Finite element crash simulations and impact-induced injuries

A bibliography (1980–1998)

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This bibliography lists references to papers, conference proceedings and theses/dissertations dealing with finite element simulations of crashes, impact-induced injuries and their protection that were published in 1980–1998. 390 citations are listed.

Keywords: Finite elements, contact-impact problems, crash simulations, impact-induced injuries, injury protection, bibliography

1. Introduction

Information is the most valuable, but least valued, tool the professional has. The output of scientific papers is growing and it is difficult to remain up-to-date with all the relevant information. The number of channels that researchers and practicing engineers have at their disposal for information retrieval is increasing rapidly. In engineering, informal knowledge channels are often the most frequently used means of obtaining information. Many professionals prefer to rely on personal judgment or on the "wisdom" of their colleagues whenever they have problems to solve. It is the author's expectation that this bibliography will save time for readers looking for information dealing with the subjects described below.

This bibliography provides a list of references on finite element simulations of crashes and impact-induced injuries. General solution techniques as well as problem-specific applications are included. The entries have been retrieved from the author's database, MAKEBASE. They are grouped into the following sections:

- crash and impact simulations where occupants are not included (aircraft and helicopter crashworthiness, automobile crashworthiness, and vehicle rail structures)
- aircraft-birdstrike impacts
- impact-induced injuries
- human surrogates
- injury protection

2. Crash and impact simulations where occupants are not included

The subject of this section is the finite element simulation of contact-impact problems and problems where acceleration loading is included. References listed in the bibliographical section are divided into crashworthiness of aircrafts and helicopters, automobiles, and vehicle rail structures. Interactions with occupants are not included. In the past, finite element simulations of vehicle crashworthiness with occupants included have been limited due to the lack of software and limited computing capabilities. Fast developments in computer hardware, implementation of parallel processing techniques, and coupling of finite element analysis codes with multi-body dynamics codes have opened a new era in contact-impact biodynamics studies. The application possibilities of the finite element method have been expanded in order to allow for the complex modeling of vehicle and integrated occupants. Papers on these topics are listed in the next sections.

Topics include: *aircraft and helicopter crashworthiness* – 2D and 3D aircraft and helicopter impact and crash analyses; flutter impact problems; aircraft gas turbine engines and components; fan fuselages; helicopter fuselages; helicopter rotor blades; multiple blade shed incidents; aircraft propellers; helicopter sub-floor structures; aircraft seats; wing-type structures; light aircraft structures; impacted ice in rotating airfoils; aircraft impact with reinforced concrete

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buildings; impact of aerospace structures with debris; reentry vehicle response to impact; space modules impacting water; impacted windows for the space shuttle; damage models for impact problems; *automobile crashworthiness* – 2D and 3D automobile impact/crash analyses; front end impact problems; side impact problems; rear crash analyses; crash simulation of rear engine automobiles; two vehicles in frontal impact; rollover simulations; vehicle cab frames; joints under car crashes; roof crush analyses; impact on various car components (wheels and tires, seats, etc.); windshield impact response; analyses of bumper systems; crash energy management; adaptive methods in crash analyses; stochastic analyses of crash problems; identification of parameters; application of supercomputers; *vehicle rail structures crashworthiness* – 2D and 3D analyses of train vehicles and components; wheel/rail impact problems; collapse of rail vehicle bodies.

3. Aircraft-birdstrike impacts

Collisions of aircrafts with birds are a threat to the safety of the aviation transportation and in addition they cause costly material damage to civil and military aviation. To predict the damage and its consequences, finite element simulations can be performed to study the contact-impact phenomena at soft-body impact problems. The impact load in connection with a birdstrike is hydrodynamic, time-dependent and decreases from the centerline of the impact region.

The following topics are handled: 2D and 3D simulations of a birdstrike on an aircraft canopy; bird impact on fan and compressor blades; soft-body impact problems.

4. Impact-induced injuries

Two main types of models in research of impact injuries can be distinguished: crash dummy models and real human body models. The latter category may be subdivided into human body component models and global human body models. As a result of finite element studies, stresses, strains, and also global motions (accelerations, velocities, displacements, reaction forces, etc.) within the human body or specific organs are obtained. These quantities are related to tissue damage or other indicators of injury. References dealing with global human body models as well as dummies are listed in the next section.

