

**Numerical Simulation of a Flight Recorder's Protective Case Penetration
Resistance Test**

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ABSTRACT

Development of a durable flight recorder's protective case is a very difficult engineering problem. To save information, the case must be strong enough to withstand intensive accidental thermal and mechanical loading in aircraft crash. So the case must meet strong requirements. One of the toughest of these demands is that any flight recorder's case must be strong enough to withstand a penetration resistance test - an impact of pin at any angle at a speed of 7.7 m/s.

This paper presents the results of a series of 3D numerical simulations of penetration resistance test of a flight recorder's protective case. The simulations performed with LS-DYNA. The computer simulations showed the most severe direction of pin impact to the case.

INTRODUCTION

One of the main sources of information about the reasons of aircraft crashes is flight recorder. To protect storage device from damage a flight recorder must have strong protective case. Requirements of flight availability [1] determine mechanical and thermal effects, which the case must stand, and order of carrying out of tests [2] of a flight recorder's protective case. One of the toughest of these tests is penetration resistance test. One of demands to this test is that a penetration pin must strike onto the weakest point of the case.

The way of structure development by experimental tests only is very expensive approach to the problem. Modern software of an engineering analysis gives to designers the ability to forecast deformation of construction subjected by different external loads. Using of numerical simulation allow to reduce time the duration of the design process and save money on experiments.

Numerical simulation of a flight recorder's protective case penetration resistance test is a very difficult problem of mechanical engineering. There are the following features:

- necessity to take into account geometrical and physical non-linearity
- necessity to resolve contact problem with variable in time and space contact boundaries
- necessity to model behavior of sand

Solution of this problem with high accuracy can be implemented only with modern engineering software, such as LS-DYNA [3]. Now Sarov Open Computing Center has LS-DYNA licenses for 3 processors.

This paper presents the results of series of 3D numerical simulations of penetration resistance test of a flight recorder's protective case. The simulations performed with LS-DYNA.

Description of The Construction

Investigated protective case consists of 10mm cylindrical shell with screwed spherical lids on butt-ends. Material of the case is titanium alloy. Heat-insulating material of low density is placed inside the case. The storage device is installed in the center of the case.

Penetration Resistance Test

Protective case is fixed in required position on metal plate with thickness 6.35 mm. The plate lies on layer of sand with depth of 500 mm. The sand is moistened in proportion of 1 liter of water to 15 kg of sand. A massive body with weight of 227 kg

drops from height of 3 meters onto the case. The penetration pin is fixed at the bottom part of the massive body. The dimensions of the pin are as follows: diameter - 6.35 mm and length - 40 mm. The pin is made of high-strength hardened steel (HRC 39-45).

Computer Models

Preliminary it was assumed that the numerical simulation are need to be done for 5 variants of position of the penetration pin relative to the protective case:

- impact to the center of lid (Variant 1)
- impact to the cylindrical shell at the mid-ship (Variant 2)
- impact to the cylindrical shell at distance 25 mm from the mid-ship (Variant 3)
- impact to the cylindrical shell at distance 50 mm from the mid-ship (Variant 4)
- impact to the cylindrical shell at distance 65 mm from the mid-ship (Variant 5)

3D computer models for the first and the second variants are shown on Figure 1. A half of the construction is modeled using plane of symmetry. For the sand the following boundary conditions are used: at the bottom side all displacements and rotations are constrained, at the flank sides displacements are constrained only in the normal direction.

Entire finite element model consists of ~400000 elements. Model of the protective case consists of ~130000 elements, model of the sand – ~60000, model of the plate – ~20000 and model of the heat-insulation – ~180000.

