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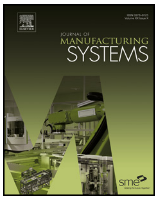

Feasibility analysis of composite fuselage shape control via finite element analysis

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ABSTRACT

Composite parts have been increasingly used in aircraft industry because of their high strength-to-weight ratio and stiffness-to-weight ratio. Due to the diversity of suppliers and fabrication process variation of composite parts, dimensional variability of composite fuselages inevitably exists. In order to improve the dimensional quality and increase the productivity, a new shape control system has been proposed to conduct dimensional shape adjustment before the assembly process. By using finite element analysis, we conduct the feasibility analysis of this new shape control system. Firstly, we develop a finite element model with detailed material property, ply design, fixture structure, and actuators installation considered. The finite element model is then validated and calibrated by physical experimental data. Feasibility analysis via FEA includes single-plane dimensional control capability analysis, double-plane scheme analysis, stress/strain analysis, and failure test. We conclude that the single-plane with ten actuators scheme is feasible for the shape control, and the actuators do not damage the fuselage.

1. Introduction

Composite materials have been increasingly used in aircraft industry due to their advantages like high strength-to-weight ratio, high stiffness-to-weight ratio, corrosion resistance, and high durability [1]. Aircraft parts made from composite materials, such as fairings, spoilers, floor beams, and flight controls have been developed. These composite structures realize better weight savings over aluminum parts [2]. A new generation of large aircraft is designed mostly with composite fuselage and wing structures. As an example, a commercial aircraft has major structural parts made from composite materials, and the composite parts represent more than 50% by weight [3]. Dimensional control of the assembly process for these advanced composite parts requires an in-depth knowledge of composite structures, materials and properties, which is very important for the quality management, high productivity of manufacturing process and running safety of assembled aircrafts. However, due to the diversity of suppliers and multiple manufacturing batches from each supplier, the dimensional variability of composite fuselages inevitably exists. For instance, a report showed that a gap of 0.3 in. occurred when the nose-and-cockpit section lined up with the fuselage section [4].

For the sake of reducing dimensional variability and residual stress of the composite fuselage assembly process, a shape control system with multiple actuators is proposed to adjust the dimension of the composite fuselage before assembly. In the current practice, a “pogo” shape control system is used to reduce the dimensional deviations between the real composite part and the ideal shape. The photo and schematic diagram of the current “pogo” system are shown in Fig. 1(a) and (b). The disadvantages of the current system include that (i) the capability of dimensional shape control is very limited, (ii) it takes a long time to adjust the actuators to get an acceptable dimensional shape, and (iii) highly skilled engineers are required to conduct the adjustment. Therefore, a new shape control system is designed to realize better dimensional quality control. As shown in Fig. 1(c) and (d), ten actuators are assigned cross the edge of the lower semi-circle of the fuselage. These ten actuators can provide push and pull forces to change the in-plane shape of the fuselage. An automatic shape control system will be developed that can effectively and efficiently adjust composite parts to an optimal configuration [5]. The new shape control system can (i) compute the optimal actuators’ forces to minimize the dimensional deviations of current composite parts and the ideal shape; (ii) implement the adjustment automatically; (iii) release the workloads of highly skilled engineers. Before the development of automatic shape con-

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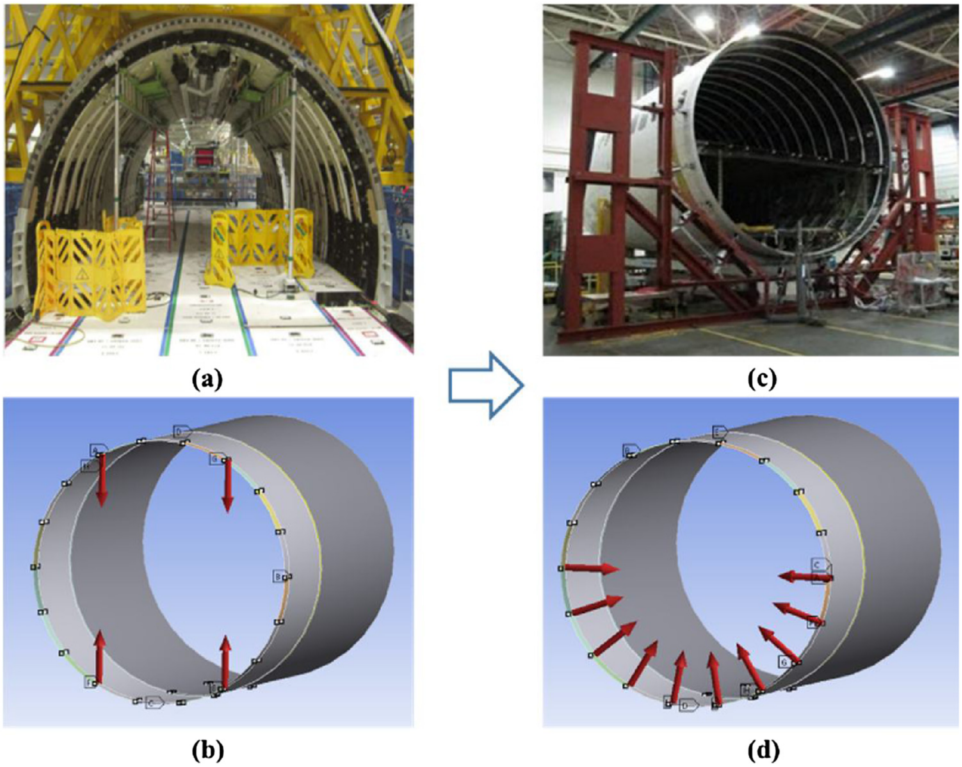