Impact-induced injuries under investigation include: 2D and 3D dynamic finite element studies of brain, head, neck, head–neck, head–spine, spine, articular cartilage, thorax, ankle, ankle–foot, knee–joint, patellofemoral joint, cervical spine motion segment, pelvis; thoracic–abdominal impact problems; diffuse axonal injury; injury to blood–brain barrier; whiplash neck behavior.

5. Human surrogates

More and more interest is focused on the dynamic response of the whole human body during automobile impact situations. This response is difficult to study by experimental tests when exceeding injury levels and therefore in some cases the cadavers or hybrid dummies are used to help to define the injury criteria. The hybrid dummies are developed as occupant substitutes in automobile collision testing to measure forces/accelerations on occupants during collision tests. Finite element models are used either to predict the behavior of a new system or to study aspects of an existing system that cannot be measured experimentally. An accurate mathematical model of the human body contains head, neck and skeleton represented by bones, their joints, various soft tissues, and internal organs.

Topics in this section are: occupant dynamic responses; occupant kinematics; human body impact problems; integrated occupant–car crash simulations; dummy models for crash simulations; SID dummy; BioSID dummy; EuroSID dummy; DotSID dummy; Hybrid III dummy; laminated glass head model; vehicle–dummy–airbag modeling.

6. Injury protection

At least a half million people die each year as a result of automobile accidents and about 15 million are injured. What we need is to increase safety of vehicles and thereby reduce occupant injuries as well as costs generated by these accidents. Seat belts, airbags and collapsible structures are three primary components of the safety systems in cars seeking to reduce serious or fatal injuries of occupants. Finite element techniques have been implemented to analyse and simulate injury protection systems and this is a main subject of this section.

The following topics are included: occupant protection in frontal and side impacts; occupant–airbag simulations; airbag modeling; seat side impact airbags; belt modeling; seat–seat belt design; helmet–head under impact; side impact protection; design of steering column; aircraft crash injury protection; pedestrian-safe car hood and bumper design; barrier impact test simulations; guardrail systems.

Acknowledgement

The bibliography presented is by no means complete but it gives a comprehensive representation of different finite element applications on the subjects. The author wishes to apologize for the unintentional exclusions of missing references and would appreciate receiving comments and pointers to other relevant literature for a future update.

BIBLIOGRAPHY

Crash and impact simulations where occupants are not included

Aircraft and helicopter crashworthiness

[1] H. Abbas et al., Reaction-time response of aircraft crash, *Computers & Structures* **55** (1995), 809–817.

[2] Y. Bangash, Aircraft crash analysis of the proposed sizewell B containment vessel, in: *9th Int. Conf. Structural Mechanics in Reactor Technology*, Balkema, Rotterdam, 1987, pp. J307–314.

[3] A.O. Bolukbasi and D.H. Laananen, Application of the nonlinear finite element method to crashworthiness analysis of aircraft seats, in: *24th Structures, Structural Dynamics and Material Conf.*, Lake Tahoe, 1983, pp. 448–456.

[4] A.O. Bolukbasi and D.H. Laananen, Nonlinear finite element method in crashworthiness analysis of aircraft seats, *J. of Aircraft* **21** (1984), 512–519.

[5] H.C. Briggs, Evaluation of flutter impact for repaired T-38 stabilizers, in: *25th Structures, Structural Dynamics and Material Conf.*, Palm Springs, 1984, pp. 67–72.

[6] J.R. Brooks and L.A. Anderson, Dynamics of a space module impacting water, *J. of Spacecraft and Rockets* **31** (1994), 509–515.

[7] F. Buchhardt et al., A nonlinear 3D containment analysis for airplane impact, in: *7th Int. Conf. Structural Mechanics in Reactor Technology*, Chicago, 1983, pp. J9/6.

[8] H.D. Carden, A review of crash-related analyses conducted at NASA's Langley Research Center, in: *6th Int. Conf. Vehicle Structural Mechanics*, Detroit, SAE P-178, 1986, pp. 179–192.

[9] J.F. Chedmail et al., Equivalent loading of airplane impact taking into account the non-linearities of impacted reinforced concrete building, in: *7th Int. Conf. Structural Mechanics in Reactor Technology*, Chicago, 1983, pp. J9/3.

[10] J.D. Cronkhite and L.T. Burrows, Crashworthiness of helicopter composite structures, in: *Proc. National Special Meeting on Composite Structures*, American Helicopter Soc., 1983.

