Selected problems in modeling of the dynamic, fast-changing phenomena

Jacek Toczyski

Faculty of Power and Aeronautical Engineering, Warsaw University of Technology
Nowowiejska 24 Street, 00-665 Warsaw, Poland
e-mail: jtoczyski@meil.pw.edu.pl

Abstract

Paper describes investigation of sensitivity of results of an explicit dynamic analysis to FE model parameters in a typical fluid-structure interaction (FSI) problem. As an example the problem of detonation of C4 explosive charge inside a medium airplane fuselage was chosen. Three cases of extent of the Euler mesh (the domain which contains air and the charge) were examined. Studies confirm very strong requirements of correlation of analysis results with experimental data. Without such a correlation it is difficult to discuss the validation of results obtained from the "explicit" codes.

Keywords: highly-dynamic events, fluid-structure interaction, LS-Dyna

1. Introduction

In the paper selected elements of investigation of sensitivity of results to details of modeling of a typical fluid-structure interaction problem are discussed. Chosen example describes detonation of C4 charge inside a thin-walled fuselage of a medium airplane.

All calculations were performed using the commercial explicit FE code, LS-Dyna V971.

2. Problem description

Figure 1 shows the FE model used in numerical simulations. It represents a simplified section of the fuselage. Geometry of the structure was described in detail in [2].

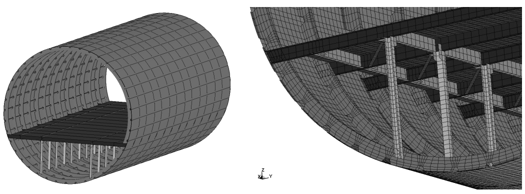

Figure 1: FE model of the fuselage

The model is meshed with QUAD elements using the *Belytschko-Leviathan shell* formulation.

The structure (excluding the floor, which is composed of GFRP layers and the Nomex honeycomb core) is made of aluminium alloy (2024-T3). The material constants of the alloy were assumed from [1]. The explosive charge of mass m_0 is located between two frame beams, 20cm above the floor, 20cm from the skin.

In order to decrease computation time, the size of the Euler mesh was reduced. The analyzed section of the fuselage was only partially covered by the Euler mesh. It was assumed that the influence of mechanical effects of a shock wave on the structure, at some distance from the explosive charge, is negligible.

Three cases of extent of the Euler domain are shown in Figs. 2, 3 and 4. The cases differ both by length ("axis-wise"), as well as by width ("side-wise"). It appeared from subsequent analyses, that the 3. case – which is short one, but encloses entire cross-section in the Euler domain – gives definitely the best, "physically sensible" results.

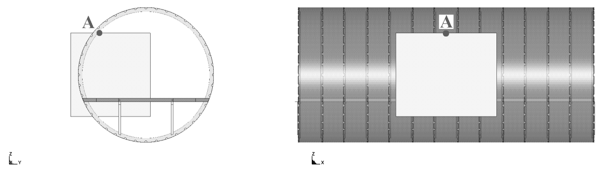

Figure 2: Model 1 – dimensions of the Euler mesh: 1765mm x 1855mm x 2230mm

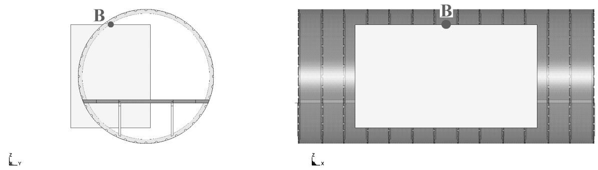

Figure 3: Model 2 – dimensions of the Euler mesh: 1765mm x 2305mm x 4030mm

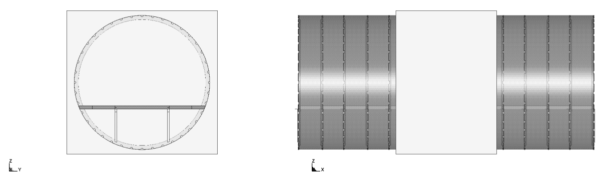

Figure 4: Model 3 – dimensions of the Euler mesh: 3340mm x 3205mm x 2230mm

Simulation of the blast was performed using the Arbitrary Lagrangian-Eulerian (ALE) formulation. Fluid-structure interaction was described using a dedicated coupling algorithm with an option allowing erosion of Lagrangian elements.

3. The Euler domain

The Euler domain is modeled using HEXA elements with the *1 point ALE multi-material element* formulation.

At the free surfaces of the Euler mesh the pressure of 1 bar is applied in order to ensure that the analyzed thermodynamic system will, after the explosion, return to the equilibrium state.

The FE model used also:

- the linear polynomial equation of state (described in detail in [4]) as an EOS modeling the behavior of air,
- the JWL equation of state as an EOS describing the detonation process of C4 explosives.

Required input data – coefficients of the equations of state as well as properties of the explosive charge were accepted from the literature [3, 5].

