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Effects of hinges and deployment angle on the energy absorption characteristics of a single cell in a deployable energy absorber

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ABSTRACT

Numerical simulation is carried out to investigate the crushing characteristics of a single cell in a fan-shaped deployable energy absorber (FDEA) under quasi-static axial loading. FDEA can effectively improve the crashworthiness behavior of aircrafts with the advantages of saving space and deploying actively. Hinges are added to the single cell to meet the need of fan-shaped deployment. The finite element model is established to study the effects of hinge's parameters, including material properties such as Young's modulus, yield strength and the tube thickness, on the single cell's energy absorption characteristics. The relationship between the deployment angle and the specific energy absorption (SEA) of the single cell is also studied. The numerical results indicate that the energy absorption increases rapidly as yield strength and the hinge's thickness increase, while it only has minor correlation with Young's modulus of the material. Three different modes of the cell appear during its axial crushing as the deployment angle increases. Besides, experiments were conducted to observe the crushing mode of the straight single cell, and the results are compared with the numerical simulation results. Finally, a theoretical model of a straight single cell with hinges is proposed to predict the mean crushing force, which is in good agreement with the numerical simulation.

1. Introduction

The overall crashworthiness design of commercial aircraft has become the focus of design engineers since it is commonly used as an efficient tool of transportation. In the past few decades, many researchers and engineers have been studying how to introduce effective and light-weight energy absorption system in both military and civil aircraft fuselages so as to improve their crashworthiness. The energy absorption device being currently studied can be generally classified into two categories. The first category called "passive energy absorption device" could absorb kinetic energy and offer attenuation of intense dynamic load during an impact event through crushing of the energy absorber such as crushable honeycombs materials and multi-cell structures [1–4]. The second category called "active (or semi-active) energy absorption device" includes vented airbags [5,6], non-vented airbags [7,8] and hybrid airbag systems [9], which could deploy immediately before impact to provide attenuation and dissipate impact energy through active venting system. In recent years, a deployable multi-cell energy absorber (DMEA) has attracted many attentions [10–13]. The reason is that the internal structures of aircraft and spacecraft are usually designed under strict weight demand and space constraints. Compared to previous passive energy absorption devices, the unique advantages of DMEA are laid on small installation space and large available stroke. Under the normal state, DMEA is folded and occupies little space. In case of emergency, when the aircraft crash cannot be avoided, the pilot will send out a command to deploy DMEA through actuators. Effective energy absorption stroke of DMEA can be designed much longer than that in passive energy absorption devices, thus providing enough asymptotic crushing stroke to dissipate impact energy when colliding with ground so as to improve the crashworthiness of aircrafts and protect the aircraft and occupants.

Among the deployable structures, the design idea of fan-shaped deployable structures has demonstrated advantages of convenience, easily operating, direction insensitivity and stable energy absorption process. First sponsored by NASA in the study of this new type of energy absorption device with respect to crash energy management for light aircraft, Kellas and Jackson [10] adopted an expandable honeycomb-like structure with flexible hinges at each junction of cell walls to make the structure easy to be fabricated and much convenient for fan-shaped or linear deployment. The energy absorber would be normally stowed under a frangible (or removable) aerodynamic

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cowling until a command is given to deploy it. The vertical drop test of fuselage section indicated that DMEA dissipated nearly all the kinetic energy during the impact event, which proved that DMEA was a superior energy absorber for light aircrafts. Littell et al. [11] conducted a full-scale crash test of a MD-500 helicopter with DMEA installed at the bottom. The resultant data showed that the loads on the dummy models were in low risk level under the injury criteria and the fuselage maintained its structural integrity, which successfully verified the feasibility of utilizing DMEA to attenuate loads under real impact conditions. Annett and Polanco [12] summarized the finite element models of full-scale crash test of an MD-500 helicopter for pre-test predictions and post-test validation. The pre-test simulation revealed that the fuselage suffered small damage but occupant loads were within the affordable injury limit. Comparison of the post-test simulation and real crash test results proved that the finite element simulation of the whole system was a valuable and effective prediction tool for impact event, and it could provide guidance for crashworthiness design of helicopters. Recently, Hu et al. [13] further carried out numerical simulation to study the crushing characteristics of fan-shaped DMEA with consideration of parameters such as deployment angle, hinge radius and wall thickness of middle cells. The different energy absorption features between multi-block and single-block were also discussed.

However, the previous studies of fan-shaped DMEA were mainly focused on the overall energy absorption characteristics, and there was no quantitative analysis about the effects of the hinge parameters, which include the material properties and the structural dimensions, and the deployment angle on the energy absorption of the structure. The present paper mainly investigates the energy absorption characteristics of a single cell in fan-shaped DMEA. Numerical model is established to analyze the influences of hinge's material properties such as Young's modulus, yield strength and hinge thickness on the single cell's energy absorption capability. The relationship between the deployment angle and the energy absorption capability of the single cell is also studied. In addition, a crushing test of a straight single cell with hinges was performed and the results are compared with the simulation results to verify the validity of the numerical simulation. Finally, a theoretical model of a straight single cell with hinges is proposed to predict the energy absorption behavior, and it is found that the theoretical predictions satisfactorily agree with the numerical simulation.