[11] R. Danisch et al., Analysis of pile-soil-structure interaction for aircraft impact, in: *7th Int. Conf. Structural Mechanics in Reactor Technology*, Chicago, 1983, pp. K11/4.

[12] A. De Rouvray et al., Numerical techniques and experimental validations for industrial applications, in: *Structural Impact Crashworthiness*, G.A. Davies, ed., Elsevier, Amsterdam, 1984, pp. 193–242.

[13] E. Deletombe et al., Different engineering methodologies for crash analysis of commercial aircraft structures, in: *Numerical Methods in Engineering '92*, C. Hirsch et al., eds, Elsevier, 1992, pp. 667–673.

[14] T.B. Dewhurst, Impact load on containment rings during a multiple blade shed in aircraft gas turbine engines, in: *Int. Gas Turbine and Aeroengine Cong. Expo.*, Orlando, 1991, 7 p.

[15] T.B. Dewhurst and P. Tang, Use of imposed displacements to determine impact forces in a multiple blade shed incident, in: *Int. Gas Turbine and Aeroengine Cong. Expo.*, Cincinnati, 1993, pp. GT-127.

[16] U. Edlund, A coupled elastic-plastic damage model and its application to impact problems, in: *3rd World Congress on Computational Mechanics*, Chiba, Japan, 1994, pp. K7–2.

[17] E.L. Fasanella et al., Structural analysis of the controlled impact demonstration of a jet transport airplane, in: *27th Structures, Structural Dynamics and Material Conf.*, San Antonio, 1986, pp. 324–332.

[18] E.L. Fasanella et al., Structural analysis of the controlled impact demonstration of a jet transport airplane, *J. of Aircraft* **24** (1987), 274–280.

[19] E.L. Fasanella et al., Crash simulation of an unmodified Lear fan fuselage section vertical drop test, in: *Ann. Forum Proc.-Am. Helicopter Soc.*, Washington, 1998, pp. 305–313.

[20] D.C. Fleming and A.J. Vizzini, Off-axis energy absorption characterization of composites for crashworthy rotorcraft design, *J. of the American Helicopter Society* **41** (1996), pp. 239–246.

[21] S. Gomathinayagam et al., Damage-zones of containment structures under aircraft impact loads, *Computers & Structures* **52** (1994), 581–590.

[22] Y. Gong, Crashworthiness design and analysis of aircraft structures, in: *1st Int. Conf. Engineering Computation and Computer Simulation*, Changsha, China, 1995, pp. 94–101.

[23] J.L. Handrock and L.I. Weingarten, Reentry vehicle response to impacts with rigid targets, in: *1994 Pressure Vessel and Piping Conf.*, **PVP 272**, 1994, pp. 225–231.

[24] J.L. Hart, MAGNA analysis of the T-38 aircraft student canopy response to in-flight aerodynamic pressure loads, in: *AIAA/AHS/ASEE Aircraft Design and System Operations*, San Diego, 1984.

[25] E. Haug et al., Static and dynamic finite element analysis of structural crashworthiness in the automotive and aerospace industries, in: *Structural Crashworthiness*, N. Jones, ed., Butterworth, 1983.

[26] R.J. Hayduk et al., Application of the non-linear finite element computer program DYCAST to aircraft crash analysis, in: *Structural Crashworthiness*, N. Jones, ed., Butterworth, 1983, pp. 283–307.

[27] D. Isobe and M. Morishita, Impact analysis of space structure due to collision with hypervelocity space debris by using ASI-FEM, in: *4th World Congress on Computational Mechanics*, Buenos Aires, 1998, pp. 284.

[28] K.E. Jackson and E.L. Fasanella, Innovative composite fuselage design for improved crashworthiness, in: *Ann. Forum Proc.-Am. Helicopter Soc.*, Washington, 1998, pp. 350–361.

[29] A.F. Johnson et al., Predictive methodologies for the crashworthiness of aircraft structures, in: *52nd Ann. Forum-Am. Helicopter Soc.*, 1996, pp. 1340–1352.

[30] M.F. Kanninen and P.E. O'Donoghue, Research challenges arising from current and potential applications of dynamic fracture mechanics to the integrity of engineering structures, *Int. J. of Solids and Structures* **32** (1995), 2423–2445.

