Part Consolidation of an Avionics Pedestal by Topology Optimization-based DfAM (Design for Additive Manufacturing)

K. Conklin[a], B. Poldon[a], and I. Y. Kim[a]

[a] Department of Mechanical and Materials Engineering, Queen's University
E-mail: kimiy@queensu.ca

Abstract

A parts consolidation process, driven by a topology optimization-based DfAM (Design for Additive Manufacturing) method, has been applied to the flight deck control panel for a Bombardier business jet with the objective of component and joint count reduction. Accordingly, this will also translate to a reduction in assembly time and total unit cost. Initially, the original pedestal model was simplified to create a design space that accounted for assembly and maintenance needs as well as the space required for the electronics and controls. Topology optimization was performed to support the additive-manufactured based re-design process and provide an efficient material layout specific to the pilot effort limit loads and flight/ground effort limit loads experienced by the structure. The finalized redesign consisted of an outer sheet metal shell based similarly on the original design, and two polymer 3D printed components comprising the interior of the pedestal to support the avionics themselves. The two additively manufactured parts replaced a large number of previously machined metallic components, resulting in a significant part and joint count reduction. To verify the redesigned pedestal met all performance criteria, a linear static stress analysis was performed on the control panel structure. The appropriate ultimate loads and emergency loads were applied to the structure and the redesigned pedestal met the no-failure stress performance criteria. Additionally, the reduction in part count and joint count resulted in a cost reduction for the redesigned pedestal, meeting the main goal for this project.

Keywords –
Topology Optimization, Parts Consolidation, Additive Manufacturing, Aerospace, Finite Element Analysis

1 Introduction

As modern aerospace technology becomes increasingly powerful and efficient, the industry is turning to new manufacturing methods and materials for strong, lightweight, and low-cost solutions. Topology optimization (TO) is an advanced design tool that aims to find the ideal layout of material within a given design domain to maximize some component of structural performance. Topology optimization has been used extensively in the design of aircraft components, such as fuselage structures, seat side struts, and wings, as it allows designers to improve strength, reduce weight, and/or decrease cost by allocating material to the load paths of the structure [1] [2] [3]. Additive manufacturing (AM) is a technology that involves building a part by layer as opposed to classical subtractive or formative manufacturing methods. Additive manufacturing is becoming increasingly used in the aerospace as it is ideal for high complexity, low volume parts. Given that TO typically produces geometrically complex structures, AM is a great complement to TO as increases in part complexity are essentially free of cost.

The work completed in this paper aims to leverage the benefits of topology optimization and additive manufacturing to perform parts consolidation on a flight deck control panel. Parts consolidation and the associated reduction in joints produce savings in assembly costs by reducing assembly time and streamlining the manufacturing process.

2 Topology Optimization

CATIA models of the full pedestal were provided by Bombardier which were then used to generate the design space. A number of simplifications to the design were made to allow for easier meshing in the later stages of the project. These simplifications included chamfer, radii, and bolt hole elimination. Voids in the design domain were added based on the depth of the electronic components gathered from the CATIA model and the spacing required for the wire harness assemblies. This data was used in combination with dimensions of a 95th percentile human hand to allow extra spacing required for installation and maintenance procedures. Non-designable regions were also determined in this stage of the project and the three areas identified were: cockpit floor attachment locations, front cockpit attachment locations, and electronics mounting locations.

A finite element model was created from the geometry of the design space, which was used to determine the load paths throughout the structure. The entire meshed model of the design space consisted of approximately 180,000 hexahedral finite elements and 230,000 nodes. The various loading cases provided by Bombardier were ultimate loads, meaning that the component material was allowed to yield but not completely fail. There were three types of loading considered for this component: pilot effort loads that were applied to the avionics controls and flight/ground loads as well as the emergency loads which were inertial loads applied to the entire structure.

