations by simply removing the "index flag" and installing the new "index flag". The "index flag" is simply "pinned" into the support post and released for production.

Figure 5: Initial installation of A380 panel-build posts & formboards on-site at Broughton, N. Wales

The approach proved extremely successful. Using the 3-D CAD part definitions and the developed tooling definitions, tooling engineers were able to quickly translate the part geometry into indexes, which were final machined to exacting tolerances. Just six weeks after the final design release, the first assembly jigs were fully validated and parts were loaded. Every aircraft component was exactly in the right place. (See Figure 6.) The approach was used throughout the wing assembly system for panel-build and wing majors tooling systems. The elimination of the requirement to field set thousand of index points removed significant time and expense from the A380 wing panel tooling program. Further, this approach provided the aircraft designers with the flexibility to make modifications to the stringer and hinge line geometries very late in the program without driving the critical path to the right.

Figure 6: Completed A380 panel-build fixture with stringers partially loaded

CONCURRENT BUILD ON A340-600 HIGH GROSS WEIGHT

The success of the A380 program has now been extended to other programs. The approach is currently being adapted to an existing program to address changes, which result from the introduction of a variant aircraft. Airbus has recently introduced a new High Gross Weight version of the A340-600. Small changes to the wing structure would under normal conditions require significant tooling changes or even the procurement of all new tooling. For in-jig assembly systems such as the LVER process (1), it could eliminate the ability to use the system for the continued manufacture of both variants. To minimize cost and maximize the usage of existing assembly equipment, it was decided to adapt the existing tooling system to the determinate assembly process. This approach permits the manufacture of the two different variants in the same system with only minor tooling changes.

To implement this system, the existing formboards are replaced with the pegboard style formboards. Two sets of stringer indexes adapted to these boards are manufactured for the variant types. To reconfigure from one variant to the next, only the index plates must be changed. This can be accomplished in less than one shift and does not require time-consuming and expensive metrology equipment. Plate clamps are swung out of position; the stringer index is removed from its locating dowels and replaced with the variant's index plate. Color codes are used to assist the operators with index type. This provides significant enhancements to tooling flexibility and cycle time reduction.

CONCLUSION

Determinate assembly for aircraft tooling has been proven for tooling manufacture on both A380 and A340-

600 wing assembly projects. The dramatic improvement in 3-dimensional CAD modeling capabilities coupled with significant accuracy enhancements of commodity style CNC machines has brought the concept of determinant assembly into reality. The "pegboard" formboard concept has clearly demonstrated the gains, which can be achieved with this approach. In the future, this process will be extended to other components and areas of aircraft manufacture. The process provides aircraft designers with more time to optimize their designs and still maintain the aggressive new delivery standards. The benefits in reduced lead-times, product flexibility and reduced tooling costs are dramatic.

ACKNOWLEDGMENTS

The authors wish to thank the many members of both the A380 and A340-600-HGW component and tooling design and manufacturing teams both at Airbus UK, Ltd. and at Electroimpact, Inc. Their combined efforts to communicate, solve problems, and implement those solutions have helped make these new aircraft programs a reality.

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