

Aircraft Wing Build Philosophy Change through System Pre-Equipping of Major Components

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ABSTRACT

In the civil aircraft industry there is a continuous drive to increase the aircraft production rate, particularly for single aisle aircraft where there is a large backlog of orders. One of the bottlenecks is the wing assembly process which is largely manual due to the complexity of the task and the limited accessibility. The presented work describes a general wing build approach for both structure and systems equipping operations. A modified build philosophy is then proposed, concerned with large component pre-equipping, such as skins, spars or ribs. The approach benefits from an offloading of the systems equipping phase and allowing for higher flexibility to organize the pre-equipping stations as separate entities from the overall production line. Its application is presented in the context of an industrial project focused on selecting feasible system candidates for a fixed wing design, based on assembly consideration risks for tooling, interference and access. Further industrial, human and cost factors are discussed to establish project competitiveness. The main findings show a potential to reduce assembly time of systems equipping operations by 30% together with a lower ergonomic impact score. The paper also presents design rules derived from the case study towards a system design for a pre-equipping build philosophy. Primarily, cross component interfaces should be avoided as much as possible. Access for phase one structural operations need to be considered as well as major component jig pickup points. To increase system installation independence, layout considerations of components should lead to sufficient access to all components at any installation stage.

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INTRODUCTION

The definition of a product's assembly line structure heavily influences production rates and cost [1]. Generally speaking a desired production rate is to be achieved at minimal cost, leading to a distribution of assembly tasks to a number of work stations, operating in sequence and parallel. The cycle time for the stations defines the production rate as well as idle time within workstations. Mathematically speaking, this is a form of the well-known Bin Packing Problem [2]. The allocation of such tasks is defined by hard physical precedence constraints, such as requiring a bracket to be fitted before the assembly of a pipe can take place. In addition soft constraints are considered such as how to organize assembly operations effectively, including tooling, infrastructure and worker environment.

In the case of an aircraft, the product is highly complex. A large number of assembly operations are required involving a multitude of hard precedence constraints. Also, parallel operations are much more common since the product is large and physical space is available for operators. With all these sequential and parallel processes the control

of an equal balanced work time, also called cycle time, for each station is difficult. Disruptions in a given station will lead to an impact on the overall factory production rate. Hence any changes in build philosophy which are able to reduce such disruptions are desirable. Equipping aircraft components, specifically wings, are also a difficult environment to work in from an ergonomic perspective. Once the wing box is closed, in-tank and in-leading edge work requires operators to hold strenuous and demanding positions [3].

An approach taking within the automotive industry changes the sequential build approach to a modular setup [4]. This modularity comes in form of two aspects. The modular designs allow a common base chassis to host different modules and so form product variation. The assembly line, driven by this modular design allows for increased independent and parallel activities to take place, before modules are joined. Such an assembly line is highly flexible and has the potential to cut production costs significantly [5].

With large order backlogs for the two major civil aircraft manufacturers in the single aisle aircraft category, improvements in assembly and production techniques are essential [6][7]. Hence this paper focusses on the concept of major component pre-equipping which aims to relieve some of the issues for aircraft assembly time, by moving operations to a separate equipping station before the main production line commences. The station will allow for a controlled environment and an ergonomically improved part orientation. By decoupling the system equipping assembly operations from the linear flow of mostly structural operations, a more modular build philosophy is achieved.

SEQUENTIAL & PRE-EQUIPPING BUILD PHILOSOPHIES

A theoretical production philosophy process is considered for the assembly and equipping of aircraft wings. It consists of two major phases. In the first the structural parts of the wing-box are assembled by mounting spars, ribs and skins in a large fixed jiggging structure. Drilling, bolting and sealing are carried out on the stationary wing structure. Phase two moves the closed wing box out of the jig and onto an assembly line. The wing now undergoes further minor structural modifications and tests before the system component installation takes place. The assembly line consists of sequential stations for work to be completed before the wing is moved to the next station at the defined cycle time. Figure 1 shows a simplified representation of such a two phase process and the work content associated with each station. The coloured bars represent the different parallel activities in each assembly station, balanced and terminated at the same cycle time as indicated by the black lines. Alternatively, the wing could be moving continuously along the production line while equipping takes place.

