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Experiment and numerical simulation of a full-scale helicopter composite cockpit structure subject to a bird strike

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A B S T R A C T

Bird strike is one of the most critical safety issues in aviation, which usually leads to catastrophic casualties. In this paper, an effective FE–SPH coupling model is developed to investigate the structure crashworthiness performance of a helicopter composite cockpit (HCC) subject to a bird strike by using an explicit nonlinear finite element code ANSYS/LS-DYNA 3D. The mechanical parameters of the bird constitutive model are obtained by a bird strike test on flat plate and the validated bird model is subsequently implemented to simulate a bird striking on HCC according to Federal Aviation Regulation 29.631. A full-scale HCC bird strike experiment is also performed under the same impact condition to certify airworthiness requirement as well as validate the FE model. The high agreement between the experiment and numerical analysis builds confidence in future use of FE method as a predictive tool. Based on numerical results, a structure design modification is also performed to enhance the structure stiffness and improve bird strike resistance.

1. Introduction

Collisions between birds and aircrafts during the taking-off, cruising and landing phases have become an increasingly serious and catastrophic issues for aircrafts safety. According to the statistic data from Federal Aviation Administration (FAA), the number of bird strike accidents annually has increased by six times from 1795 cases to 10,856 cases in year 1990 and 2013 respectively, with total accident number of 138,257 cases with 14 years [1]. Such intensive bird strike accidents have caused huge fatalities, namely, at least 103 aircrafts and 262 lives were lost in civil aviation field from year 1912–2008 where annual property loss was increased from 614 million to 1.28 billion US dollars [2]. Helicopters only counts for less than 0.5% of bird strike accidents while 17% of casualties occur in helicopter related accidents [3], which poses a pressing need in airworthiness for studying the dynamic behavior of the cockpit structures in helicopters.

Naturally, a full-scale bird strike experiment validation is the most direct approach to investigate the crashworthiness of the cockpit structure subject to the bird strike, required by the certificate authorities before the proof of operation. However, it is time-consuming and expensive, but with relatively little useful physical information due to the nature of such destructive experiments where each specimen should be replaced in every test [4,5]. On the other hand, strict and rational theoretical analysis is rather difficult considering the nonlinearity in material behavior, large deflection and high strain rate of the cockpit structure induced by the intense impulse and short duration of the impact loading [3,4,6–8].

Recently, with the development and maturity of the numerical methods, finite element analysis has been the most effective yet abundant information extraction approach to evaluate and optimize the design of the laminated cockpit glass. Similar structures in automotive industry, i.e. laminated windshield under dynamic loadings has been extensively studied by numerical approaches [9,10]. It was a more complicated structure in the cockpit than the automotive windshield as well as the much higher impact speed where the striking bird body exhibits fluidic behaviors, i.e. about more than 80 m/s, in the aircraft cockpit case such that more sophisticated numerical method should be adopted. Therefore, two numerical methods, i.e. decoupling and coupling methods, are suggested and widely accepted to analyze bird strike problems [2]. The decoupling method uses a pressure pulse to describe the bird,

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applied directly on the structure to calculate its response independently [2,11]. By this way, the analytical model could be greatly simplified thus significantly enhance the computation efficiency. The most critical disadvantage is the ignorance of the interaction between the bird and structures on the applied load, leading to a coarse solution [11]. To overcome the shortcoming, coupling methods are suggested including Lagrange, Arbitrary Lagrange Euler (ALE) and Smooth Particle Hydrodynamic (SPH) methods [2–4,6,12–15]. With the development of computation capability, coupling methods become prevalent in the bird strike related studies, e.g. windshields [3,7,16–21], aircraft airframes [22], leading edges [4,5,13,23,24], engine fan blades [25,26], composite structures [6,27,28], sandwich panels [29,30] and among others. These studies have confirmed the validity and accuracy of the coupling method to numerically simulation bird strike problem.

However, these numerical simulations provide sufficient insights for single case while a general methodology for bird strike certification compliance with an effective but simple finite element model is still lacking. To fill this blank, driven by industrial demand for reducing experiment costs and time consume, a collaborative research project between academic and industrial company is proposed to develop an effective bird strike resistance compliance methodology for airworthiness certification requirements with the help of numerical simulation method. For this purpose, a comprehensive full-scale three-dimensional FE model of the helicopter composite cockpit (HCC) structure (as shown in Fig. 1) in combined with a SPH bird model is carefully developed by using an explicit nonlinear finite element code ANSYS/LS-DYNA 3D, in which the constitutive parameters of the SPH bird model are calibrated to correlate a bird strike test on flat plate. To validate the numerical simulation method, a bird-strike experiment is also carried out on a full-scale HCC by using air cannon to provide the specified velocity according to Federal Aviation Regulation 29.631(FAR 29.631) [31]. Numerical simulation results match the corresponding experiments well, proving the effectiveness of the FE model. Furthermore, based on numerical results, a structure improvement is also proposed and accepted by industrial partner in order to enhance structure stiffness as well as reduce its deformation caused by bird strike.

