

Implementing Determinate Assembly for the Leading Edge Sub-Assembly of Aircraft Wing Manufacture

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ABSTRACT

The replacement for the current single-aisle aircraft will need to be manufactured at a rate significantly higher than that of current production. One way that production rate can be increased is by reducing the processing time for assembly operations. This paper presents research that was applied to the build philosophy of the leading edge of a laminar flow European wing demonstrator. The paper describes the implementation of determinate assembly for the rib to bracket assembly interface.

By optimising the diametric and the positional tolerances of the holes on the two bracket types and ribs, determinate assembly was successfully implemented. The bracket to rib interface is now secured with no tooling or post processes other than inserting and tightening the fastener. This will reduce the tooling costs and eliminates the need for local drilling, de-burring and re-assembly of the bracket to rib interface, reducing the cycle time of the operation.

Ultimately, self-indexing components mean that there is more flexibility as to what point in production the bracket can be attached to the rib. This allows for a reduction in cycle time and cost, whilst increasing production flexibility. This research has improved the design for wing manufacture capability of the company.

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INTRODUCTION

In order to meet the forecasted demand increase for single-aisle aircraft, wings are to be manufactured at a rate significantly higher than that of current production [1]. Current production is operating at full capacity and will not meet the future demand. The focus of this paper is the implementation of determinate assembly for the attachment of high-lift device brackets to their corresponding ribs. The findings of this work have been applied to the laminar flow European wing demonstrator currently under construction.

To aid the increased production rates for the next generation of aircraft wings, the assembly time needs to be reduced whilst achieving the cost and performance targets. The increased production rate required for this next generation aircraft has seen a specific target of a 50% reduction in lead-time for assembly tooling set-up [2]. One way to reduce assembly tooling set-up times is to eliminate it. Traditionally aircraft are not made with design for manufacture (DFM) techniques. The primary objective for an aircraft designer has been weight reduction for performance improvement.

Current aircraft assembly requires the drilling of holes at the point of assembly. Both components arrive at the assembly location without holes. The components are orientated and constrained in the correct position relative to each other and the holes drilled through both parts at the same time. The components are then separated; cleaned and de-burred. This method requires a large amount of costly tooling hardware and is inefficient as the components are effectively assembled twice. The development of an entirely new 'high volume' aircraft presents an opportunity to integrate new DFM technologies into the design of the wing at an early stage. The focus of this paper is the implementation of determinate assembly for the attachment of the high-lift device brackets to the ribs.

Determinate assembly involves assembling parts without the use of tooling [3]. It makes use of features on the components to locate and orientate parts for one-way assembly [4]. Determinate assembly allows parts to self-index using the hole

patterns, rather than with the use of tooling. This has the potential to reduce or eliminate the tooling for the rib to bracket assembly process.

This paper is concerned with the assembly of two different high-lift device brackets to their corresponding ribs. The components identified for determinate assembly have been split in to two cases. Case one is fastening the Standard Bracket to Ribs A1, A2, A3 and A4. Case two is fastening the Custom Bracket to Ribs B1, B2, B3 and B4. Case one ribs all have the same hole pattern; four holes of equal size. The standard bracket also has four holes of equal size. The case one rib hole pattern and custom bracket can be seen in [Appendix A](#). Case two ribs have a pattern of six holes of three different sizes. The custom bracket also has 6 holes of three different sizes. The case two rib hole and custom bracket can be seen in [Appendix A](#).

Paper Outline

This paper will first outline determinate assembly and discuss its benefits. It will then outline how a mathematical model was developed and then used to create a software tool to facilitate the calculation of the required tolerances for determinate assembly. The findings of the study will be outlined along with the recommendations from this study; further work and conclusions will follow.

DETERMINE ASSEMBLY OVERVIEW

The current method of assembly see the two components assembled are aligned and constrained using the tooling; the components are then drilled while clamped together using a jig to ensure the drilling process is being carried out in the correct place. [Figure 1](#) outlines the result of the current practice for attaching aerospace components. Although this ensures the holes in the two components are aligned, there is a substantial cost associated with the tooling [5]. An example of which is if the design of a component is changed during production, the tooling will be scrapped, redesigned and replaced incurring a substantial cost and increased lead time.

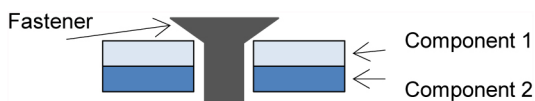


Figure 1. Traditional Assembly Hole Schematic

Determinate assembly proposes the allocation of tighter positional tolerances to component holes during their manufacture [6]. If this is done then the components will be 'self-indexed' against each other rather than relying on conventional tooling [7]. This will ensure that they will be able to be assembled with the appropriate fastener when they are interfaced on the assembly line. [Figure 2](#) shows the outcome of the holes of determinate assembly. The translation is due to the positional tolerance on the holes. The positional tolerances need to be tight enough so that even at worst case the resultant hole is large enough for the required fastener.

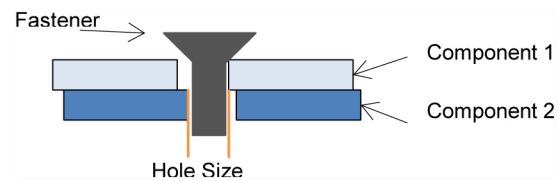


Figure 2. Determinate Assembly Hole Schematic

The literature shows that there is a direct link with the tightness of a specified tolerance and the cost of manufacturing; the cost of manufacture increases significantly as the tolerances become tighter on a component [8][9]. The Natural Laminar Flow (NLF) wing design aims to reduce the running costs for the airlines. However, due to the tighter than normal tolerances, the wing manufacturing costs may increase. This has the potential of increasing the purchase price of the next generation aircraft; this will reduce or even eliminate the cost benefit of the reduced drag aircraft for the customer and will impact the saleability of the aircraft.

