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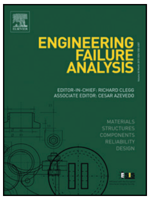

Comparing different fidelity models for the impact analysis of large commercial aircrafts on a containment building

Xinzheng Lu [a,*], Kaiqi Lin [a], Song Cen [b], Zhen Xu [a], Li Lin [b]

[a] Key Laboratory of Civil Engineering Safety and Durability of China Education Ministry, Department of Civil Engineering, Tsinghua University, Beijing 100084, China
[b] Department of Engineering Mechanics, School of Aerospace Engineering, Tsinghua University, Beijing 100084, China

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ABSTRACT

Three Boeing 767 finite element models with different fidelities are built using CATIA, Hypermesh and LS-DYNA in this study. The impacts of these models on a rigid wall and a containment building are simulated with LS-DYNA. The simulation results show that the time histories of the impact forces and impulses differ significantly among these models for the low-speed impact case. With the increase of the impact velocity, the time histories of impact forces and the damage of the containment building become similar. Moreover, the impact on the back side of the containment building will occur only when the high fidelity model impacts the containment building with a high velocity. The over-simplified aircraft models will underestimate the impact load and induce a different failure mode compared to the high fidelity model. The internal structures of an aircraft should be accounted for in the impact simulation. This investigation provides a reference for further studies of aircraft impacts on containment buildings.

1. Introduction

As an emerging energy, nuclear power has been widely valued and developed around the world. Since the “September 11” terrorist attack in 2001, the safety of containment structures against aircraft impacts has drawn a lot of attention worldwide. In 1968, Riera proposed the well-known Riera's equation (Eq. (1)) to calculate the impact force of an aircraft on a rigid wall [1]:

$$F(t) = P_f[x(t)] + \mu[x(t)]v(t)^2 \tag{1}$$

in which $\mu[x(t)]$ is the mass per unit length at location x, $v(t)$ is the velocity of $\mu[x(t)]$, and $P_f[x(t)]$ is the static force required to crush the aircraft axially located at the coordinate $x(t)$, which is controlled not only by the strength of the surface skin but also by the internal structures of the aircraft. Riera's equation provides a simplified and practical method for calculating the time-history of an aircraft impact. A full scale aircraft impact experiment was then conducted by Sugano et al. [2], and the reliability of Riera's equation was validated according to the experimental results.

There are two main approaches to assess the aircraft impact: (1) applying the impact load calculated by Riera's equation directly on the impacted area of the containment building to perform a time history analysis and (2) using a coupled finite element (FE) model including the aircraft and the containment building to perform the simulation of the entire impact process, i.e., the aircraft–target interaction analysis method. Previous studies have shown that the impact forces calculated by Riera's equation will be over-conservative [3,4]. Therefore, the aircraft–target interaction analysis is becoming more popular because of its higher accuracy than Riera's equation. This interaction model requires the establishment of a detailed FE model of the aircraft and the containment building.

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[*] Corresponding author.

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Many studies have been conducted to simulate the impact of commercial aircraft by using the aircraft–target interaction analysis method. The FE models of the aircrafts with different fidelities are used [3–11]. For example, Wierzbicki and Teng [5] and Karim and Fatt [6] simulated the impact between the aircraft and the World Trade Center in the "September 11" terrorist attack. However, the FE models of the aircraft used in their works are oversimplified. Even the geometry of the FE models significantly diverges from the real aircraft. Lee et al. [7] and Arros and Doumbalski [3] performed the impact simulations of a Boeing 747 on structures. Note that only the surface skin of the aircraft was considered in the FE models. Although the complex geometry and mass distribution of the aircraft were considered in their works, the internal structures of the aircraft were ignored, which may limit the accuracy of the simulation results.