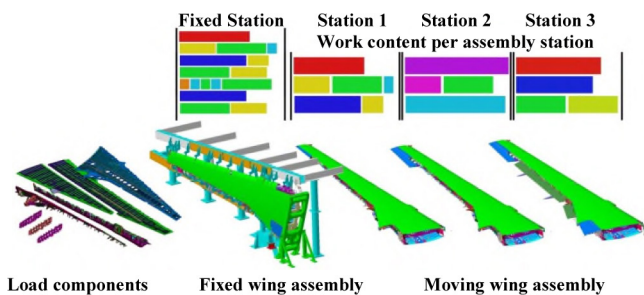


Figure 1. Two phase sequential build philosophy

This arrangement of the wing assembly is essentially a sequential build process. Parts are merged together to produce a larger assembly which is then fitted out with subsequent smaller system parts, one by one until the wing is completed. It benefits from a clear separation between structural (dirty) and system (clean) related tasks. Hence few drilling or fettling takes place after the closed wing-box arrives at the stations for system equipping.

In a second type of assembly philosophy work content is reduced during the late system equipping stations and moved forward to a pre-equipping station dealing with the major wing components. Essentially this extends the total number of bays and hence potentially allows for a reduced cycle time. Fully equipped major

components are then loaded into the fixed jigs and the wing box is closed. Final testing and equipping takes place in the moving assembly line in phase two. This process is shown in Figure 2.

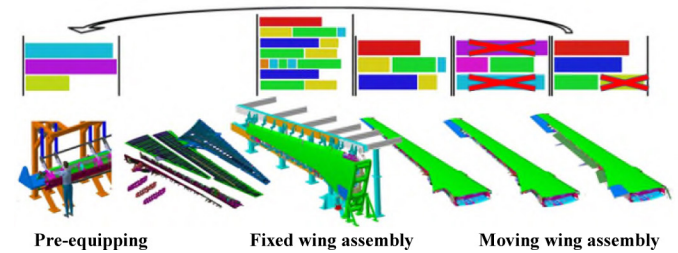


Figure 2. Two phase pre-equipping build philosophy

Alternatively the pre-equipping activities could be offloaded to a tier one OEM supplier directly hence reducing infrastructure, storage and personnel costs. The equipped major components are then supplied directly to the fixed jigs in phase one.

The pre-equipping approach requires substantial system protection, handling and interference considerations. Even though structural and system equipping tasks are still executed separately, the equipped components now need to pass through the whole structural build activities.

METHODOLOGY

This paper proposes a methodology to identify opportunities for offline pre-equipping for a complex system installation process. The procedure includes the following steps:

- Initial feasibility assessment by interfaces
- System location assessment
- Ranking

In the initial feasibility assessment each system is evaluated using two criteria. The first looks at the number of main interface components and the second whether the interfaces, such as mounting brackets, are already present to install the systems. Systems that interface to only one main component and have the interfaces in place are considered to be candidate parts for pre-equipping.

The second step in the methodology is to perform a detailed assessment of the system location of the components taking into account any assembly operations that will be undertaken after the pre-equipping stage. For this stage access to the full CAD assembly of the systems and / or the physical installations is required.

The third step in the methodology is to rank the feasible pre-equipping opportunities. A risk analysis for each feasible system is performed covering access, damage and interface considerations and risk mitigation is identified where possible. The risk level for each feasible system is then scored using a probability-consequence matrix as shown in Table 1. Risk mitigation scores are defined in five levels with the scores scaled based on the level of investment required to mitigate the risk. A third score defines the amount of time required to mitigate the risk.

work required for each system candidate risk to provide a pre-equipping implementation. The scoring values and their descriptors are given in Table 1.

