UDC (629.7.015.4+629.78):519.6

А. Г. НАРЫЖНЫЙ, В. Н. ПАВЛЕНКО
A.G. NARYZHNYI, V. N. PAVLENKO

МОДЕЛИРОВАНИЕ МЕХАНИЧЕСКИХ ПРОЦЕССОВ В СИСТЕМАХ И АГРЕГАТАХ ИЗДЕЛИЙ КОСМИЧЕСКОЙ ТЕХНИКИ
SIMULATION OF MECHANICAL PROCESSES IN SYSTEMS AND UNITS OF AEROSPACE ENGINEERING PRODUCTS

The literature on the simulation of mechanical processes in systems and units of aerospace engineering products is reviewed. The increasing structural complexity of the simulated objects, the interdisciplinary nature of the processes as well as the complex nature of the contact interaction and significant deformations and element displacements are highlighted. Various methods of space discretization are often used for the simulation with a single model. The simulation is considered as a competitor or a supplement to the experimental methods for studying complex systems of aerospace engineering.

*Keywords: aerospace engineering, mathematical modeling, vehicle, vane, impact loads***.**

1. Numerical simulation of structural deformation under shock and impact loads using a coupled multi-solver approach / *X. Quan, N. K. Birndaum , M. S. Cowler, et al.* // Proc. 5th Asia- Pacific Conference on Shock and Impact Loads on Structures, November 12–14 , 2003, Hunan, China. – 9 p.
2. LS-DYNA. Keyword user′s manual. Version 971. – Livermore: LSTC, 2006. – 1520 p.
3. *Zenkevich O*. Finite Elements and Approximation (*in Russian*) / *O. Zenkevich, K. Morgan*. – Moscow: Mir, 1986. – 318 p.
4. *Belytschko T*. Meshfree and Particle Methods / *T. Belytschko, J. S. Chen*. – John Wiley and Sons Ltd, 2007. – 384 p.
5. Arbitrary Lagrangian-Eulerian methods / *J. Donea, A. Huerta, J.-P. Ponthot, et al.* // Encyclopedia of Computational Mechanics. – John Wiley & Sons, 2004. – P. 1 – 38.
6. *Hallquist J.* Recent developments in LS-DYNA / *J. Hallquist* // Proc.7th European LS-Dyna Conference, 2009, Solzburg. – P. 1 – 52.
7. *McCallum S. C.* The influence of bird-shape in bird-strike analysis/ *S. C. McCallum, C. Constantinou* // Proc. 5th European LS-DYNA Conference, 2005, Birmingham. – P. 1 – 11.
8. Horizontal tailplane subjected to impact loading / *M. Hormann, U. Stelzmann, M. A. McCarthy, et al.* // Proc.8th International LS-DYNA Conference, 2004, Detroit. – P. 10 -11 – 10-30.
9. *Iannucci L.* Bird strike modeling using a new woven glass failure model / *L. Iannucci, M. Donadon* // Proc. 9th International LS-DYNA Conference, 2006, Detroit. – P. 18-41 – 18-54.
10. Effect of ply number & orientation of composite structure in bird strike analysis / *N. L. Trivikram, R. Y. Mrityunjaya, V. Ramesh et al.* // Proc.4th ANSA & μETA International Conference, 2008. – 5 p.
11. *Hormann M.* FE-application in aircraft structure analysis / *M. Hormann* // Proc.10th International LS-DYNA Conference, Detroit, 2008. – P. 16-27 – 16-46.
12. *Guida M.* Evaluation and validation of multi-physics FE methods to simulation bird strike on a wing leading edge / *M. Guida, F. Marulo, M. Meo* // 2007. – P. 2.
13. http://www.mscsoftware.com.
14. *Lavoie M.-A.* Application of the SPH method for simulation of aerospace structures under impact loading / *M.-A. Lavoie, A. Gakwaya, M. N. Ensan* // Proc. 10th International LS-DYNA Conference, 2008, Detroit. – P. 9-35 –9-42.
15. *Starke P.* Hail impact simulation on CFC covers of a transport aircraft / *P. Starke, F. Mayer* // Proc. 8th European LS-DYNA Users Conference, May 2011, Strasbourg. – 11 p.
16. An approach to capture the ejection mitigation requirements of FMVSS 226 with finite element simulations / *A. Haufe, G. Dimitru, A. Hirth et al.* // Proc. 8th European LS-DYNA Users Conference, May 2011, Strasbourg. – 18 p.
17. *Birch R. S.* Post-test simulation of airliner wing subject to tire debris impact / *R. S. Birch, C. Berger, M. Kracht* // Proc. 5th European LS-DYNA Conference, 2005, Birmingham. – P. 1 – 6.
18. Fan blade bird strike analysis using Lagrangian, SPH and ALE approaches / *A. A. Ryabov, V. I. Romanov, S. S. Kukanov, et al.* // Proc.6th European LS-DYNA Conference, 2007, Gothenburg. – C. 1.183 – 1.194.

