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Full-scale crash test and FEM simulation of a crashworthy helicopter seat

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Abstract: Crashworthy seat structure with considerable energy absorption capacity is a key component for aircraft to improve its crashworthiness and occupant survivability in emergencies. According to Federal Aviation Administration(FAA) regulations, seat performance must be certified by dynamic crash test which is quite expensive and time-consuming. For this reason, numerical simulation is a more efficient and economical approach to provide the possibility to assess seat performances and predict occupant responses. A numerical simulation of the crashworthy seat structure was presented and the results were also compared with the full-scale crash test data. In the numerical simulation, a full-scale three-dimensional finite element model of the seat/occupant structure was developed using a nonlinear and explicit dynamic finite element code LS-DYNA3D. Emphasis of the numerical simulation was on predicting the dynamic response of seat/occupant system, including the occupant motion which may lead to injuries, the occupant acceleration-time histories, and the energy absorbing behavior of the energy absorbers. The agreement between the simulation and the physical test suggestes that the developed numerical simulation can be a feasible substitute for the dynamic crash test.

Key words: full-scale crash test; seat/occupant system; finite element model; energy absorption; crashworthiness

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Introduction

Structure crashworthiness has been proposed and becomes one of the most important requirements in the design of aerospace application due to a fast growing concern for higher occupant survivability during potential accidents in recent years. Besides the energy absorption of landing gears and subfloor structures[1-5], the seat is also designed with energy absorbers as a critical component to limit impact forces and protect occupants from injuries in emergences[6-7]. At present, seat crash test is the exclusively reliable validation method accepted by Federal Aviation Administration (FAA)[8-10], for a new type of crashworthy seat to evaluate the pass/fail criteria of the human tolerance. One of the impact conditions for seat certification is illustrated in Fig. 1 by sledding test or drop tower test which produces a triangular-shaped acceleration of the seat/occupant system. Obviously, the repeated tests at an early stage of the design not only take a large amount of time, but also greatly increases the design cost. However, with the development of numerical methods, many crashworthiness problems can be well

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handled efficiently. Numerical methods are also hoped to be used to study dynamic seat tests, to predict occupant responses and gradually replace the dynamic tests to reduce time and money compensation. Many researches have been carried out on seat crashworthiness with numerical methods. Laananen et al.[11-12] developed two useful numerical programs named (SOM/LA) and (SOM/TA) for seat performance evaluation. Hu et al.[13] carried out a full-scale vertical drop test and multi-rigid body dynamic simulation by MADYMO code to evaluate a new crashworthy helicopter seat/occupant system. In addition, comparing with (MADYMO), the finite element method can allow more detailed and accurate representation of physical structures. In this context, an explicit transient dynamic finite element codes LS-DYNA3D and commercial Hybrid Ⅲ dummy will be employed to investigate a new type crashworthy seat. Results from the numerical simulation are also compared with the full-scale crash test to validate the analytical model.

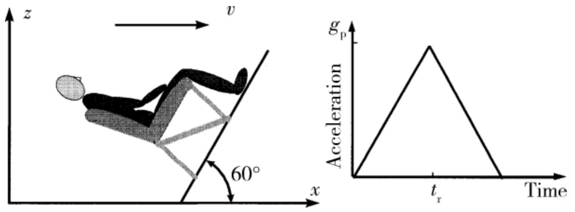


Fig. 1 Dynamic test requirement

1 Method of finite element simulation

The helicopter seat structure is mainly made up of three parts: a framework, a movable seat part and energy absorbers, as shown in Fig. 2. The seat is made of aluminum alloy 2 124. The framework is clamped at the carriage floor to support movable weights of the seat/occupant system. The movable seat part consists of the seat pan, seat back and seat cushion. The seat cushion, used as a buffer, is made of the polyurethane foam. A pair of inversion tubes is used as energy absorbers for the seat.

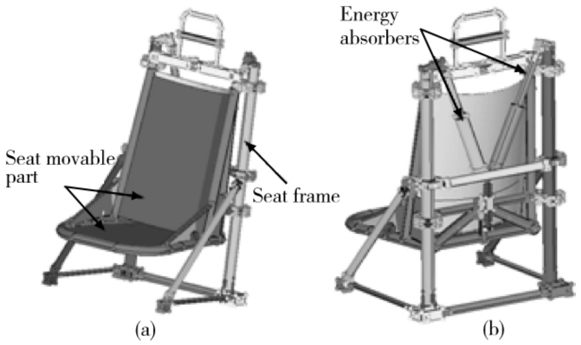


Fig. 2 Helicopter seat structure

According to FAA regulation, a 50th FAA Hybrid Ⅲ anthropomorphic test dummy (ATD), as shown in Fig. 3, equipped with a pelvis load cell and accelerometers at the head and chest locations, is selected to simulate a 95th Chinese male as they are similar with geometry sizes. Comparing with Hybrid Ⅲ, which is widely used in the automotive arena, the main modification of FAA Hybrid Ⅲ ATD is substituting a straight lumbar column for the curved one, so the FAA ATD can be used for better predicting compressive lumbar load and allowed in the development and certification of aircraft seats.

