Multibody and Spatial Plastic Hinge Approach for Impact and Crashworthiness Analysis of an Aircraft Fuselage Section

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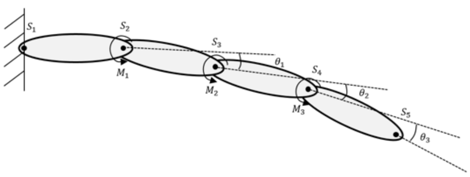
Abstract
In modeling structural dynamics of mechanical systems, spatial plastic hinges can be utilized to describe the kinematic and dynamic responses of the structures. This study focused on the modeling and analysis of an aircraft fusealge section utilizing a collection of rigid linkages connected by a collections of kinematic joints and coupled with torsional and bending spring-dampers, whose properties are determined from component tests. For illustration, a Boeing 737 fuselage section impacting a solid surface at 9.14 m/s is modeled using a multibody with spatial plastic hinge method. The deformation shape and dynamic response of the multibody model show reasonably good agreement with the experimental test article as well as with the detailed finite element (FE) model.

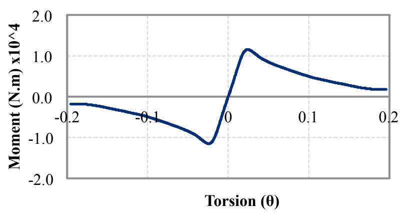
Figure 1: Drop test of a narrow-body Boeing-737 fuselage section [1]

In this study, the mathematical code MADYMO 7.5 is utilized to reconstruct the multibody fuselage section and to replicate the drop test conducted by the Federal Aviation Administration, as shown in Figure 1 [1-3]. The multibody model consists of a fuselage skin and structure, a stiff auxiliary fuel tank and a stiff cargo door located at the right side of the fuselage. The fully instrumented fuselage section weighed at approximately 4,000 kg. The fuselage section is then impacted onto a solid surface at 9.14 m/s to replicate a severe but survivable impact condition.

The formulation of plastic hinges can be done by interconnecting a collection of bodies using kinematic joints with resisting spring-dampers. The 2D plastic hinge as shown in Figure 2(a) is modeled using a multibody system with 4 rigid bodies of equal length denoted by $S_iS_{i+1}; i = 1, 2, \dots, 4$. Each pair of bodies are interconnected by torsional spring-damper and has a mass m_i, and moment of inertia J_i. The angles θ_i represents the relative orientation between the bodies S_iS_{i+1} and $S_{i+1}S_{i+2}$. The resistive motion of the bodies are represented by the bending moment/rotational angle $(M - \theta)$. The mechanical model of the plastic hinges shown here is to illustrate the vertical bending characteristics of the plastic hinges as shown in Figure 2(b). In the 3D spatial plastic hinge modeling, the axial torsion are also included in addition to the bending effects.



(a)



(b)

Figure 2: (a) 2D representation of mechanical model of plastic hinges; (b) Bending characteristics of plastic hinge

Illustrated in Figure 3 is the impact sequence of the fuselage from the test article, the FE fuselage model and the multibody fuselage with plastic hinges. It is shown that the fuselage multibody model is in good agreement with the physical test and the FE model. Due to the presence of a stiff cargo door on the right side of the fuselage, the test and simulated results shows that the left fuselage undergo higher deformation than the right side. In addition, the stiff auxiliary fuel tank which populates majority of the aft section contributed to greater deformation to the forward section of the fuselage section.

