

Applying Design for Assembly Principles in Computer Aided Design to Make Small Changes that Improve the Efficiency of Manual Aircraft Systems Installations

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ABSTRACT

The installation of essential systems into aircraft wings involves numerous labour-intensive processes. Many human operators are required to perform complex manual tasks over long periods of time in very challenging physical positions due to the limited access and confined space. This level of human activity in poor ergonomic conditions directly impacts on speed and quality of production but also, in the longer term, can cause costly human resource problems from operators' cumulative development of musculoskeletal injuries. These problems are exacerbated in areas of the wing which house multiple systems components because the volume of manual work and number of operators is higher but the available space is reduced.

To improve the efficiency of manual work processes which cannot yet be automated we therefore need to consider how we might redesign systems installations in the enclosed wing environment to better enable operator access and reduce production time.

This paper describes a recent study that applied design for assembly and maintainability principles and CATIA v5 computer aided design software to identify small design changes for wing systems installation tasks. Results show positive impacts for ergonomics, production time and cost, and maintainability, whilst accounting for aircraft performance and machining capabilities.

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INTRODUCTION

Aircraft system installation is still largely a manual process due to the complexity of the installation tasks, difficulty of access and relatively low production volumes. However, as the aircraft market increases, the need to investigate ways to reduce the burden on installers becomes more pressing. Whilst the production volumes are increasing it is still not cost effective to automate these processes, and effort therefore needs to be made to minimize the burden on the operators during the manual installation of aircraft systems.

This paper presents an investigation into how design for assembly and maintainability principles can be applied to ease systems installation in aircraft wings. Ergonomic issues associated with the current systems installation process were identified during a field study on the wing assembly line at a high value wing assembly facility. A range of installation issues were identified and the installation processes were simulated and ergonomics evaluated using the Rapid Upper Limb

Assessment (RULA) analysis tool in CATIA. Design methods from design for assembly, maintainability and ergonomics were applied to investigate how the manual systems installation process could be improved for a simple design problem. The results are compared and discussed.

LITERATURE REVIEW

Design for Assembly (DFA) has been widely studied and has been applied extensively in industry, particularly for mass production. Boothroyd, Dewhurst and Knight [1] define DFA as "the design of the product for ease of assembly". DFA helps manufacturers to create "world class products with improved quality, lower cost, and with shorter design cycle" by helping them to "understand the costs of production from the earliest stages of the development while at the same time bringing a relentless focus to the part count" [2]. DFA provides a structured approach to assessing the ease of assembly for a product as a basis for redesign.

Maintainability is defined as “the relative ease and economy of time and resources with which an item can be retained in, or restored to, a specified condition” [3]. Design for Maintainability (DFMt) aims to minimize maintenance costs by considering the maintainability requirements from early in the design process. Physical features that affect maintainability are accessibility, visibility, testability, complexity, interchangeability, identification and labelling, verification and simplicity [4]. DFMt principles are used in this research in order to assess the accessibility factors that are important for systems installation tasks. MIL-HDBK-472 Procedure III [5] provides a quantitative maintainability prediction methodology that was designed to predict maintenance downtime for military ground equipment, but has also been widely applied to other systems maintenance including aircraft systems. This method allows maintainability predictions to be performed at the design stage, and can be used as a basis for comparing the maintainability of design alternatives.

MIL-STD-470a [3] and MIL-STD-1472f [6] also establish human engineering design criteria for military systems, equipment and facilities. Maintainability principles and practices are applied in the design of the systems to achieve acceptable performance by maintenance personnel and minimize skill requirements and training time. Ergonomics guidelines have been produced for engineers [7] but design engineers often lack the time and understanding needed to sufficiently incorporate human factors [8].

Although there has been a paucity of research exploring ergonomics specific to aircraft assembly, wider evidence suggests that poor design for ergonomics is strongly associated with performance errors and quality decrements, particularly for high-demand tasks [9]. Poor consideration of ergonomics in design for assembly also impacts on worker health. Musculoskeletal disorders (MSDs) are far more prevalent in manufacturing than other sectors [10; 11] and the physical strain is exacerbated when tasks are performed in confined spaces [12] and demand force and repetition [13]. Due to these costly impacts on product quality and human performance it is widely recognised that better consideration of ergonomics needs to be integrated into the design of products and processes to optimise human work and output [14; 15; 16]. Computer aided design human modelling tools are now becoming the common technique for predicting and preventing ergonomic risk [17].

METHODOLOGY

The methodology adopted in this paper utilises design for assembly and maintainability principles in combination with Computer Aided Design (CAD) software to investigate small design improvements that could improve the efficiency of manual aircraft system installations. The methodology has been applied to a design problem as the case study in this paper.

Firstly a field study was undertaken to better understand the problems faced by operators installing systems. CATIA v5 was then used to model the system installation environment and the operator so that the postures adopted by operators during system installation could be simulated in CAD. An ergonomic assessment was performed using the RULA analysis function in CATIA v5 Human Activity Analysis Module to assess the operator ergonomics and a number of tasks were identified as candidates for redesign.

One installation task was selected for further assessment and the existing design was assessed using Boothroyd, Dewhurst and Knight's [1] Design for Assembly method and selected items from MIL-HDBK-472 Procedure III for maintainability prediction.

Four possible design solutions were then proposed to improve the assembly efficiency and each design option was assessed using the same design for assembly and maintainability criteria.