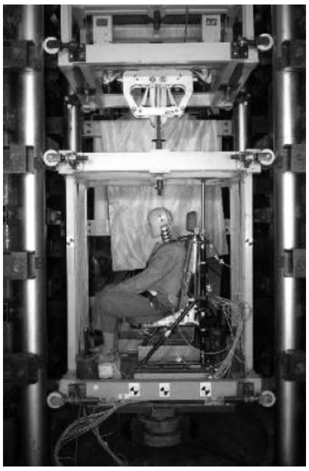


Fig. 3 Assembly of the test facility[13]

The finite element model (FEM) of the seat/occupant system, preprocessed by Hypermesh, is shown in Fig. 4, according to the physical test facility in Fig. 3 (details in Ref. [13]). The seat model consists of frames, seat pan, seatback, cushions, restraint systems, energy absorbers(reversion tubes) and rigid floor, as well as a 50th finite element Hybrid Ⅲ commercial dummy, as a component, is also contained. The support frames are simulated by beam elements, except the two rails are modeled with shell elements which are convenient for defining the sliding interaction between the beams and four sliders. The seat pan and seatback are simulated by quadrilateral shell elements and cushions are modeled using hexahedral solid elements coincident to nodes of the formers. The inversion tubes as energy absorbers are modeled with nonlinear spring elements. A rigid flat plate is used to model the carriage floor and connected with the bottom of the seat frame using the keyword * constrained extra nodes[14]. In the simulation, the hands were laid on the lap of the dummy to be in conformity with real test configuration.

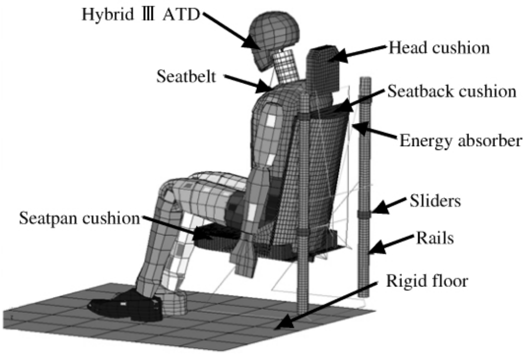


Fig. 4　Finite element model (FEM) model of seat/occupant system

An automatic surface to surface contact type[14] is defined between the feet and the rigid floor. Another two same contacts are also defined, one between the lower torso and the seat pan cushion, and the other between the upper torso and the seatback cushion. In addition, an automatic node to surface[14] contact type is defined to model the interaction between the seatbelt and the occupant. The coefficients of friction are assigned 0.4 for all contact definitions.

The cushion foam is modeled with material type 57, which is mainly used for seat cushions to represent highly compressible low density foam and allows a user-specified hysteresis response curve for unloading. It should be noted that the numerical problem (negative volume) may occur and cause an error termination due to the signification mismatch between the stiffness of the seat foam material and hard dummy material and large forces exerted on the foam by the dummy segments at the time of the crash. The foam element may become so distorted that the volume of the element is calculated as negative. Some approaches are necessary to overcome negative volume problems.

The spring elements are model with material type S06, which provides a general nonlinear spring with arbitrary loading and unloading definitions with optionally hardening and softening definitions. In addition, the dynamic strain sensitivity is accounted for in * section discrete option.

The restraint system is simulated by one dimensional seatbelt elements with the material type B01, whose stretch characteristic including load and unload curves are defined according to the experimental tests. Four retractors are used to tighten the seatbelt as is shown in Fig. 5.

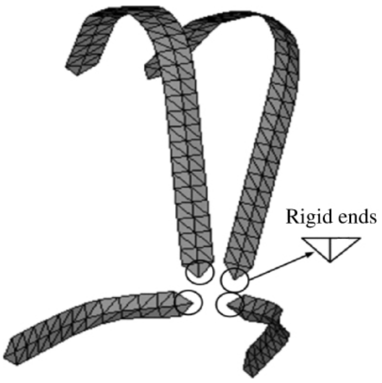


Fig. 5　FEM belt model

Meanwhile, parameters of great importance to the analysis such as the hourglass suppression mode, bulk viscosity definition, accuracy, and scale factor on stable time step are also carefully considered.