[31] J.A. Keller et al., Experimental/theoretical correlation of analysis for helicopter rotor blade/droop stop impacts, in: *38th Structures, Structural Dynamics and Material Conf.*, Kissimmee, 1997, pp. 345–357.

[32] J.H. Kerr and E.P. Fahrenthold, Three dimensional hypervelocity impact simulation for orbital debris shield design, *Int. J. of Impact Engineering* **20** (1997), 479–489.

[33] Y.A. Khulief and H.T. Chiu, Transient dynamics of aircraft propellers during touch-down impact, *Computers & Structures* **31** (1989), 413–419.

[34] C.M. Kindervater, Aircraft and helicopter crashworthiness: design and simulation, in: *Crashworthiness of Transportation Systems*, J.A.C. Ambrosio, ed., NATO ASI, 1997, pp. 525–577.

[35] D. Kohlgrueber and A. Kamoulakos, Validation of numerical simulation of composite helicopter sub-floor structures under crash loading, in: *Ann. Forum Proc.-Am. Helicopter Soc.*, Washington, 1998, pp. 340–349.

[36] Y. Kuwabara et al., Study on modeling technique of structures subjected to aircraft impact, in: *9th Int. Conf. Structural Mechanics in Reactor Technology*, Balkema, 1987, pp. J301–306.

[37] M. Lawson, Engine structural dynamics for aircraft safety on the CRAY, in: *Science and Engineering on Supercomputers*, E.J. Pitcher, ed., Springer, 1990, pp. 265–271.

[38] D. Liebe et al., Application of MSC/DYNA to shock and impact problems in aircraft industry, in: *18th MSC NASTRAN User Conf.*, 1991.

[39] J. Marco, Shock loading on a wing type structure, in: *5th Austral. Aeronautical Conf.*, Melbourne, 1993, pp. 301–307.

[40] R.E. McCarty et al., Three dimensional nonlinear dynamic finite element analysis for the response of a thick laminated shell to impact loads, in: *26th Structures, Structural Dynamics and Material Conf.*, Orlando, Part 2, 1985, pp. 341–356.

[41] J. Mens and J.C. Bianchini, Computer codes for development of helicopter crashworthy structures and test substantiation, in:*AHS/NAI Int. Seminar*, Nanjing, China, 1985.

[42] H. Moore et al., Integration of a crashworthy troop seat system into the CH-53D sea stallion, in: *Ann. Forum Proc.-Am. Helicopter Soc.*, Washington, 1998, pp. 314–332.

[43] G.C. Nayak et al., Axi-symmetric aircraft crash upon a containment structure, in: *3rd World Congress on Computational Mechanics*, Chiba, Japan, 1994, pp. N5–3.

[44] A.B. Pifko and R. Winter, Theory and application of finite element analysis to structural crash simulation, *Computers & Structures* **13** (1981), 277–285.

[45] S. Sarkar and S.N. Atluri, Effects of multiple blade interaction on the containment of blade fragments during a rotor failure, *Finite Elements in Analysis and Design* **23** (1996), 211–223.

[46] R.J. Scavuzzo et al., Impact ice stresses in rotating airfoils, *J. of Aircraft* **28** (1991), 450–455.

[47] S.B. Segletes and J.A. Zukas, Hypervelocity impact simulations of whipple shields, in: *17th Space Simulation Conf.*, Baltimore, MD, 1992.

[48] H. Senf et al., Experimental and numerical investigations concerning the dynamics of penetration processes, in: *Topic Conf. Shock Waves Cond. Matter.*, Menlo Park, CA, 1981.

[49] W. So and E.C. Francis, Dynamic finite element analysis of solid propellant impact test, *J. of Spacecraft and Rockets* **28** (1991), 658–662.

[50] T. Sugano et al., Local damage to reinforced concrete structures caused by impact of aircraft engine missiles, Part 2 – Evaluation of test results, *Nuclear Engineering and Design* **140** (1993), 407–423.

[51] D.W. Tennant et al., Comparison of crash computations using different constitutive relations for validation of aircraft crash models, in: *1996 ASME Pressure Vessel and Piping Conf.* **PVP 325**, 1996, pp. 95–104.

[52] R.C. Tennyson et al., Study of the crashworthiness of light aircraft structures, in: *22nd Structures, Structural Dynamics and Material Conf.*, Atlanta, Georgia, 1981, pp. 276–285.

