THE SAILPLANE COCKPIT STRUCTURE DURING EMERGENCY LANDING CONDITION

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Abstract

The article describes the compliance evaluation of the glider cockpit crashworthiness numerical simulations with the static test. The design of the test and the numerical simulation model were prepared in accordance with JAR 22.561(b)(2) requirements. The next part demonstrates suggestion of crashworthiness methodology evaluation of glider cockpit with help pilot injuries criteria. The whole simulation was developed using the nonlinear explicit transient dynamic computer code MSC. Dytran. The test and the simulations were carried out by the Institute of Aerospace Engineering, Brno University of Technology.

1. Introduction

Increasing state of the art in aerospace engineering causes enhancement of the requirements for safety and reliability. The trend did not avoid glider cockpit structures. Complex geometry of a glider cockpit and the influence of deformation complicate analytical calculation or computation simplification to the extent that accuracy of calculation would be very low. That is why the most effective method of the prediction of the resistance of the cabin is using finite element methods (FEM) analysis. The FEM offer inclusion of maximum parameters which determine the behavior of the structure and thus we can obtain high accuracy of the prediction.

Dynamic impact testing is widely used in automobile industry. The tests are also included to aeronautics regulation requirements JAR/FAR 23 but their scope and requirements during certification process are evidently lower. The current trend is to increase the safety and reliability to prevent accidents instead of investing money into expensive crash analysis. Interest of glider pilots and producers in impact testing and passive safety increased in the past. Nevertheless, implementing enhanced impact testing into the regulation requirements is not expected because of high cost of impact testing. The alternative is utilization of FEM analysis.

The aim of the work is to discuss the crashworthiness evaluation methodology with help injury criteria of the pilot and to demonstrate an application of the FEM analysis.

2. Glider description

The modeled sailplane fuselage is a single seat upper–wing monoplane made of glass fiber composites material. The supporting structure of the sailplane cockpit is made-up from wooden bulkheads and a composite sandwich skin (see figure 1).

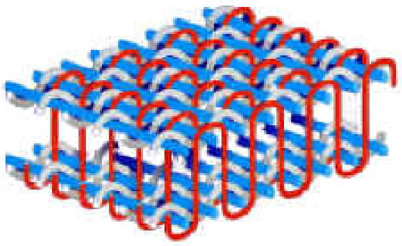

Fig. 1: 3-D paraglass fabric

The core sandwich composite skin is made from nontypical 3-D paraglass fabric. The close cross section frame reinforces the edge of the cockpit. The frame is filled with foam. The wing hinges are connected and reinforced by aluminum pipes. Take off weight is 300 kg.

3. Descriptions of finite element simulations

The geometrical model of the sailplane was created in Unigraphics NX3 and subsequently exported to preprocessor MSC Patran. Global element size is 0.02 m.

The model was loaded by beam system. The system was modeled in order to simulate a real beam system used in the experiment. The beam system applies a load to the glider structure through wing hinges and pilot seat. The BEAM and ROD elements are used for the load system simulation. The ROD elements simulate vertical ropes and the BEAM elements simulate transverse beams (see figure 2.) Material model of the beam system is linear DMATEP. Loading of the glider cockpit complies with JAR 22.561(b)(2) [3] requirements.

The impact surface (see figure 2.) is modeled with help RIGID. The surface is absolutely rigid and has zero thickness. The impact surface constant velocity 0.3535 m/s realized the loading the glider cockpit. End of the loading system was fixed. Constraint was assigned in all wing hinges, thus the glider cockpit was only able to move in the direction of the impact surface’s normal vector.

Material model MAT8 and MAT8A was used to simulate all composite materials. The failure criteria of the composites were prescribed same for all the composites. The failure criterion of maximum stress (STRSS) was used for fibers and matrix at compression and tension and modified Tsai-Wu criterion (MODTSAI) was used for shear matrix failure description. The multi-layered face sheets of the skin were modeled as laminated shell elements (PCOMP). Laminate modeler which is integrated in MSC Patran was used.