Fig. 1. (a) Current “pogo” system, (b) schematic diagram of current “pogo” system, (c) new shape control system, (d) schematic diagram of new shape control system.

trol system, a feasibility analysis of the new shape control system for the composite parts should be conducted systematically.

In the literature, Pinkerton and Moses assessed the capabilities of a new out-of-plane displacement piezoelectric actuator called thin-layer composite-unimorph ferroelectric driver and sensor (THUNDER) to alter the upper surface geometry of a subscale airfoil to enhance the performance under aerodynamic loading [6], and the assessment was based on physical experiments. Sofla et al. [7] reviewed the recent activity in conceptual design, prototype fabrication, and evaluation of shape morphing of an aircraft wing, especially for smart materials including shape memory alloys, piezoelectric actuators, and shape memory polymers. Sodano et al. [8] presented the feasibility of using macro-fiber composites for vibration suppression and structural health monitoring. The aforementioned literature focused on the feasibility of variability monitoring and control during the design of composite fuselage and wings. For the assembly process of composite parts, Dong and Kang proposed an approach based on response surface method and analyzed the relationship between part variation and assembly variation/stress via virtual experiments and finite element model [9]. Zhang and Shi built a stream of variation (SoV) model for prediction and control of dimensional variations of composite part assembly in single-station [10], and multi-station process [11]. In their model, different sources of variabilities such as composite part manufacturing errors, fixture position errors, and relocation-induced errors were considered for analysis of dimensional variation and its propagation. Gómez et al. proposed a supporting model and ad-hoc software for the decision-making process during the conceptual design of aircraft final assembly lines [12]. The aforementioned literature gave a general framework of dimensional variation modeling of the composite parts assembly process and conceptual design of aircraft assembly line. However, there is no systematic analysis of the feasibility of the newly proposed automatic shape control system.

Feasibility analysis based on pure physical experiments is very expensive and time-consuming. Usually, before testing the real system with physical experiments, feasibility analysis based on computer simulation needs to be done. Finite element analysis (FEA) is a typical computer simulation method to analyze the complex properties of composite materials for aerospace applications [13]. The advantages of FEA include accurate representation of complex structures, inclusion of dissimilar material properties, capture of local effects, and accurate representation of the total solution. By using the commercial software like ANSYS or ABAQUS, it is viable to analyze the mechanical properties and predict dimensional, stress, and strain responses of the composite fuselage under different actuators’ forces.

In order to implement the feasibility analysis of the new shape control system, an accurate finite element model is developed to mimic the fabrication process of a composite fuselage. The finite element model is calibrated and validated by physical experimental data, and the finite element model can accurately predict the dimensional shape change of the fuselage under different settings of actuators’ forces. Then, feasibility analysis of the shape control system is conducted through dimensional control capability analysis, stress/strain analysis, and failure test.

The remainder of this paper is organized as follows. Section 2 introduces the detailed procedure of the finite element modeling of the composite fuselage and the actuator settings. Section 3 is the calibration and validation of the finite element model by comparing it with the physical experimental results. Section 4 consists of the feasibility analysis of the dimensional control capability, stress/strain analysis, and failure test. Section 5 provides the summary of the work.

2. Finite element modeling

In this section, we show the finite element modeling of the composite fuselage. With the commercial software ANSYS Composite