[53] D.E. Thomson et al., Foreign object impact assessment of a high-Mach engine inlet, in: *34th Structures, Structural Dynamics and Material Conf.*, La Jolla, 1993, pp. 2848–2855.

[54] R.G. Thomson and C. Caiafa, Designing for aircraft structural crashworthiness, *J. of Aircraft* **19** (1982), 868–874.

[55] R.G. Thomson et al., Research at NASA on crash dynamics, in: *Structural Impact Crashworthiness*, G.A. Davies, ed., Elsevier, 1984, pp. 1–43.

[56] S. Wang, Finite element analysis for shock absorbers of pilot seats, *Computers & Structures* **28** (1988), 217–222.

[57] T.M. Wasfy and A.K. Noor, Computational procedure for simulating the contact/impact response in flexible multibody systems, *Computer Methods in Applied Mechanics and Engineering* **147** (1997), 153–166.

[58] R. Winter and A.B. Pifko, Finite element crash analysis of automobiles and helicopters, in: *Structural Impact Crashworthiness*, G.A. Davies, ed., Elsevier, 1984, pp. 278–309.

[59] R. Winter et al., Crash simulation of composite and aluminum helicopter fuselages using a finite element program, *J. of Aircraft* **17** (1980), 591–597.

[60] S.C. Wu and G.S. Chen, Contact-impact analysis of deployable space systems, in: *34th Structures, Structural Dynamics and Material Conf.*, La Jolla, 1993, pp. 2058–2068.

[61] G.Q. Zhu et al., Modelling strength degradation of hypervelocity impacted windows for the space shuttle, *Ceramic Engineering Science Proc.* **18** (1997), 447–454.

[62] T. Zimmermann et al., Aircraft impact on reinforced concrete shells. Influence of material nonlinearities on equipment response spectra, *Computers & Structures* **13** (1981), 263–274.

[63] J.A. Zukas and S.B. Segletes, Hypervelocity impact on space structures, in: *Symp. Dynamic Response on High Energy Excitation*, ASME, **225**, 1991, pp. 65–71.

Automobile crashworthiness

[64] T. Acharnhorst et al., Zur Aussagekraft von Berechnungsmethoden für die Simulation des Crashverhaltens von Automobilen, Verein Deutscher Ingenieure, Wurzburg, 1986.

[65] C. Albertini et al., Precision measurements of vehicle crashworthiness by means of a large Hopkinson bar, *J. of Physics IV* **7** (1997), 79–84.

[66] S. Ando et al., Crash simulation methods for vehicle development at Mazda, in: *Science and Engineering on Supercomputers*, E.J. Pitcher, ed., Springer, 1990, pp. 475–482.

[67] J.H. Argyris et al., Computer simulation of crash phenomena, *Int. J. for Numerical Methods in Engineering* **22** (1986), 497–519.

[68] T. Ariyoshi, Development of a beam element model for an analysis of a motor vehicle rear end crash, *SAE Trans.*, 1990, 900463.

[69] M. Bahrami and A. Habib Nia, Finite element modeling of front end crash of a jeep type vehicle, in: *Design: Analysis, Synthesis and Applications*, London, **PD 64**, ASME, 1994, pp. 23–25.

[70] K.J. Bathe et al., Advances in nonlinear finite element analysis of automobiles, *Computers & Structures* **64** (1997), 881–891.

[71] D. Beaudry et al., The application of finite element modeling in the design of a crash attenuation system for a lightweight commuter car, in: *1989 Int. ANSYS Conf.*, D.E. Dietrich, ed., SAS, 1989, pp. F 11.

[72] T. Belytschko et al., Adaptivity in crashworthiness calculations, in: *Winter Ann. Meet.*, New Orleans, **AMD 169**, ASME, 1993, pp. 53–65.

[73] D.J. Benson et al., The application of DYNA3D in large scale crashworthiness calculations, in: *ASME Int. Computers in Engineering Conf.*, Vol. 1, Chicago, 1986.

[74] D.M. Bhalsod, On analytical approaches in crash simulation, *SAE Trans.*, 1989, 891975.

[75] D. Bigi et al., Stochastic analysis of crash problems by response surface techniques, in: *Comp. Tech. Contact Impact Penetration Performances*, **AMD 103**, ASME, 1989, pp. 31–40.