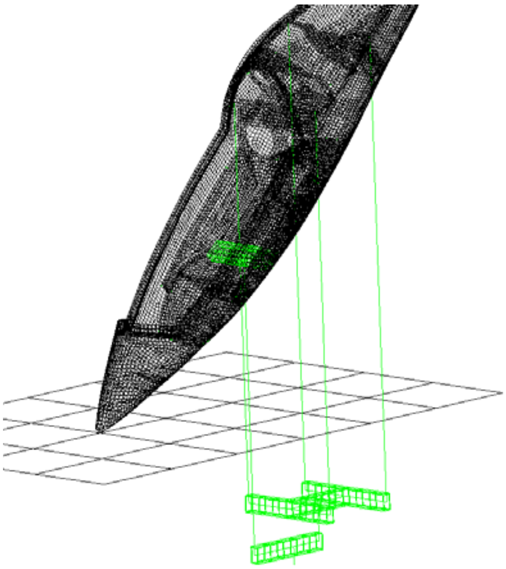

Fig. 2: Full pre-test FEM model

Fig. 3: The static test

The numerical model was running with a help of the MSC.Dytran simulation software package, on cluster computer under operation system Linux, processor OG 23x Intel Xeon 2.6 GHz.

From the results we can see that deformation of the cockpit started at the cockpit nose at the contact point with the impact surface. The cockpit started to crush and collapse. The first failure appeared at 4374 N at the displacement 20mm (see figure 4.). Maximum force was 11650 N at the displacement 148 mm at the time of simulation 0,419 s. Subsequently the force started to rapidly decrease. Simulation was terminated due to an unstable calculation.

We consider that unstable calculation and premature termination causes considerable differences in material properties between laminate plies from 3-D paraglass fabric and filament fabric which is composed into one multilayer composite material. The 3-D paraglass has considerably lower stiffness and ultimate strength however thickness (3mm) is 30 times higher than filament fabric ply. Mechanical behavior of the 3-D paraglass is very similar to behavior of foam therefore application using 2-D shell elements brings that instability.

The problems with instability of the calculation and its premature termination were also at the dynamic case of loading. Therefore we could not obtain proper results necessary for evaluation of pilot injury criteria. We canceled dynamic simulation and dynamic crash test of that glider cockpit. For pilot injury criterion assessment methodology demonstration fictive glider cockpit created within the frame of Aerospace Research Centre program “Effect of Composites Glider Cockpit Geometry on Crashworthiness” [8] was used. The differences of the cabins are at the geometrical dimensions, reinforcement and seats. Composite materials from filament fabric used for both gliders have same materials and material models. The 3-D paraglass was not used and static loading calculation reached the proper end of simulation. The static loading performance of the new glider cockpit is comparable with static test and FEM simulation of the previous glider. The new glider cabin with an anthropomorphic dummy is on the figure 5.

The 50th percentile male Hybrid III anthropomorphic dummy was modeled using the ATB code. ATB is an independent computer code developed by the Air Force Wright Laboratory as a numerical dummy model, and it is integrated within the MSC.Dytran software. The ATB dummy model consists of hinged segments with inertias, joint properties, and contact surfaces defined to represent a Hybrid III dummy. The 1-D elements with PBELT properties are used for modeling safety belts. During the simulation cockpit impacts on the ground under the angle 45° with velocity 55 km/h.

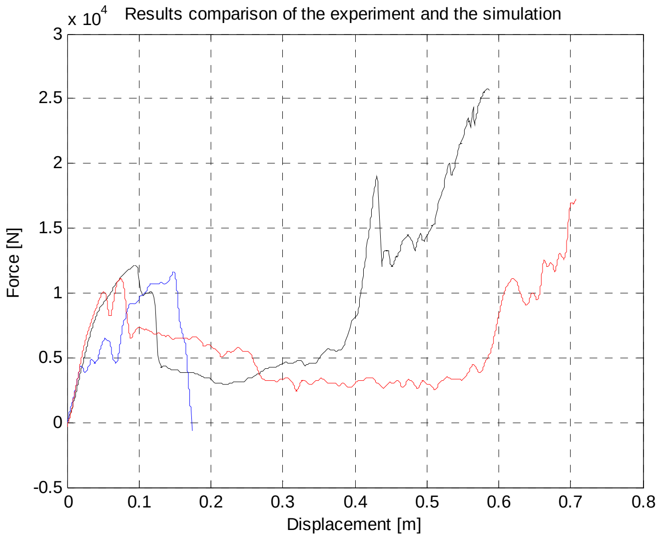

Fig. 4: Reaction force - displacement for all used sailplane cockpits at the static loading, the black curve is test, the blue one is original FEM model, the red one is the FEM model used in dynamic crash.