All nodes in the whole model are assigned an initial velocity of 12.8 mm/ms, as well as they are also assigned a constant acceleration gravity of 9.8×10^{-3} mm/ms^2 to account for the free fall gravity force. The floor is constrained in all directions except in Z direction and a prescribed acceleration field taken from the experimental data (refer. Fig. 6) is applied to it in negative Z direction for simulating the real effect of the vertical drop. To eliminate the numerical oscillation in LS-DYNA output, a SAE60 filter has been used for all the acceleration and force responses.

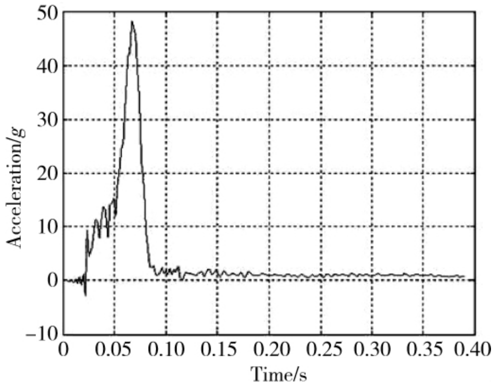


Fig. 6 Floor acceleration time history from crash test

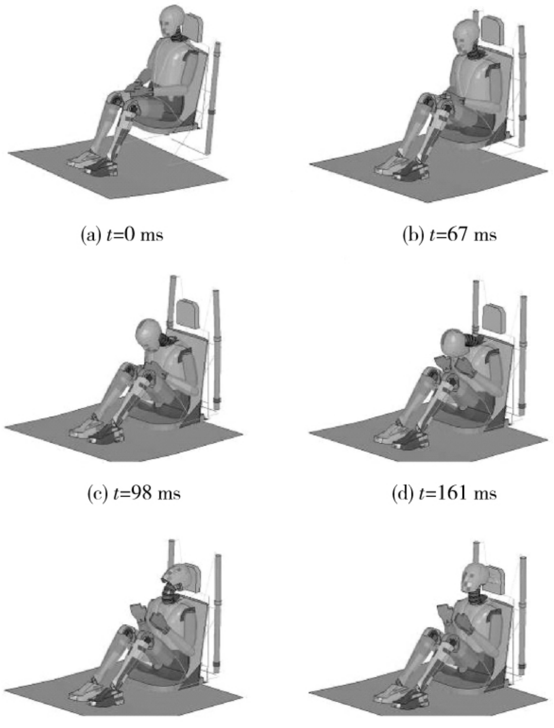

(a) t=0 ms
(b) t=67 ms
(c) t=98 ms
(d) t=161 ms
(e) t=223 ms
(f) t=350 ms

Fig. 7 Typical photograph of the crash process

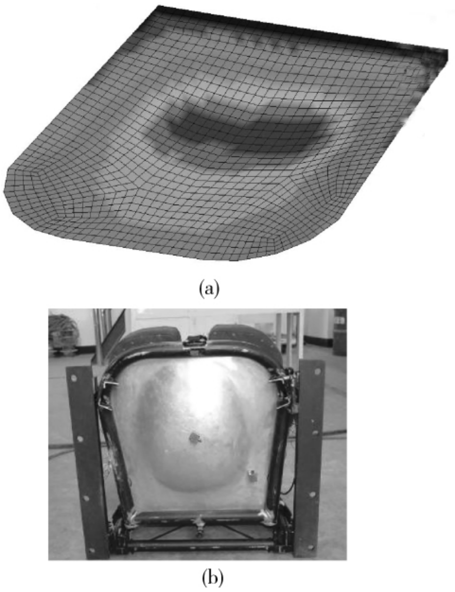

(a)
(b)

Fig. 8 Seat pan deformation

2 Results

2.1 Whole seat/occupant system response

A sequence of figures taken from numerical results is depicted in Fig. 7. Agreement of dummy positions is qualitatively satisfactory, compared with the high-speed photographs for the crash seat/occupant system (details in Ref. [13]). In addition, the final deformation of seat pan structure and the final position of the seat are also indicated in Fig. 7 and Fig. 8, respectively. It can be observed that an agreement is qualitatively satisfactory, comparing with the experiment data.

2.2 Occupant and energy absorber response evaluation

To verify the numerical model, the time histories of occupant response, absorber axial force are, respectively, depicted in Fig. 10(a)～(d). Comparing the numerical predictions and experimental results, the agreement is qualitatively acceptable except a lower biofidelity is observed in the head response as shown in Fig. 9(c), where there is a high peak in head acceleration after 240 ms due to head impact against the backrest, while no collision is observed in physical test though the dummy head is extremely close to the headrest. This is probably because the non-linearity and viscosity of the Hybrid Ⅲ head/neck is not well reproduced by the numerical model. At present, the biofidelity for head/neck is still in further research. For the absorb-