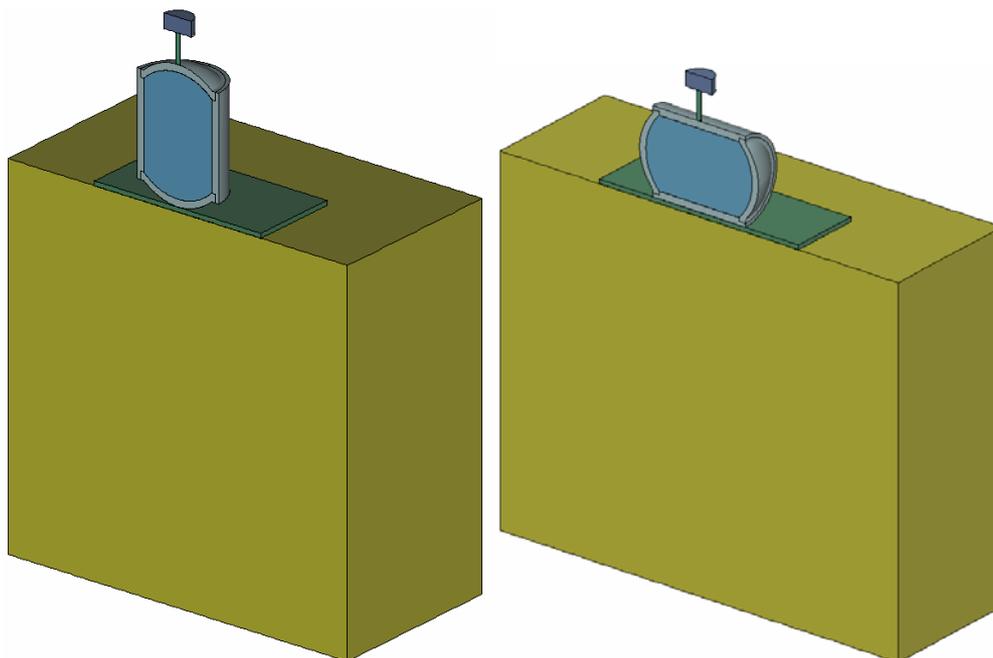


Figure 1 Computer models for Variants 1 and 2

To improve accuracy of solution, finite element mesh is concentrated in the vicinity of point of impact (Figure 2). The massive body is modeled as a cylinder with fictitious density constrained with the top end of the pin. The density of the cylinder is calculated according to the mass of the massive body.

Material model MAT_PLASTIC_KINEMATIC is used for the case, the plate, the pin and the heat-insulation. Material model MAT_SOIL_AND_FOAM is used for the sand. Equation of state of the sand is determined by a tabulated curve of pressure versus volumetric strain. This curve is presented in [4] and corresponds to static behavior of sand with moisture 11%

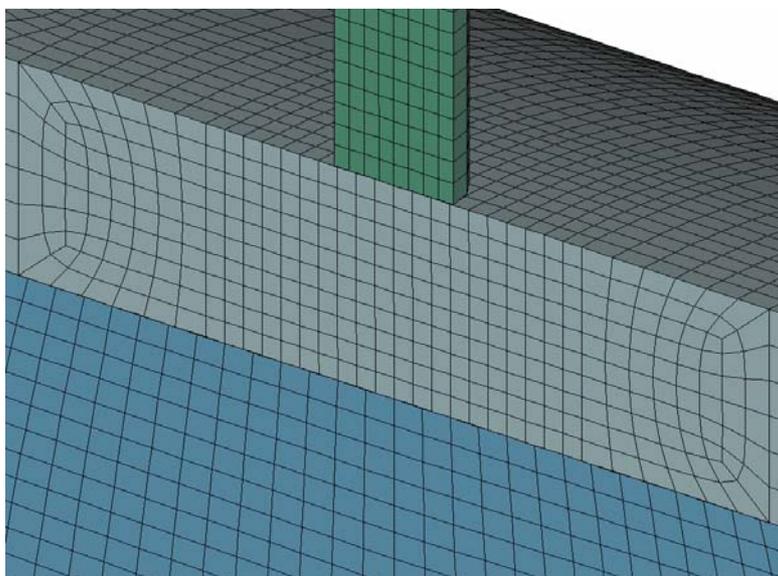


Figure 2 Fragment of finite element mesh

Threaded connection of lids with cylindrical shell is modeled using contact algorithm AUTOMATIC_SURFACE_TO_SURFACE with static coefficient of friction FS=1. This approach allows to investigate opening of threaded connection during deformation. Physical-mechanical properties of materials are presented in Table 1.

Table 1 Physical-mechanical properties of materials

Material	Elastic modulus (GPa)	Poisson's ratio	Density (g/cm ³)	Yield strength (MPa)	Hardening modulus (MPa)
Protective case	115	0.3	4.43	830	1500
Heat insulation	0.01	0.1	0.3	3	6
Plate	200	0.3	7.8	270	900
Pin	200	0.3	7.8	1200	25000

Value of time step is ~0.07 μ s. Time of solution for 1 variant is ~150 hours of processor AMD Athlon™ MP 2000+.

Results of Calculations

The main results of calculations are presented in Figures 3-8. Figure 3 shows deformed shape of construction for Variant 1 at time t=15 ms, when the velocity of the massive solid =0 (Figure 4). Depth of cavity in sand for this variant is 60 mm.