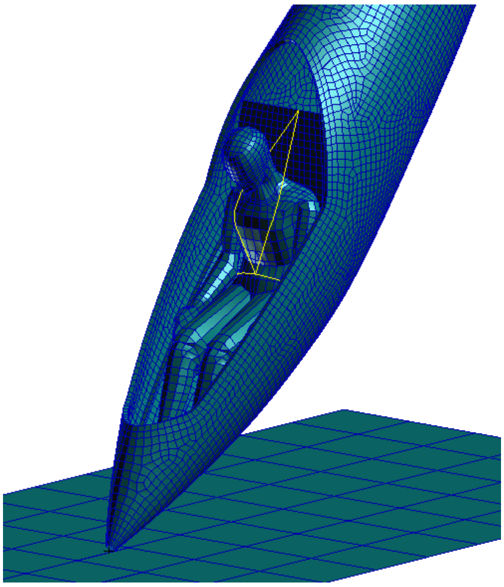

Fig. 5: The dynamic FEM model with ATB test dummy

4. Kvazi -static test and correlation with FEM simulation

The sailplane was fixed under the angle 45° to the steel-frame sled moving on a vertical stand. The steel-frame sled with sailplane was equilibrated by sand bags with the help of pulley mechanism. The vertical loading force was realized by two hydraulic cylinders with beam mechanism and rope system (see figure 3). The measured data and records were: the force acting on the forward portion of the fuselage, displacement of the steel-frame sled and records taken from three video cameras. Relationships force/displacement between static test and FEM simulation of both cockpits are at the figure 4.

5. Dynamic impact test evaluation methodology

Suggested methodology is based on evaluation of pilot injuries after the crash. The injury criteria are adopted from aeronautics and automotive requirements. From many criteria we selected few that cause serious injuries after glider accident (selection was made using expert assessment). Head impact criteria (HIC), neck injury criteria (NIC), spinal injury criteria and criterion of maximum safety belt load were selected.

Formulation of the HIC is same for automotive and aeronautic regulation requirements. The HIC requires g's measurement of the time history results acceleration at the centre of mass and time duration (1). Differences between automotive and aeronautic requirements are in time duration interval and HIC limit value [4][6]. Criterion HIC is applicable in case of a pilot's head contact with cockpit interior or with other part of his own body.

$$HIC = \left[\frac{1}{(t_2 - t_1)} \int_1^2 a(t)dt \right]^{2,5} (t_2 - t_1) \leq 1000 \quad (1)$$

Neck injury criterion is used only in automotive regulation requirements. We added this criterion on a base of some fatal glider accident where pilot died due to serious neck injury. The NIC calculation is defined in ref. [1]. Supposed frontal impact to the hard surface is the most serious for head - spinal column connection in Occipital condyle. From all present NIC in [1] was selected NIC defined by Federal Motor Vehicle Safety Standards (FMVSS). It is divided to two points:

- Normalized Neck Injury Criterion (Nij)
- The criterion of the limit value monitoring (peak tension and peak compression)

The criteria for neck injuries are determined using the axial compression force, the axial tensile force, and the shearing forces at the transition from head to neck, expressed in kN, and the duration of these forces in ms. The neck bending moment criterion is determined by the bending moment, expressed in Nm, around a lateral axis at the transition from the head to the neck.

