Numerical Investigations on Pilot-Glider-Environment System during the Impact against a Deformable Barrier

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Abstract

A simulation model of PW-5 glider crash against a deformable barrier at a velocity of v=54.7 km/h is presented in this paper along with calculated loads transferred to both glider's composite cockpit structure and pilot's body. The attention was focused on the issue of pilot's safety; i.e., on one of the problems considered within the framework of aircraft accident analysis. The research aimed at the development of a numerical model of the pilot-glider-surroundings system, which could allow for the analysis of aircraft accidents in view of pilot's safety. In order to ensure experimental verification to allow for quality assessment of the numerical model, a crash test was conducted at a special test track under conditions consistent with the settings of the subsequent simulation.

Keywords: biomechanics, crashworthiness, finite element methods, impact, numerical analysis

1. Introduction

Nowadays the lack of experimental data, necessary for designing modern and more safe gliders, has became a very important problem. According to the rules for gliders covered by the JAR-22 (CS22) [1] the glider design should prove the safety of pilot during correct landing procedure (with the defined level of vertical speed) and/or during a „hard landing", when levels of acceleration and forces affecting the pilot do not exceed "acceptable" values. However, a small number of accidents involving casualties as well as relatively weak interest in the crashworthiness issues caused that crash tests of gliders are not obligatory and, as a consequence, no procedures associated with crash accidents were established.

The presented problems allows one to formulate the following research aims:

- collecting data on the loads acting upon the human body (accelerations and forces) and upon a glider cockpit structure during the "hard landing" process, including such dynamical issues as load history, strain and damage propagation;
- development of a physical model representing phenomena that can be observed in the pilot-glider system when the glider cockpit (with the pilot inside it) hits against a ground barrier, development and testing of the mathematical model by means of numerical simulations;

2. Method

The simulation model was developed in the MADYMO software environment. MADYMO is used for analyzing occupant safety and optimizing component and vehicle design worldwide. Main field of application is road safety [7, 8]. However it become more and more often used also in aircraft engineering. Extensive database with numerical models of many crash-dummies and human body of different size creates a strong part of the software.

2.1. Glider's model

The physical model of the glider is based on the material model described in [2]. Glider cockpit protecting pilot's body against the internal and external elements, is the basic component of glider's structure in terms of pilot's safety. Therefore, the pilot cockpit was rendered strictly according to the technical documentation as the most important component of the physical model. Only the gauges, the radio and the canopy were omitted, leaving just bare shell of the control panel, which the pilot may potentially hit.

The tail section of the glider was omitted and replaced by a carriage of a mass similar to that of the cut-off section. The carriage was moving the cabin during the experimental test. Wings were modelled using a steel wing spar with weights suspended thereto to simulate the mass of the wings. The model of the glider's front part with a dummy pilot is shown on Fig. 1.

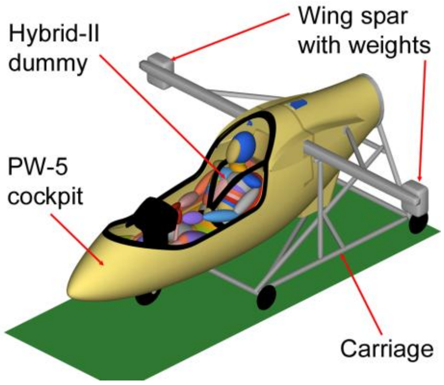

Figure 1: Glider model – general view.

The numerical model of the glider cockpit was created using FEM. The model was composed of a total of 85785 nodes that form 87545 four-node shell elements. The entire set was divided into 46 "components", mainly for functional reasons, such as interconnections between larger components of the structure, contact interactions and variable properties of the elements, etc..

A model of isotropic material with a module describing destruction by brittle cracking was used for the modelling of material properties of the glider's cockpit. The justification behind this approach is that the model itself is a large and very complex composite structure, which requires time consuming computations and very powerful computers. Another serious problems are associated with an in-depth investigation of nonisotropic properties of composite materials and their modelling, as well as with the achievement of stability in the case of more complex material models [3, 4, 5, 6].