2. Bird strike experiment

2.1. Test facility

In this article, a bird strike on HCC experiment was carried out to certify its bird strike resistance performance by using impact test facility as schematically shown in Fig. 2. The impact test facility mainly consisted of the following components: HCC specimen, air cannon, fixture, high-speed camera, velometer, accelerometers, strain and displacement measure device, and rigid wall. The HCC specimen was mounted to the fixture with the impact point located on the center of the main frame (as shown in Fig. 3). The location of the accelerometers, displacement transducers and dynamic strain gauges were installed as shown in Fig. 3, respectively.

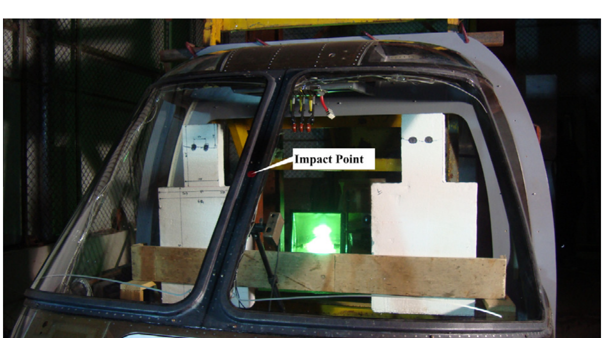

Fig. 1. Helicopter composite cockpit specimen.

A killed chick on the spot was employed to mimic the bird projectile, wrapped by a plastic sheet to avoid its spread during the flight. The total weight of the bird projectile used in the experiment was about 1 kg according to FAR 29.631. The bird projectile was propelled with the velocity of 86.1 m/s from the air cannon to strike on HCC. A laser velometer was used to measure the velocity of the bird projectile as well as a high-speed camera with the sample rate of 100,000 frame/s was used to capture this process of bird strike on HCC. The time history of the structure deformation could be measured by strain gauges and displacement transducers mounted on the cockpit structure. A rigid wall was also used to collect the flying debris pieces of bird projectile.

2.2. HCC specimen

Fig. 4 showed the detailed CAD (computer aided design) geometry model of the HCC structure studied in this paper. This cockpit was a complex composite structure and could be divided into five parts: main load-bearing frame (MLBF), main windshields (MW), skin, top windshield (TW) and bottom windshield (BW). The every part of the HCC specimen was summarized in Table 1 and the detailed description was as follows:

(1) The MLBF was a typical thin-walled structure, which has a box cross-section with flanges, as highlighted in Fig. 4(8). It was fabricated of G827/5224 composite material manufactured by a resin infusion process. The mechanical properties of G827/5224 were tabulated in Table 2. The lay-ups of MLBF were $[0/45/0/90/0/0/-45/45/0/0/90]_s$ with total thickness of 5.2 mm with an even thickness distribution on each layer.
(2) The MW was a three-layer laminated glass, i.e. tempered glass/PVB layer/tempered glass. Each layer had the same thickness of 3 mm. The MW was glued to the MLBF flanges, as highlighted in Fig. 4(8).
(3) The TW and BW were both made of single-layer soda-lime glass with the thickness of 3 mm.
(4) The skin was fabricated of the sandwich structure with metallic honeycomb core and composite facets as highlighted in Fig. 4(9). Both the top and bottom facets of the sandwich were made of the composite materials (named G803/5224) with the thickness of 0.6 mm. The mechanical properties of G803/5224 were listed in Table 2 and every facet lay-up was $[0/45/0/-45/0]$. The metallic honeycomb core was manufactured from aluminum alloy with core height of 10 mm, core cell size of 5 mm and core cell wall thickness of 0.2 mm.

3. Finite element modeling

A FE–SPH coupling model was developed by using the nonlinear explicit finite element code ANSYS/LS-DYNA 3D for numerical simulation of a bird strike on the HCC. The main objective of present numerical simulation was to provide an effective analytical tool for the study of HCC bird strike resistance performance in detail to support the HCC design and airworthiness certification. The details of whole FE model including the HCC and bird SPH elements were depicted in Fig. 5, corresponding with its geometry model (refer to Fig. 4).