The Nij is calculated according to the equation:

$$Nij = \frac{Fz}{Fzc} + \frac{Mocy}{Myc} \leq 1 \quad (2)$$

Fz	Force at the transition from head to neck
Fzc	Critical force
Mocy	Total bending moment
Myc	Critical moment

Dummy size		50 % Male
Peak limits	Tension (N)	4170
	Compres. (N)	4000
Nij Intercepts	Tension (N)	6806
	Compres. (N)	6160
	Flexion (Nm)	310
	Extension (Nm)	135

Table 1: Neck force and moments limits

Linear tension/compression and moment combination creates envelope of critical neck loading (see figure 6). The table 1 describes critical values of the neck injury envelope for 50th percentile male Hybrid III.

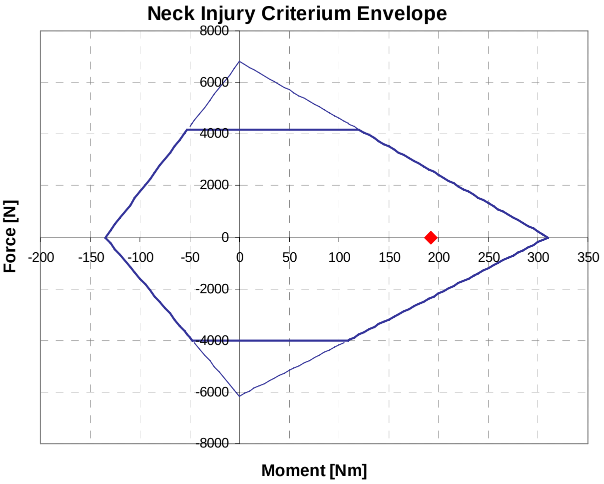

Fig. 6: The final neck injury criterion envelope. The red point is maximum load on pilot’s neck in FsEM simulation.

The spinal column injury criterion is widely applied at rotor aircraft safety standards and for military ejection seats. For general aviation aircrafts FAR/JAR 23 regulations use this criterion. The criterion is applied to lumbar column. Maximum compressive load must not be higher than 6.7kN. The compression load acts at the head – pelvic direction. Recent studies published relationship between critical spinal load and age of pilot [5] (see table 2). For suggested methodology we used spinal criterion from JAR/FAR 23 requirements.

Age	Loads (kN)
20-39	7,14
40-59	6,67
60-79	3,01

Table 2: Maximum column spinal load depends on age of pilot.

Maximum safety belts load is used as a quantification of thorax loads. Automotive and aeronautic regulations have different methodology. The automotive regulation requirements describe thorax injuries seriousness with help thorax deflection and acceleration. The aeronautic regulations choose different way. The regulation FAR/JAR 23 converted thorax criterion injuries into critical safety belts loads. The ATB model segments are defined as a rigid ellipsoids and deflection of the dummy thorax can not be available therefore it is more useful to use the thorax injury criterion from FAR/JAR 23 regulations. The maximum load for diagonal safety belts is defined on 6.7 kN and for dual safety belts on 8.9 kN. The glider used for presented simulation is equipped with dual safety belts.

6. Dynamic FEM analysis results

The simulation finished at the time 0,149s. The figure 7 shows the dependency of the dummy’s head center of mass acceleration on time. The head does not hit the cockpit interior or other part of the dummy therefore the value of acceleration and head impact criterion HIC is low. HIC=78.04

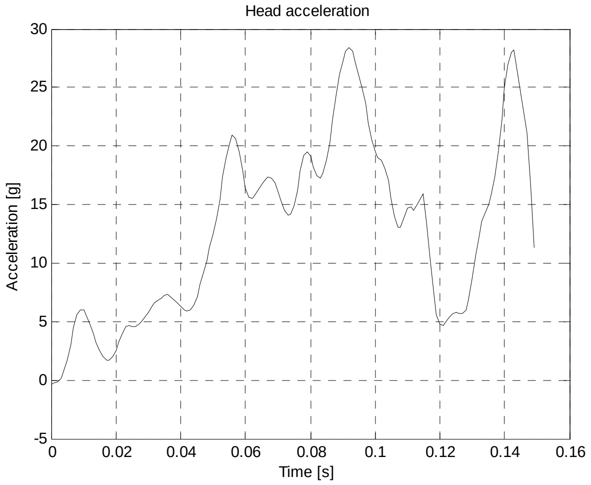

Fig. 7: Head acceleration at the centre of gravity

The figure 8 shows evaluation of the neck injuries criterion. The neck was exposed to low force but considerably higher bending moments during the crash. The maximum bending moment is 192 Nm. The maximum value Nij positioned to Neck Injury Criterion Envelop is highlighted as a red point in the figure 6.