For this work it means that it is not acceptable practice to make the tolerances on the components as tight as the manufacturing processes will allow in order to facilitate determinate assembly. The output of this work is to calculate to what extent the tolerances can be relaxed, whilst still enabling the implementation of determinate assembly to reduce manufacturing and inspection costs [10].

Determinate assembly offers many advantages over traditional techniques. The first and perhaps the most important benefit, in the short term, is the benefit of reducing the costs of production. Determinate assembly has been proven to reduce the costs associated with production through the reduction in initial tooling costs [6] and elimination of tooling maintenance costs [4][6][11]. The parts are lined up manually using key features, such as drilled holes [3][6][12], the fastener is then inserted and tightened, no tooling and no elaborate work holding devices are required.

The literature reports a reduction in lead time for the assembly of components [12] there is no downtime associated with the recalibration of tooling or repairs due to tool wear and operational damage [5][12]. Studies have shown that quality of components is improved as there is a high degree of accuracy in the component manufacture [6]. There is no tolerance stack due to the elimination of tooling traditionally used to index the components [5]; this means there is less re-working or product scrapping during assembly increasing assembly efficiency [12]. Additionally as there is no assembly fixtures the component tolerance is not used up by it.

Determinate Assembly use in Aerospace

This section will outline some of the current uses of determinate assembly. Boeing were able to use determinate assembly for the 777 seat tracks attachment to the floor beams [7]. Boeing report that the new determinate assembly floor panel facility was 75% smaller than the previous facility.

reducing infrastructure overheads. Determinate assembly also facilitated considerable savings on reworking caused by misaligned tooling. Employee satisfaction was increased by eliminating the poor ergonomic working positions and heavy tooling [11].

Boeing 737 stowage bins were assembled using jigs, determinate assembly allowed the company to save money on creating tooling jigs for each stowage bin [7]. Each bin had holes pre-drilled which indexed with the holes in the bulkhead. No drilling was required at the point of assembly. The use of determinate assembly for the Boeing 747 major fuselage eliminated the need for reworking. This enabled Boeing to reduce assembly lead time and increase quality whilst simultaneously reducing cost through the elimination of assembly tooling [5].

METHODOLOGY

Prior to this study the proposed positional and the geometric tolerances on the rib and the two bracket hole patterns did not permit the use of determinate assembly.

In order to provide a reliable and repeatable method of determining the hole diametric and positional tolerances, the decision was made to develop a software tool. It will allow future projects and application areas to define the tolerances required to implement determinate assembly quickly and accurately without having to develop additional mathematical models. The software tool is an Excel spreadsheet.

The software tool requires the user to input the lower limit of the hole size and the known positional tolerance. The tool provides an output value, the size of the resultant hole. The user interface of the tool instructs the user what values to input where and how to interpret the output. There are notes in the software the tool; these can be seen in [appendix B](#).

The variables in the determinate assembly analysis were numerical values for different tolerance measurements, both the positional tolerance and the geometric tolerance of the holes. Defining the relevant data ensured the Excel tool was simple to use and effective in gap prediction. Mathematical analysis provided the background for the tool. The tolerances on the components were then calculated using the software tool to demonstrate its effectiveness and to complete the first objective to implement determinate assembly.

The following components were selected for determinate assembly consideration and split in to two cases ([Appendix A](#)).

• Case 1

Fastening ribs A1, A2, A3 and A4 to the standard bracket.

• Case 2

Fastening ribs B1, B2, B3 and B4 to the custom bracket.

Modelling the Problem

This problem is modelled as shown in [Figure 3](#) in a simple schematic. It shows two parts each with two holes. Each part has the same nominal distance between the holes with the same positional and diametric tolerance. The red circles represent the holes in part A; the blue circles represent the holes in part B. The two components are drilled in separate locations prior to assembly and considered for assembly together by passing fasteners through the holes.

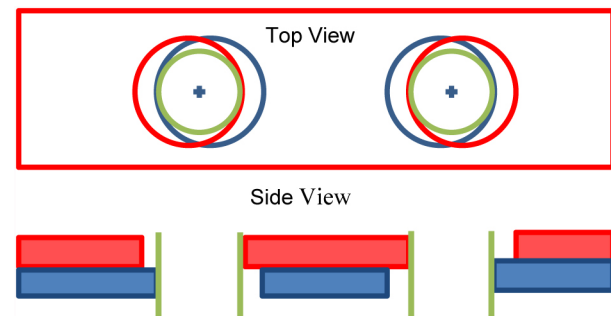


Figure 3. Schematic of assembly interface

The worst case for component assembly is when the following is true:

1. The holes in part A are drilled as narrow as the positional tolerance allows.
2. The holes in part B are drilled as wide as the positional tolerance allows.
3. The holes are drilled as small as the geometric tolerance allows.

The worst case creates the smallest resultant hole in which to put a fastener. If the resultant hole is smaller than the maximum value of the specified bolt diameter, determinate assembly will not work. Conversely if the maximum specified bolt diameter is smaller than the resulting hole then determinate assembly will work. The fastener sizes were defined previously for structural integrity of the wing and so were unmodifiable. The findings of this study have been independently approved by the design team to ensure that the implementation of determinate assembly does not compromise the structural integrity of the wing.

Mathematical Model

The following subsection will outline the mathematical model used to formulate the software tool. [Figure 4](#) below was taken from the initial drawings of a study that was to look into determinate assembly applications.