Table 1. Method ranking criteria

	Indicates a probable occurrence	Indicates very likely occurrence	Indicates an observed occurrence	Indicates a condition by design
Indicates restriction to carry out work. Power tool & equipping within 20cm of system components	1	2	3	4
Indicates significant restriction to carry out work. Power tool/ equipping within 5cm of system/ components	2	4	6	8
Indicates confirmed access & interference restriction. Physical contact/damage possibility visually confirmed	3	6	9	12
Indicates a condition preventing application with the current design	4	8	12	16

Score	2	3	4	10	40
Mitigation	Change in equipping process or tooling usage	Addition of system protection components	Addition & removal of temporal fasteners	Change in Jig & template design	Change in system design

Score	1	2	3
Verification work content	Basic investigation	+ Mock system demonstrator	+ on line trials

Assembly time savings due to improved operator visibility, reachability and position have been estimated with a combination of two theoretical methods. The two are the classical design for assembly (DFA) approach as presented in [8] and a tool use and acquisition time estimation method (MOST) [9]. Detailed information on the assembly sequence numbering system and the calculation of the time estimates may be consulted in those references. The method breaks assembly operations down into individual steps, assigning statistical time estimates and penalty values for access and visibility. This allows for time reduction estimation if the assembly process changes into a more favourable condition in the pre-equipping philosophy. Some promising results have been shown in the application of these two methods in combination [10].

Next to the assembly time impact, the ergonomic and postural conditions have been studied with the help of the Rapid upper limb assessment (RULA) [12] method and observations on the shop floor. RULA first introduced in the 90s, provides a quick muscle and posture impact overview to screen for operator risks to upper limb disorders. Originally a work sheet method, it is now also available in CAD tools such as CATIA. Table 2 shows the range of scores

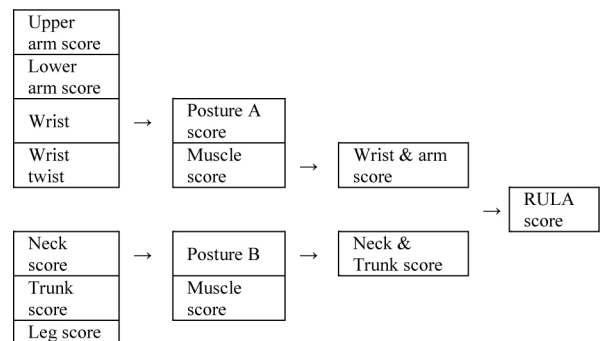
assigned to each upper body limb. Together they then form a single final score via the process shown in Table 3. Further detail on the RULA method application is available in [11].

Table 2. RULA score ranges per limb

Segment	Score Range	Color associated to the score					
		1	2	3	4	5	6
Upper arm	1 to 6						
Forearm	1 to 3						
Wrist	1 to 4						
Wrist twist	1 to 2						
Neck	1 to 6						
Trunk	1 to 6						

Muscle	Binary	0	1
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Table 3. RULA scoring process



Finally, the feasible systems can be plotted based on their risk score and the estimated reduction in installation time. The most desirable candidates are those which offer a high time benefit and a low “risk” cost as shown in Figure 3.

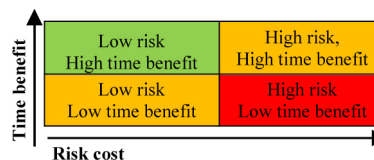


Figure 3. Conceptual view of risk vs cost trade-off

INDUSTRIAL APPLICATION STUDY

The methodology has been applied in a near term change context to assess the pre-equipping philosophy potential of current assembly activities at an aircraft OEM factory. Hence the application study does not allow design modification to the actual aircraft.

Wing System Pre-Equipping Feasibility

Initial feasibility was determined based on the system interfaces to the major components based on a review of the assembly work instructions for the equipping tasks. Systems which connect to multiple components cannot undergo the pre-equipping process.

In addition the fastening interfaces, such as brackets and secondary structures need to be present on the major components to install the system parts. Table 4 presents the initial pre-equipping feasibility for the studied systems.