4. Discussion of results

As a result of detonation of the explosive charge the shock pressure wave is generated. It reaches the skin first and then bounces back, not causing the perforation of the skin. In the case of model 1 and model 2, ca. 3ms after the explosion, in the central part of the top surface of the Euler mesh (point A in Fig. 2 and point B in Fig. 3), air velocity increases extremely fast (up to non-physical values). At the same time pressure of the fluid decreases significantly in this area. The disturbance (Fig. 5) leads to a very large deformation of the structure (Fig. 6, Fig. 7). Surprisingly, in model 3, in which the whole cross-section of the analyzed structure is enclose in the Euler domain, this kind of non-physical behavior of fluid does not occur. The skin is not damaged and the frame beams retain their cylindrical shape (Fig. 8).

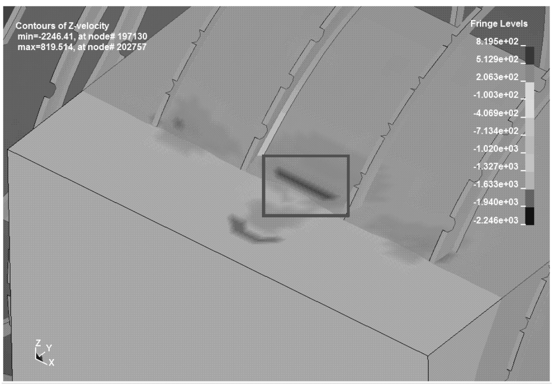

Figure 5: The Euler mesh – non-physical disturbance of the fluid

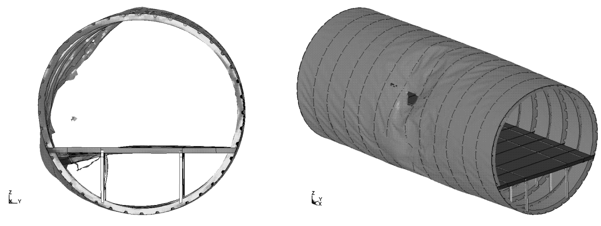

Figure 6: Model 1 – deformation of the fuselage at t =15ms

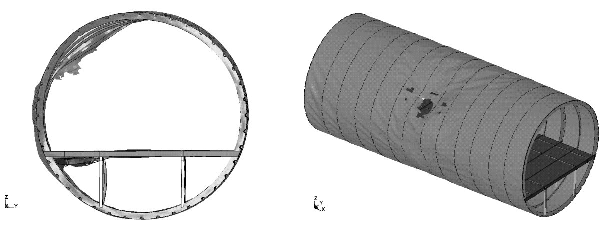

Figure 7: Model 2 – deformation of the fuselage at t =15ms

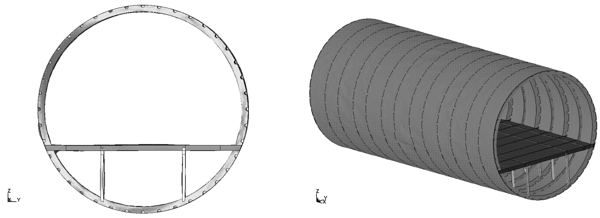

Figure 8: Model 3 – deformation of the fuselage at t =15ms

5. Conclusions

Observations, described in the paper, are just one of a row of surprising parameters sensitivity revealed during the research. The selected effects described in the paper show that the selection of parameters of the Euler domain (including its geometry and extent) has a very large influence on quality of results obtained from numerical calculations.

The effect of reducing the dimensions of the Euler mesh (in such a way that the fuselage cross-section is only partially “immersed” into it) is surprising – the non-physical disturbance in the flow of air (which finally leads to the destruction of the analyzed structure) occurs.

As the author's experience shows, the criteria of selection of “optimal” parameters for numerical models of highly-dynamic events are definitely not universal and they strongly depend on the nature of a task / a physical problem being modeled.

That clearly stresses the fact, that FE explicit analyses should be validated and verified much more strictly than we used to do it in “standard” implicit FE cases.

References

[1] Dacko, A. and Toczyski, J., Structural Response of a Blast Loaded Fuselage, *Journal of KONES*, Vol. 17, No. 1, pp. 101-109, 2010.

[2] Habas, D. et al., *Selection and Design of Scaled Simplified Sub-Aerostructures*, EU Project VULCAN: AST5-CT-2006-031011, VULCAN Deliverable D1.4, Tanagra, 2008.

[3] Kotzakolios, T. et al., *Blast response of flat panels*. EU Project VULCAN: AST5-CT-2006-031011, VULCAN Deliverable D2.1, Patras, 2007.

[4] LS-Dyna V971, Livermore Software Technology Corporation, Livermore, 2006.

[5] Włodarczyk, E., *Wstęp do mechaniki wybuchu* [*Introduction to Physics of Explosion*], PWN, Warsaw, 1994.