The figure 9 shows results dependability of force exposed to the lumbar spine on time. The FEM result goes over the representative injuries criteria. We have to point out that the seat used in dynamic FEM model was primarily intended as a supporting feature for static loading defined in JAR 22.561(b)(2). Dynamic loading was not considered.

Figure 10 shows dependability of maximum tension force in safety belts on time. The critical force 6.7 N was not reached.

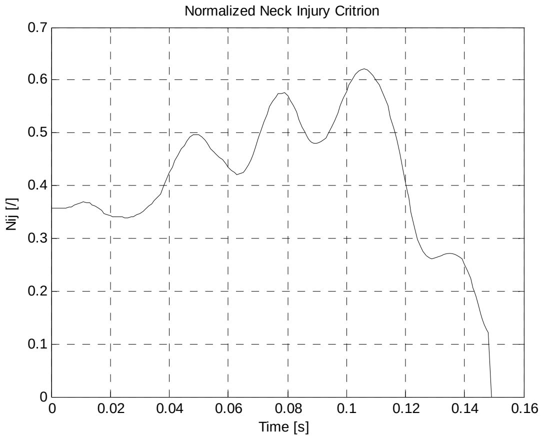

Fig. 8: Normalized Neck injury Criterion

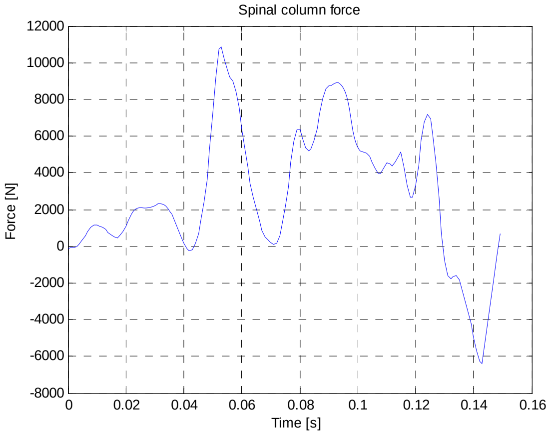

Fig. 9: Dummy pelvic vertical load

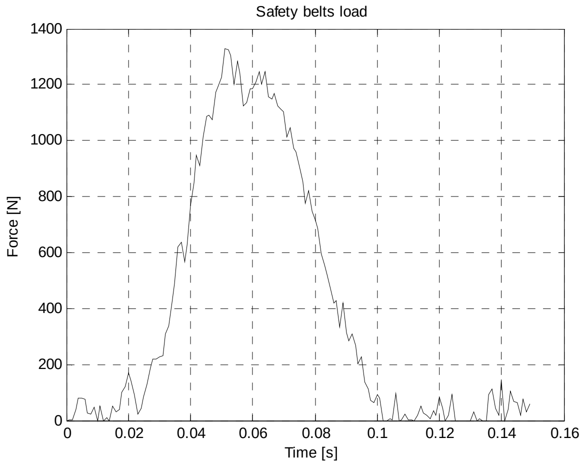

Fig. 10: Safety belt loads

7. Concluding Remarks

The static FEM simulation with experimental test and dynamic FEM simulation and evaluation with help injuries criteria has been presented. The sample structure was all-composite glider. The FEM analysis was modeled using commercial nonlinear explicit transient dynamic code MSC.Dytran. The results showed that:

1. The FEM simulation correlates with static test sufficiently. Difference between the calculated and the measured maximum force is 4% and between maximum strain energies is 2%.
2. It is necessary to reconsider capabilities of the FEM analysis of all composite full-scale structures from multilayer materials with considerably different properties especially using of 3-D fabric.
3. Supposed methodology with help injuries criteria and FEM analysis is useful tool for impact dynamic theoretical analysis.
4. Future work should be verified with dynamic crash test of full scale glider structure.