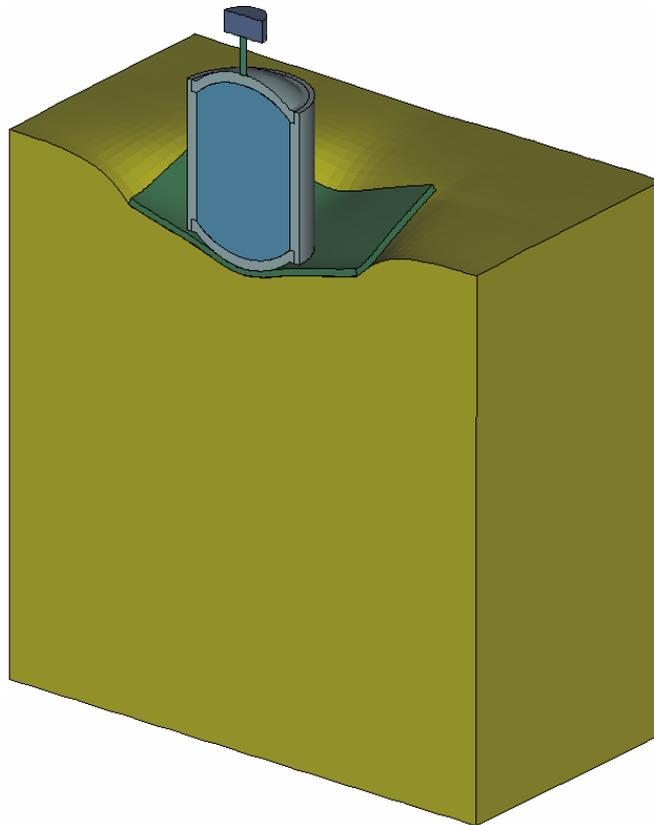


Figure 3 Deformed shape (Variant 1)

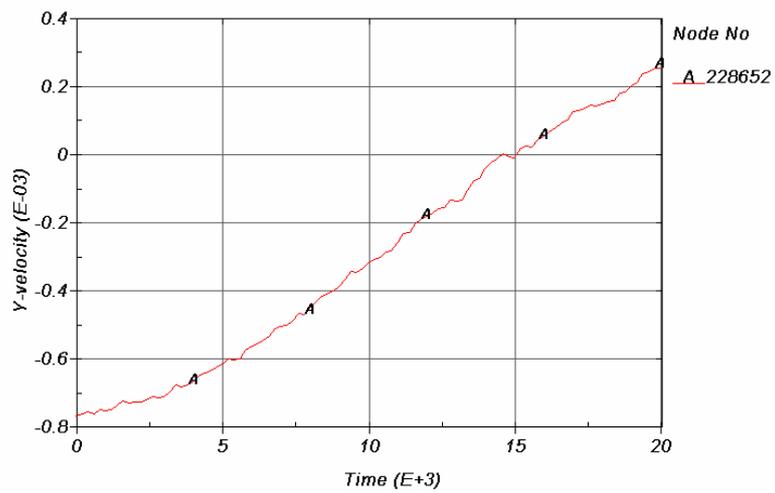


Figure 4 Velocity of the massive body versus time (Variant 1)
 Contours of effective strain in vicinity of impact at time 15 ms are shown in Figure 5