19. Modeling bird impact on a rotating fan: the influence of bird parameters / *M. Selezneva, P. Stone, T. Moffat et al.* // Proc. 11th International LS-DYNA Users Conference, 2010, Detroit. – P. 1-37 –1-46.
20. *Frischbier J.* Multiple stage turbofan bird ingection analysis with ALE and SPH methods / *J. Frischbier, A. Kraus* // ISABE-2005. – 2005. – 1016. – P. 1 – 9.
21. *Tho C.-H.* Bird strike simulation for BA609 spinner and rotor control / *C.-H. Tho, M. R. Smith, H. Chen* // Proc. 9th International LS-DYNA Conference, 2006, Detroit. – P. 18-21 – 18-22.
22. Bird strike analysis of aircraft engine fan / *Y. N. Shmotin, P. V. Chupin, D. V. Gabov et al. //* Proc.7th European LS-Dyna conference, 2009, Solzburg. – P. 1 – 6.
23. External blast load on structures. – Empirical approach / *M. Anghileri, L. Castelletti, F. Invernizzi et al.* // Proc. 5th European LS-DYNA Conference, 2005, Birmingha,.– C. 1 – 12.
24. A strategy to design bird-proof spinners / *M. Anghilieri, L.-M. Castelletti, D. Molinelli et al.* // Proc.7th European LS-Dyna Conference, 2009, Solzburg. – P. 1 – 10
25. *Wang J.* Fluid Structure Interaction for Immersed Bodies / *J. Wang, H. Chen* // Proc. 6th European LS-DYNA Conference, 2007, Gothenburg. – P. 4.3 – 4.8.
26. Jet engine fan blade containment using two alternate geometries / *K. Carney, M. Pereira, D. Revilock et al.* // Proc. 4th European LS-DYNA Conference, 2003, Ulm. – P. I-1-01 – I-1-10.
27. Development of hail material model for high speed impact on aircraft engine / *Y. Chuzel, A. Combescure, M. Nucci et al.* // Proc.11th International LS-DYNA Users Conference, 2010, Detroit. – P. 1-17 – 1-26.
28. Modeling methodologies for assessment of aircraft impact damage to the World Trade Center Towers / *S. W. Kirkpatrick, R. T. Bocchieri, R. A. Macneil et al.* // Proc. 9th International LS-DYNA Conference, 2006, Detroit. – P. 9-53 – 9-68.
29. http://www.century-dynamics.com
30. Test and analysis correlation of foam impact onto space shuttle wing leading edge RCC Panel 8. / *E. L. Fasanella, K. H. Lyle, J. Gabrys et al.* // Proc. 8th International LS-DYNA Conference, 2004, Detroit. – P. 3-11 – 3-22.
31. *Mazars G.* High - velocity impacts simulations with SPH methods in LS-DYNA / *G. Mazars, G. Desille, V. Lapoujade* // Proc.6th European LS-DYNA Conference, 2007, Gothenburg. – P. 1.195 – 1.196.
32. *Hayhurst C. J.* Cylindrically symmetric SPH simulations of hypervelocity impacts on thin plates / *C. J. Hayhurst, R. A. Clegg* // 1996 Hypervelocity Impact Symposium, Freiburg, October, 1996; International Journal Impact Engineering. – 1996. –V. 20. – 16 p.
33. On the fracture criterion of titanium alloy under dynamic loading conditions / *P. A. Mossakovsky, F. K. Antonov, A. M. Bragov et al.* // Proc. 8th European LS-DYNA Users Conference, May, 2011, Strasbourg. – 8 p.
34. *Plassard F*. Hypervelocity impact of aluminium sphere against aluminium plate: experiment and LS-DYNA correlation / *F. Plassard, J. Mespoulet, P. Hereil* // Proc. 8th European LS-DYNA Users Conference, May, 2011, Strasbourg. – 11 p.
35. A new ALE formulation for sloshing analysis / *N. Aquelet, M. Souli, J. Gabrys et al.* // Structural Engineering and Mechanics. – 2003. –Vol. 16, No 4. – P. 1 – 18.
36. *Ma J.* Modeling of fuel sloshing phenomena considering solid-fluid interaction / *J. Ma, M. Usman* // Proc. 8th International LS-DYNA Conference, 2004, Detroit. – P. 4 -15 – 4-20.
37. *Del Pin F.* An implicit incompressible CFD solver in LS-DYNA for fluid-structure interaction problems / *F. Del Pin* // Proc. 10th International LS-DYNA Conference, 2008, Detroit. – P. 15-21 –15-22.
38. *Soulaimani A.* An arbitrary Lagrangian-Eulerian finite element method for solving three-dimensional free surface flows / *A. Soulaimani, Y. Saad* // Computer methods in applied mechanics and engineering. – 1998. – 162. – P. 79 – 106.
39. *Zhang Z.-C.* How to use the new CESE compressible fluid solver in LS-DYNA / *Z.-C. Zhang* // Proc. 11th International LS-DYNA Users Conference, 2010, Detroit. – P. 6-19 – 6-20.
40. *McCallum S. C.* Simulation of hydrodynamic ram and liquid aeration / *S. C. McCallum, D. D. Townsend* // Proc. 5th European LS-DYNA Conference, 2005, Birmingham. – P. 1 – 12.
41. *Santini P.* Numerical simulation of fluid-structure interaction in aircraft fuel tanks subjected to hydrodynamic ram penetration / *P. Santini, D. Palmieri, M. Marchetti* // Proc. 21st ICAS Congress, Sept. 13-18, 1998, Melbourne, Australia. – 8 p.
42. *Fasanella E. L.* Soft soil impact testing and simulation of aerospace structures / *E. L. Fasanella, K. E. Jackson, S. Kellas* // Proc.10th International LS-DYNA Conference, 2008, Detroit. – P. 18-29 –1 8-42.
43. *Barsotti M.* Comparision of FEM and SPH modeling a crushable foam aircraft arrestor bed / *M. Barsotti* // Proc.11-th International LS-DYNA Users Conference, 2010, Detroit. –P. 16-37 – 16-54.
44. *Tutt B. A.* The use of LS-DYNA to simulate the water landing characteristics of space vehicles / *B. A. Tutt, A. P. Taylor* // Proc. 8th International LS-DYNA Conference, 2004, Detroit. – P. 1-1 – 1-15.
45. *Tabiei A.* ORION spacecraft water and land landing system simulation; an injury case study / *A. Tabiei, C. Lawrence* // Proc. 8th European LS-DYNA Users Conference, May 2011, Strasbourg. – 22 p.
46. *Anghileri M.* Water impact: experimentaltests and numerical simulations using meshless methods / *M. Anghileri, L. Castelletti, E. Francesconi* // Proc. 6th European LS-DYNA Conference, 2007, Gothenburg. – P. 1.183 – 1.194.
47. *Francesconi E.* A numerical-experimental investigation of crash behaviour of skin panel during a water impact comparing ALE and SPH approaches / *E. Francesconi, M. Anghilieri* // Proc.7-th European LS-Dyna Conference, 2009, Solzburg. – P. 1 – 10.