The method of multi-body systems was used to model the glider's carriage, including wheels, front undercarriage wheel, control stick, wing spar with weights and fastening bolts, as well as with safety belt fastener anchoring points. The application of the multi-body simulation method is in that case reasonable, since the aforementioned structures are rigid comparing to other elements of the glider’s structure or their precise modelling using FEM is not required for good performance of the entire model. A gain in computation time is a substantial and measurable benefit from that approach.

The replacement of the rear body section with a carriage and substitution of wings did not affect the glider's centre of gravity but resulted in a significant change in mass layout and geometry, which considerably affected the moment of inertia. As a consequence, the model of pilot-glider system is suitable for frontal and “symmetric” crash tests only (with movement along the body's plane of symmetry), wherein any lateral rotation is absent.

2.2. Pilot’s model

Dummy version of Hybrid II used in this study was a multibody numerical model, which represents a 50-centile man [7]. It is composed of more than 30 segments, of which external geometry (an important factor for proper modelling of contacts) is represented by over 50 (hyper)ellipsoids. Data on mass/inertia properties of the elements come from the tests and are described in the documentation. Data necessary for the determination of the ellipsoid's degree of exponent have been determined on the basis of technical drawings stored at the TNO research centre [7].

An important advantage of the numerical dummy model is that the model is fitted with built-in sensors to record typical loads applied to the human body during the crash and has pre-defined outputs of typical biomechanical risk measures, as used for evaluation of injury risk in crash biomechanics.

2.3. Ground barrier’s model

The rigid steel frame of the cage was modelled using multi-body method. The congested soil was modelled by 4502 tetrahedral viscoelastic finite elements [8].

3. Simulation results

In order to validate the numerical model, the animated simulation has been compared to the course of experimental test, recorded using a high-speed camera. A “visual comparison” of the behaviour of the “real” and “virtual” pilot-glider system revealed strong similarities [2].

Readings of the accelerations recorded during the test [8] in the rear section of the cockpit are similar to those obtained from simulation. However, time histories clearly indicates, that the simulation model generates higher peak accelerations (about 40%) and reveals some vibrations. Acceleration recorded at head’s centre of gravity [2] is similar to that obtained from simulation. Both plots are of the similar time-course and their maximal values are very close (experiment: 34.63g, simulation: 35.2g, difference: 1.65%). It means that this important — as far as the pilot safety is concerned — parameter has been precisely estimated.

Experimental [2] and simulated time-courses of the torso differ much more. Simulated plot presents some vibrations, its maximal value (42.2g) is 39% higher than that recorded during experiment (30.83g); there is also a time lag of about 0.025s between them. However taking into account pilot safety, the simulation results could be considered as satisfactory.

The same applies to the force in the lumbar spine of the pilot (but difference is about 90%). The simulated time-course is of vibrational character, while experimental plot is smooth and of much lower maximal value. Such high discrepancy could be connected with generated numerically vibrations of glider’s structure acting on pilot’s body.

The force time histories of the force developed in the shoulder safety belt are similar, the maximal values differ only 9.8%, the time lag is 0.03s.

4. Discussion and conclusions

A simplified model of the glider's composite shell, modelled as isotropic material was used in the simulation test. Although simplified, this approach to modelling seems to be justified in the case of a large structure, such as glider, which is subjected to huge impact loads.

The observation of glider's structure behaviour, involving a comparison of computer simulation with experiment, indicates that the numerical model is fairly consistent with the material experimental model on the level of process kinematics. This is further substantiated by acceleration measurements of the cockpit.

The results of computation made with MADYMO software allow the expectation that in the nearest future simulating of the glider crash in realistic way will come true. Using of a numerical model of crash phenomenon allows the saving of experimental research funds as well as the time necessary for the investigations.

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