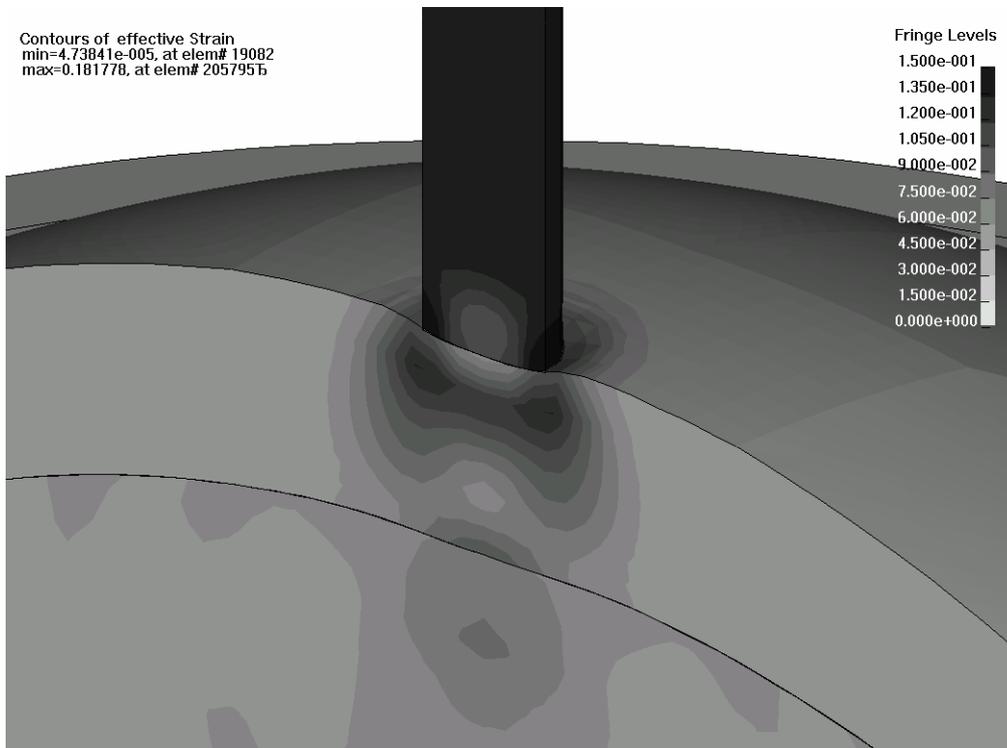


Figure 5 Contours of effective strain (Variant 1)

Figure 5 shows that the main deformations of the case are localized in quite small vicinity of point of impact. Maximum value of effective strain in the case is 14.5%. Depth of penetration of the pin into the case, calculated as difference between initial and final thickness of the case, is 0.06 mm.

Deformed shape of construction for Variant 2 is shown on Figure 6. Unlike Variant 1, time of deceleration is $t \sim 14$ ms and depth of cavity in sand is 51.6 mm.

Spacing of deformations in the case is similar to previous variant, but maximum value of effective strain is 36.9% (Figure 7), that in 2.5 times more then in the first variant.

Opening of threaded connection for Variant 2 is shown in Figure 8. For clearness, displacement scale factor for this picture is set to 5. Figure 8 shows that threaded connection is opening during impact of the penetration pin onto the cylindrical shell of the case and that can entail depressurization of the case. However, analysis of deformation of the case in this part shows that deformations, which entail opening of threaded connection are elastic. Therefore opening of threaded connection is temporary and disappears after taking down of loading.

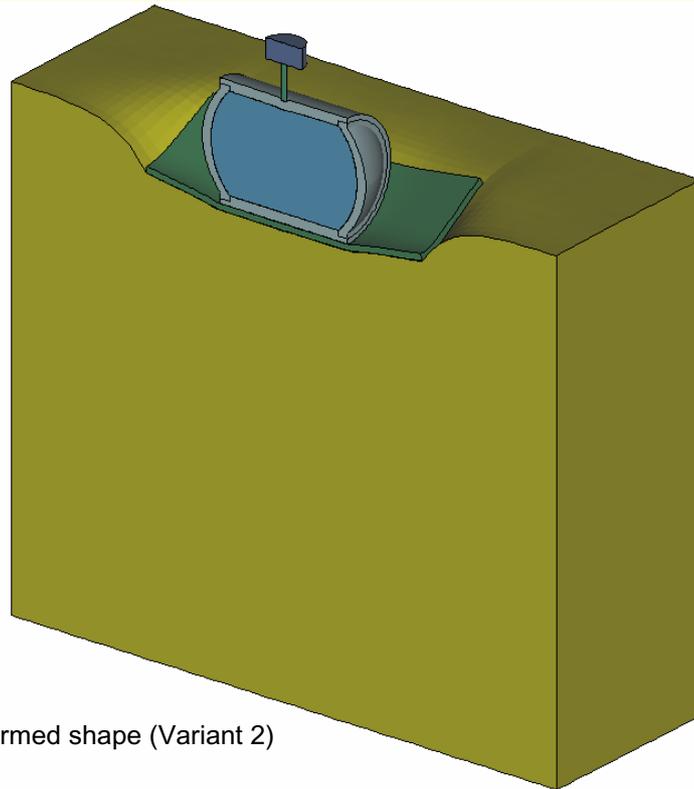


Figure 6 Deformed shape (Variant 2)