In addition, some high-fidelity models are used in existing studies. The modeling of the internal structures of an aircraft for impact simulation is considered to different extents. Wilt et al. built a high-fidelity F15-E aircraft model and conducted the impact analysis [4]. The influence of aircraft fuel (i.e., internal fuel, external tanks and the conformal fuel tanks), engines and nacelles on the impact force against the reinforced concrete (RC) wall was discussed in their model. The fuel was also modeled by Jeon et al. [8] and Kirkpatrick et al. [9]. However, the beams, fuselage stringers and wing ribs, which contribute a lot to the structural stiffness, are not considered in their models [8,9]. Siefert & Henkel [10] and Kostov et al. [11] performed the impact simulation with high-fidelity FE models including all the internal structures of the commercial aircrafts. However, the differences between such high-fidelity models and the widely used simplified models [3,5–7] lack in-depth discussions.

According to Sadique et al.'s simulation on the impact of aircrafts of different sizes [12], large commercial aircrafts (e.g., Boeing 747 and Boeing 767) can induce the most significant damage on and even the global failure of the containment building. This failure mode is different from the impact of smaller airplanes (e.g., F15-E and Phantom F4), which only induce local failure. It is necessary to establish the high-fidelity FE models of large commercial aircrafts and perform the corresponding impact simulations on the containment buildings.

To compare the influence of different fidelity FE models on the impact force and the damage of containment buildings, three large commercial aircraft (i.e., Boeing 767) models with different fidelities and a containment building model are established in this study. The mass distribution, internal structures and material models of a Boeing 767 are carefully considered in these models. The impact tests of an aircraft engine are simulated to validate the feasibility of the proposed material models. The aircraft impact simulations are then performed, and the time histories of the impact forces and impulses are compared among different fidelity FE models. This investigation can provide a reference for the further studies of the impacts of aircrafts on containment buildings.

2. Numerical modeling of the aircraft

Many types of commercial aircraft, such as the Boeing 747 [3,7,12,13], Boeing 767 [12] and Boeing 707 [12–16], and military aircrafts, such as the Phantom F4 [2,17] and F15-E [4], were used in related impact studies. The Boeing 767-200ER is selected in this study as a typical large commercial aircraft. The reasons for selecting a Boeing 767 are the following: (1) the Boeing 767 is one of the most typical large commercial aircrafts with the passenger capacity of approximately 224; and (2) a Boeing 767 is one of the two aircrafts that impacted the World Trade Center on September 11, 2001. Many related studies have been conducted using this aircraft, and substantial data are available in the literature.

The FE model of a Boeing 767 established in this study has the identical geometric shape, surface skin and internal structures as the real aircraft. Because the FE model cannot model the equipment loads of the aircraft directly, these loads are converted to masses in the structural components at the identical position according to the mass distribution of each major component in the real aircraft (Table 1). This conversion is performed to ensure the mass distribution of the FE model conforms with the real Boeing 767 (Fig. 1) [18,19].

2.1. Modeling process

The CAD model for a Boeing 767 is first created in the three-dimensional modeling software CATIA, including the aircraft skin (Fig. 2) and the internal structures. The internal details are carefully modeled following the standard data of Boeing 767, Fig. 3 is provided as an example to show the details of an aircraft wing structure. The CATIA model is then converted into the general purpose preprocess program of Hypermesh to generate the FE model, in which the beams and fuselage stringers are modeled with beam elements, whereas the floors, decks, wing ribs and engines are modeled with shell elements. The shell elements and the beam elements share nodes to ensure the compatibility of displacement. Finally, the model is meshed in Hypermesh with a global mesh size of approximately 250 mm. For the components with complex geometries or force distributions (i.e. the regions where the stress distribution varies significantly, e.g., the conjunction between the engine and the wing an aircraft), the mesh size will be refined to ensure the accuracy of the simulation.

Table 1
Mass distribution of a Boeing 767.

	Mass
Fuselage	56.96 tons
Wings	24.12 tons
Engine	4.366 tons
Total	113.4 tons