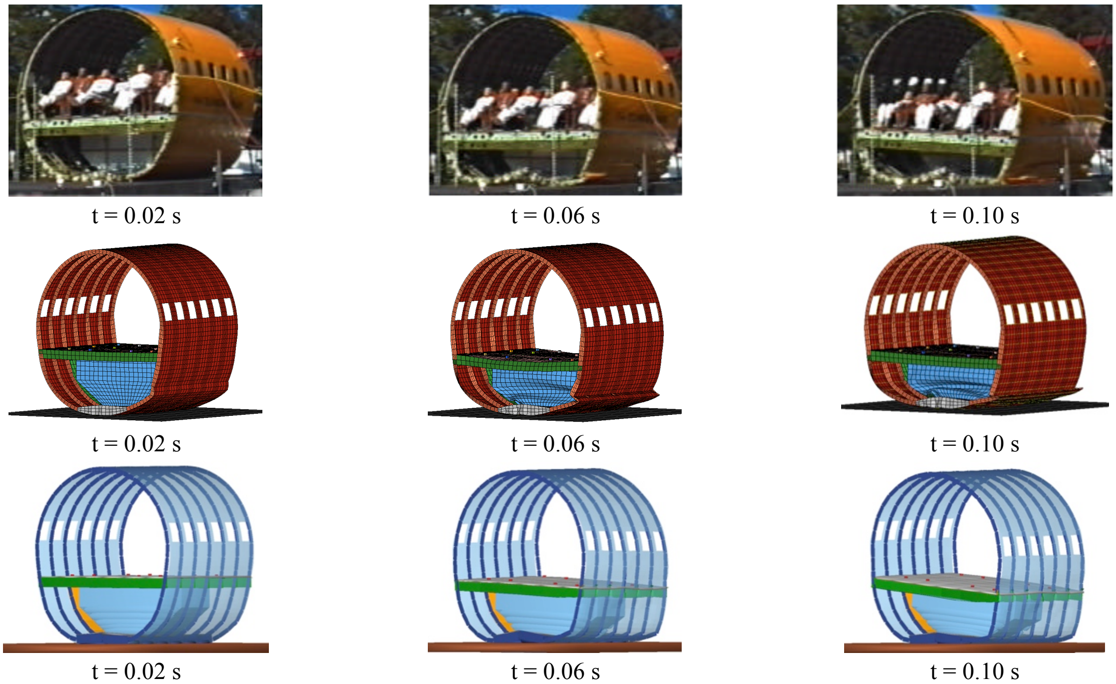
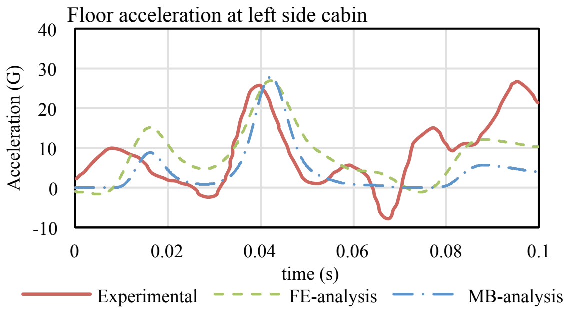
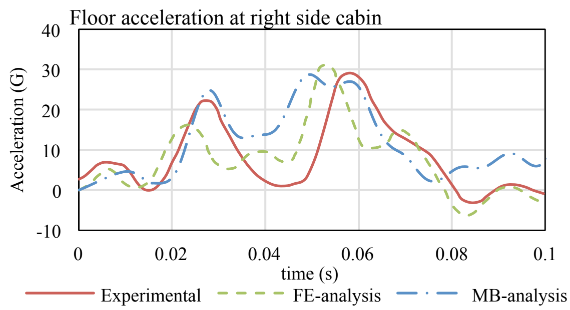


Figure 3: Deformation time sequence from the experimental test article (top) [1]; finite element model (middle) [2] and multibody model (bottom)

Figures 4 (a) and (b) represent the average cabin floor acceleration for the left- and right-side cabin recorded from the test article, FE model and multibody model. It is shown that the multibody model accurately predicted the accelerations of the cabin floor. A comparison of the left- and right-side cabin floor acceleration show that the presence of a stiff cargo door that is located on the right-side of the fuselage causes higher acceleration to be transmitted to the right-side cabin floor.



(a)



(b)

Figure 4: Average cabin floor acceleration measured at seat track (a) left-side cabin; (b) right-side cabin

In this study, the impact and crashworthiness of the fuselage section was reconstructed using the multibody modeling approach. The results clearly showed that the multibody fuselage section modeled using plastic hinges accurately predicted the structural response of the fuselage. This study demonstrate that multibody system with plastic hinges could be a viable tool for for impact and crashworthiness analysis of structures.

References

[1] A. Abromowitz, T.G. Smith, and T. Vu, “Vertical Drop Test of a Narrow-Body Transport Fuselage Section with a Conformable Auxiliary Fuel Tank Onboard,” US. Department of Transportation, Federal Aviation Administration, DOT/FAA/AR-00/56, 2000.

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[3] A. Abramowitz, “Summary of the FAA’s overhead stowage bin crashworthiness program,” Department of Transportation, Federal Aviation Administration, DOT/FAA/AR-99/4, 2010.