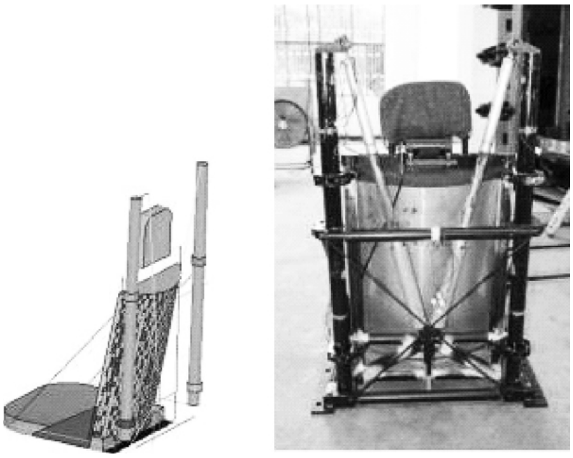
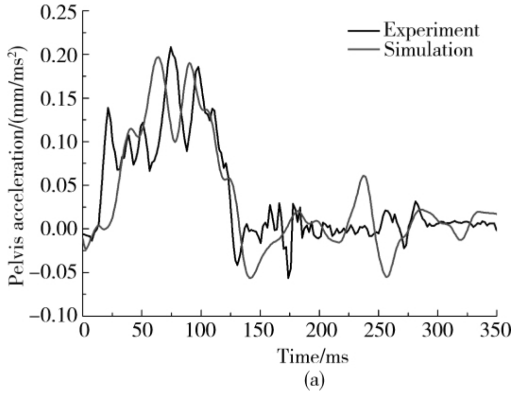
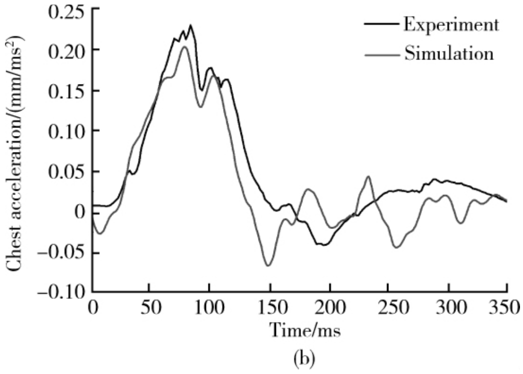


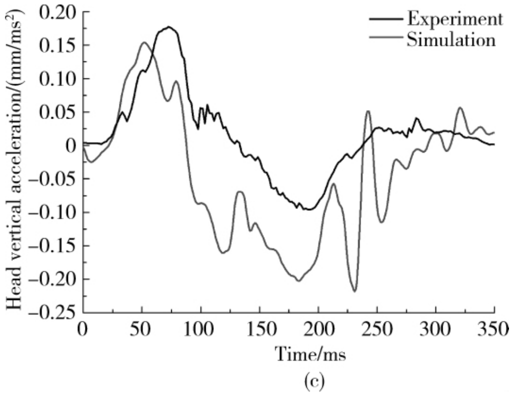
Fig. 9　Final position of seat



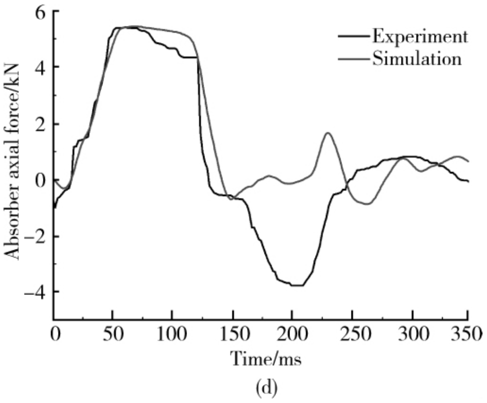
(a)



(b)



(c)



(d)

Fig. 10　Time histories of occupant response acceleration and absorber axial force

er, a rebound of the seat pan in the real test generated the large acceleration toward the opposite direction of the absorber between $t = 150$ ms and $t = 250$ ms. However, the rebound was less intense in the simulation, causing a visible deviation during this interval of the two curves.

3　Conclusions

The seat crash test was numerically analyzed using the finite element code LS-DYNA3D. The complete numerical model contained a seat structure, a commercial 50th Hybrid Ⅲ dummy and a rigid floor. The obtained response curves presented a good correlation to the experimental data and the dummy motion of the numerical model corresponded closely to the observed position from the high-speed photographs of the test. The level of agreement obtained between test and analysis built confidence in the future use of nonlinear, explicit transient dynamic finite element codes as a predictive tool that was economically feasible to evaluate the seat crashworthiness and occupant safety.

Further numerical and experimental activities may be carried out to investigate the possible optimization of the inversion tubes, seat pan and other structures for a better crashworthiness performance based on this reliable numerical model, namely to study the effects of related parameters of these structures to obtain an anticipated occupant response acceleration and absorber axial force.

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