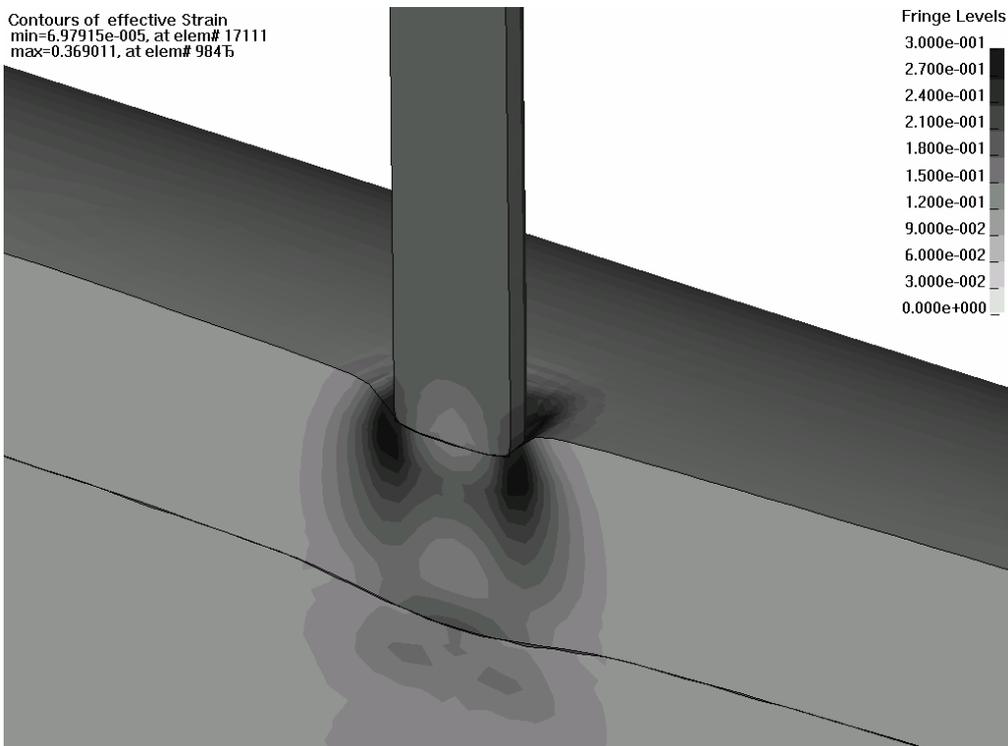


Figure 7 Contours of effective strain (Variant 2)

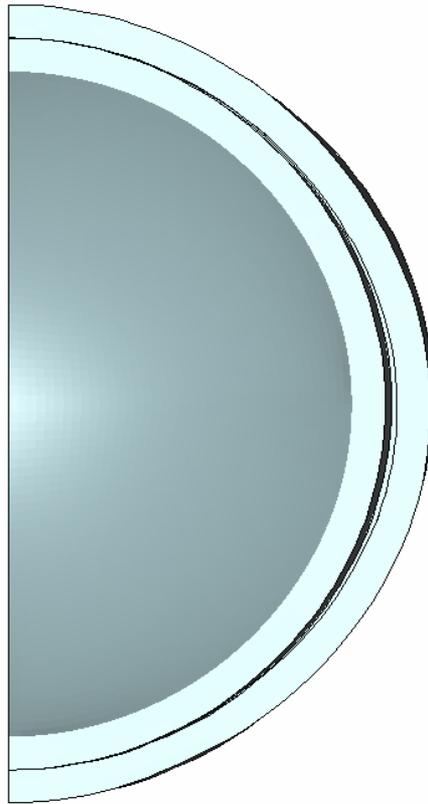


Figure 8 Opening of threaded connection (Variant 2)

Analysis of results of the others variants shows that the results for Variants 3 and 4 are close to the ones described above for Variant 2 and so they are not described here in detail. In Variant 5 the massive body does not decelerate to 0 because of case "turnover".

To define the most severe variant of the test, the following critical parameters are compared:

1. Reducing of case's thickness under the center of the pin (δh)
2. Maximum value of effective strain in vicinity of point of impact (ϵ^{\max})
3. Maximum value of opening of threaded connection (δs)

Values of these parameters for every variant of test are given in Table 2.

Table 2. Comparison of critical parameters

	Variant 1	Variant 2	Variant 3	Variant 4	Variant 5
δh (mm)	0.06	1.11	0.92	0.99	0.95
ϵ^{\max} (%)	14.5	36.9	21.5	27.6	23.3
δs (mm)	0.03	0.40	0.47	0.49	0.34

Analysis of Table 2 shows that the most severe direction of pin impact to this protective case construction is direction considered in Variant 2, since there are maximum penetration of pin into the case and maximum value of effective strain in the case. Opening of threaded connection is small for all variants and, therefore, is not critical. Moreover, in variants 3-5 penetration pin can break since during deformation position of the case would not be horizontal and there are a moment that leads to bend and, possibly, breaking of the pin.

Summary and Conclusions

Numerical simulation of a flight recorder's protective case penetration resistance test was implemented using LS-DYNA. Impacts into 5 different points of the case were investigated. Comparative analysis of the calculation results shows that the most severe variant is the impact to mid-ship of cylindrical shell of the case.

References

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