FIELD STUDY

The first objective of this research was to select system installation examples for redesign based on current levels of ergonomic and task completion difficulty. To do this a field study was undertaken in a high value aircraft wing assembly facility.

First, in preparation for the field study, a set of unpublished internal reports from prior ergonomic studies at this particular facility were reviewed as these had already found where ergonomic and task completion difficulties occur. This meant it was possible to identify a list of candidate processes suitable for redesign prior to visiting the facility in terms of *location* along the wing and the *type* the problem.

The list of candidate processes then formed the framework for the field study investigation. Systems installation work was observed and operators were interviewed in order to confirm the criticality of ergonomic / task difficulty and to gather further information to help ascertain suitability for redesign. The field study confirmed that physically demanding postures are commonly adopted for partial entry, with operators needing to twist and stretch in stressful physical positions to reach into the wing cavity from seated or standing positions. To complete tasks and alleviate their physical stress operators frequently reposition but this is often not possible - and their stresses are exacerbated - due to surrounding obstructions and congestion from equipment and other operators. The field study also confirmed that due to the limited recess space inside the cavity it is also common for operators to work blindly, by sensory feel alone, or with only head / shoulder entry (Figure 1). As all of these physical challenges impact on operator safety and wellbeing as well as task performance, details of the problem tasks and working postures adopted by operators were recorded.



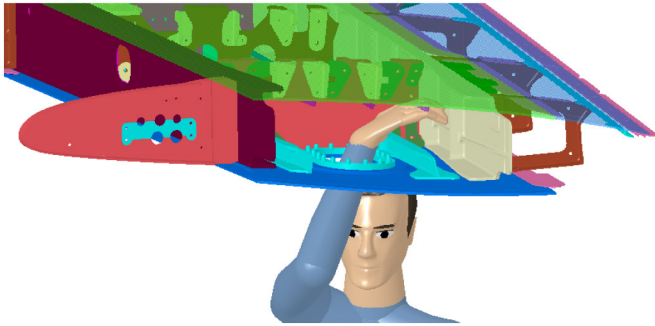


Figure 1. Example posture for wing systems installation tasks.

DESIGN ASSESSMENT

Although a number of candidate process tasks were identified in the field study, this paper will focus on the fuel system sensor bracket and cable installation. Design for assembly and maintainability principles were applied to assess the current designs with regards to assembly, design and ergonomics.

The subject of the design study is the installation of the fuel system sensor cable supports which are required for routing the cables for fuel quantity indicator probes, overflow sensors and temperature sensors in the fuel tanks. These systems contain many components, support brackets and associated cabling that must be manually installed inside the fuel tanks. For example the Boeing 777 has 17 fuel quantity indicator probes per main wing tank, and 5 on each side of the centre tank [18]. The location of the fuel probes is carefully chosen so that the effects of aircraft pitch and roll attitude changes are minimised as far as quantity measurement is concerned [18]. In the current design each support bracket is fastened to the wing rib using two fasteners, after the wing box has been closed and the sensor cables are attached to support brackets using cable-ties. The design rationale for using cable-ties is that they “provide a secure and non-aggressive fixing for wires and harnesses and guide them safely around the structure, pipework, panels and adjoining harnesses.” [19], however, the field study found that cable-tie installation is not easy in a confined space. An example support bracket and cable installation is shown in [Figure 2](#).



Figure 2. Bracket and cable installation existing design.

The following sections provide a detailed assessment of the current design considering the bracket installation and the installation of the cable onto the bracket.

Design for Assembly Assessment

A DFA assessment was undertaken for the current design following the methodology presented by Boothroyd, Dewhurst and Knight [1] to determine the theoretical minimum part count for a sensor support assembly. The current design has 6 parts (rib, bracket, 2 × fasteners, cable tie and cable). The theoretical minimum part count for this assembly based on the DFA criteria defined in [1] (listed in [Appendix A](#)) is 2 (the rib and cable are the only essential parts). All other parts could be theoretically redesigned to be integrated onto the rib. It should be noted that the DFA method provides only a theoretical minimum part count as a design aid and this may not be practical for the actual product design.

A further design assessment was performed using other design for assembly guidelines collated from [1] and summarised in [Appendix B](#). The findings for the current design are:

- DFA-1:** The bracket acts only as a link between the cable and the rib and should be eliminated if possible
- DFA-2:** Access for assembly operations is restricted due to the confined space in the closed wing. DFA principles recommend avoiding restricted operations if possible
- DFA-3:** The cable tie requires adjustment during assembly, which is not desirable from a DFA perspective
- DFA-4:** The bracket location is under-constrained during assembly and the bracket must be aligned with the fastener holes by the operator before it can be fastened to the rib
- DFA-5:** The installation of the bracket requires two hands - one to hold the part down and the other to insert the fasteners.

The DFA assessment has identified that based on DFA principles the current design is far from optimal. There are four parts in the assembly that could theoretically be eliminated, the parts must be held in position and adjusted during assembly; accessibility is also poor.

Design for Maintainability Assessment

Selected physical design factors from MIL-HBK-472 procedure III checklist A were used to assess the design of the sensor support bracket assembly with regards to accessibility. Checklist A of MIL-HDBK-472 Procedure III uses a total of 15 criteria to assess physical design factors relating to maintainability and five relevant criteria were selected to assess the accessibility of the systems installation task (a list of the selected criteria used is presented in [Appendix C](#)). The design was assessed against each factor and a qualitative score from 4 (easy to maintain) to 0 (difficult to maintain).