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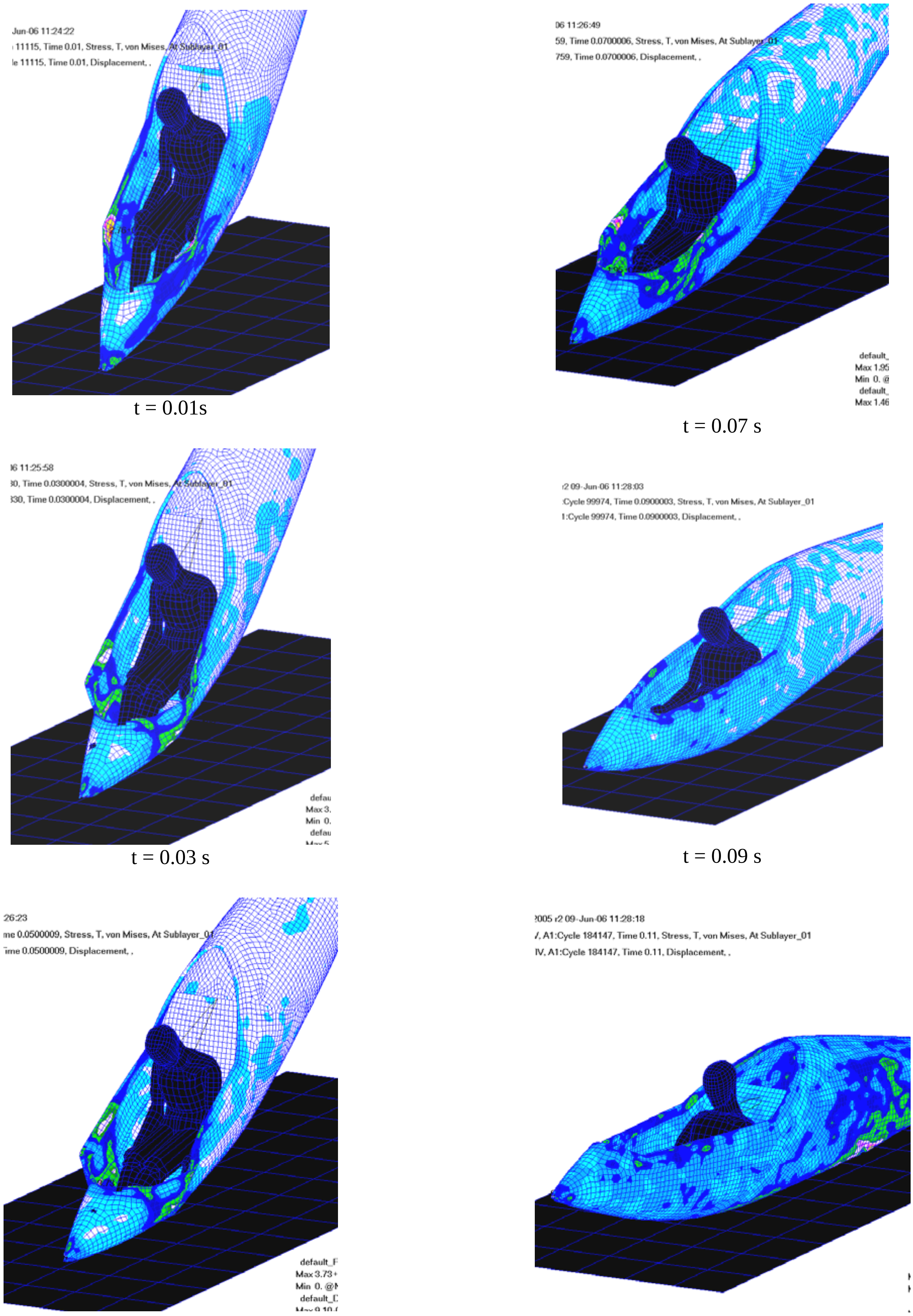

t = 0.01s

t = 0.07 s

t = 0.03 s

t = 0.09 s

t = 0.05 s

t = 0.11 s

Fig. 11: FEM dynamic simulation result