The objective function of the topology optimization was to minimize compliance subject to various volume fractions ranging from 10% to 30%. The optimization was run in OptiStruct and the results are shown in Figure 1. The primary load paths were all reinterpreted and integrated into the redesigned component. However, many of the smaller secondary load paths would lead to large overhangs that increase support structure, print time and component cost, and therefore needed to be carefully evaluated in the design stage. A cost-benefit analysis was performed for the secondary load paths regarding increased structural performance versus added manufacturing cost.

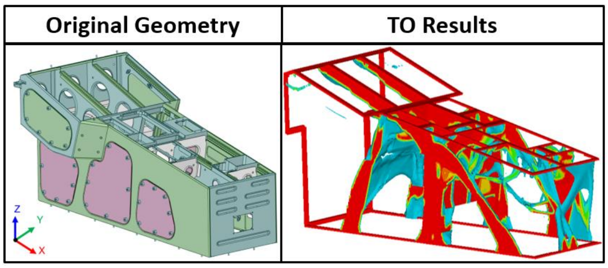

Figure 1. Original geometry and resulting load paths from topology optimization

3 Parts Consolidation and Redesign

The topology optimization results were first overlaid with the original design to aid in the result interpretation process. The next step was to determine the minimum required number of components for the design. The limiting factor in this case was the build plate dimensions of the 3D printer. Bombardier requested to use the Fortus 900mc system which has a print envelope of 914 x 607 x 914 mm. Given that the longest dimension in the design space was approximately 1m and exceeded the print envelope, a minimum number of two AM components was required. Determining where to separate the components must factor in the build orientation, print height, and support structure requirements of each new part.

It was decided to split the pedestal along the line where the width change occurs at the side chamfer brackets. This was chosen since an angle change of the top surface also occurred at this transition region, which would require additional support structure given that this surface was selected as the build surface for the AM machine. The additively manufacturing components of the redesign are shown in Figure 2 and consist of two avionics supports made of ULTEM 9085.

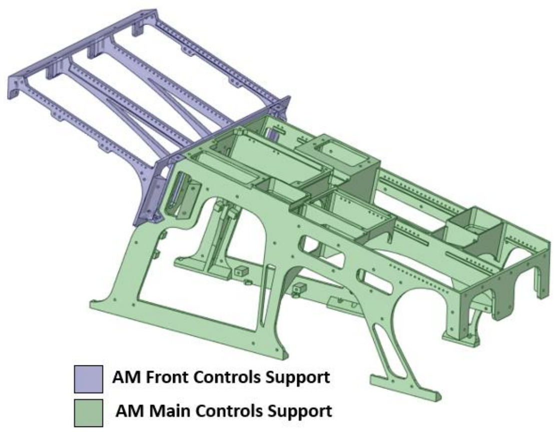

Figure 2. Redesigned components for polymer additive manufacturing

These two components closely align with the TO results while still accounting for various design constraints and DfAM best practice methodologies such as support structure minimization. The remainder of the design consisted of an outer sheet metal shell as well as the original DZUS rails, with the entire design being verified with a linear static stress analysis. This redesign allowed for the consolidation of many previously metallic parts and a large reduction in the number of joints required. The effective reduction in assembly costs achieved the main goal of this project, and demonstrated the practical benefits of applying topology optimization and DfAM based parts consolidation for the aerospace industry.

References

[1] M. Kalanchiam and B. Mannai, "Topology Optimization of Aircraft Fuselage Sturcture," International Journal of Aerospace and Mechanical Engineering, vol. 7, no. 5, pp. 820-823, 2013.

[2] G. Dima, I. Balcu and M. Zamfir, "Method for lightweight optimization for aerospace milled parts," in International Conference Interdisciplinary In Engineering, Tirgu-Mures, Romania, 2014.

[3] D. Walker, D. Liu and A. Jennings, "Topology Optimization of an Aircraft Wing," in Structures, Structural Dynamics, and Materials Conference, Kissimmee, Florida, 2015.