48. Structural analysis with vibro-acoustic loads in LS-DYNA / *M. Rassaian, Y. Huang, J. Le et al.* // Proc.10th International LS-DYNA Conference, 2008, Detroit. – P. 8-45 – 8-60.
49. *Alia A.* Acoustic and vibroacoustic modeling in LS-DYNA based on variational BEM / *A. Alia, M. Souli* // Proc.5th European LS-DYNA Conference, Birmingham, 2005. – P. 1 – 10.
50. *Aginsky Z.* Numerical analysis of nonlinear acoustic fluid-structure interaction of a two dimensional plate in an inviscid compressible fluid / *Z. Aginsky, O. Gottlieb* // ENOC 2011, 24–29 July, 2011, Rome, Italy. –2 p.
51. Development of frequency domain dynamic and acoustic capabilities in LS-DYNA / *Y. Huang, M. Souli, C. Ashcraft et al.* // Proc.8th European LS-DYNA Users Conference, May, 2011, Strasbourg. – 9 p.
52. *Taylor A. P.* Developments in the application of LS-DYNA to fluid structure interaction (FSI) problems in recovery system design and analysis / *A. P. Taylor* // Proc. 7th International LS-DYNA Conference, 2002, Detroit. – P. 10-17 – 10-26.
53. *Del Pin F.* Advances on the incompressible CFD solver in LS-DYNA / *F. Del Pin* // Proc.11th International LS-DYNA Users Conference, 2010, Detroit. – P. 6-1 – 6-4.
54. Coupling LES, radiation and structure in gas turbine simulations / *J. Amaya, E. Collado, B. Cuenot et al.* // Center for Turbulence Research. Proc. Summer Program, 2010. – Toulouse, 2010. – 10 p.