2. Numerical simulation

2.1. Geometric and finite element model

The fan-shaped DMEA is installed under belly of the aircraft and is deployed in case of crushing. Fig. 1 shows the configuration of DMEA when it is deployed by 30°, 60° and 90° . The deployment process of a single cell is shown in Fig. 2. When a single cell is fully deployed, its cross section is changed into a rectangle. This paper investigates the energy absorption behavior of a single cell with one end fixed to a rigid plate and the other free, as shown in Fig. 3. Numerical simulation for axial crushing of the single cell is done by utilizing the explicit dynamic analysis code LS-DYNA. The single cell utilizes a flexible hinge at each junction of its cell walls, and is constrained to translate vertically by the supporting rigid plate

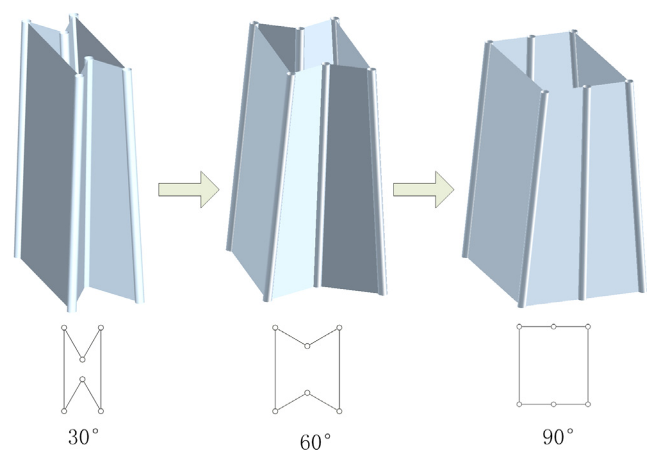

Fig. 2. Deployment of a single cell with the deployment angle of 30°, 60° and 90°.

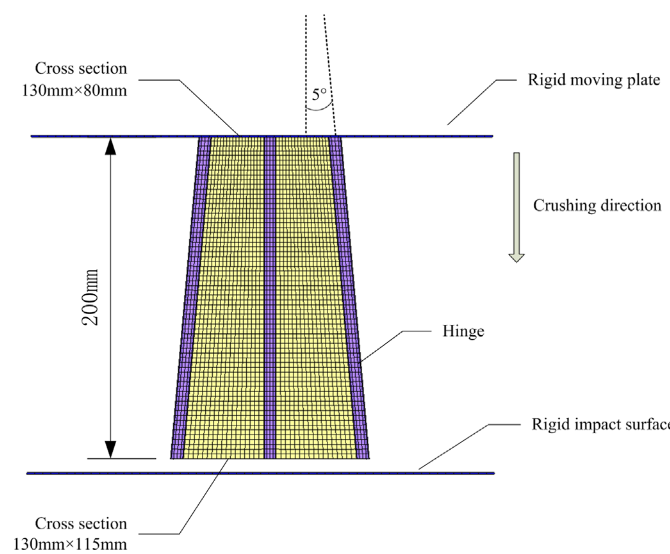

Fig. 3. Finite element model of a single cell under quasi-static crushing.

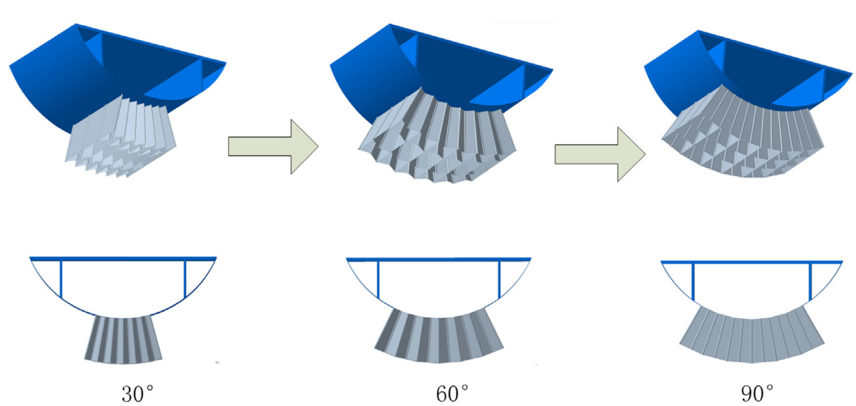

Fig. 1. Deployment of a fan-shaped DMEA with the deployment angle of 30°, 60° and 90°.