[76] C. Boneill and J.P. Mizzi, Identification of parameters for a vehicle submitted to a crash, in: *14th Bienn. ASME Conf. Mechanical Vibration and Noise*, **DE 56**, 1993, pp. 245–257.

[77] J. Bonini et al., Multimaterial joints under dynamic loading behaviour of the windscreen during a car crash: numerical determination of industrial tests, in: *Computational Methods and Experimental Measurements VI*, C.A. Brebbia, ed., CMP, 1993, pp. 353–364.

[78] R. Brasche and G. Giazitzis, On the collapse made of body structures under impact conditions, in: *XXI FISITA Cong.*, Belgrade, 1986, Paper No 865074.

[79] G. Bretz and R. Schwarz, Berechnung eines PKW-Frontalcrash für ein Fahrzeug mit langsliegendem Aggregat und Standardantrieb, IABG Rep. B-TF-2015, Ottobrun, Germany, 1986.

[80] G. Bretz et al., Berechnung eines frontalen Crashvorganges bei einer heckangetriebenen Limousine, in: *Proc. VDI Conf.-Berech. Automobilbau*, Wurzburg, Germany, 1986, pp. 507–525.

[81] A.L. Browne and T.B. Khalil, Windshield impact response: a finite element model, in: *Crashworthiness and Occupation Protection in Transportation Syst.*, **AMD 106**, ASME, 1989, pp. 59–71.

[82] S.M. Calso et al., Simulation of offset and in-line car to car rear impacts, in: *Winter Ann. Meet.*, New Orleans, **AMD 169**, ASME, 1993, pp. 149–160.

[83] F. Casciati and L. Faravelli, Randomness effects in crashworthiness analysis, *Int. J. of Non-Linear Mechanics* **26** (1991), 827–834.

[84] J.F. Chedmail et al., Numerical techniques, experimental validation and industrial applications of structural impact and crashworthiness analysis with supercomputers, in: *Supercomputer Applications in Automotive Research and Engineering Development*, Comp. Mech. Publ., 1986, pp. 127–145.

[85] C.C. Chou et al., Review of mathematical models for rollover simulations, in: *1998 ASME Int. Mechanical Engineering Cong. Expo.*, **AMD 230**, 1998, pp. 223–239.

[86] J. Crouzet-Pascal et al., Crash resistance of curved thin-walled beams, in: *Recent Advances in Engineering Mechanics in Civil Eng. Practice*, ASCE, 1983, pp. 656–659.

[87] B. Dandekar and V.T. Van, Transient dynamic analysis of an automotive bumper system, in: *8th Int. Conf. Vehicle Structural Mechanics*, SAE, 1992, pp. 129–145.

[88] Y.C. Deng and B. Tzeng, Side impact countermeasure study using a hybrid modeling technique, in: *40th Stapp Car Crash Conf.*, P-305, 1996, pp. 43–50.

[89] J. Doong and J.C. Cheng, Computer simulations for frontal impact, in: *ASME Int. Computers in Engineering Conf. Exhib.*, ASME, 1994, pp. 597–605.

[90] P. DuBois and A. Kaiser, A review of numerical simulation applied to automotive crashworthiness, in: *4th KIA Int. Academic Seminar on Automotive Technology*, Seoul, 1991.

[91] R.A. Dusseau et al., Structural responses of transit buses: impact of wheelchair loads, *Transport Research Record*, No 1521, 1996, pp. 137–146.

[92] R. Farooq, Front end design of aluminum vehicle for crashworthiness, in: *1998 ASME Int. Mechanical Engineering Cong. Expo.*, **AMD 230**, 1998, pp. 31–43.

[93] E. Fiala and U. Sorgatz, Modern methods for car body design, *Stahl Eisen* **106** (1986), 661–667.

[94] U.N. Gandhi and S.J. Hu, Data based models for automobile side impact analysis and design evaluation, *Int. J. of Impact Engineering* **18** (1996), 517–537.

[95] V. Giavotto, Crash simulation models and interactions with experiments, AGARD-Rep. No 737, 1986, pp. 3.1–10.

[96] V. Giavotto et al., Vehicle dynamics and crash dynamics with minicomputer, *Computers & Structures* **16** (1983), 381–393.

[97] K. Gruber and T. Frank, Numerical simulation of the frontal impact with total and partial overlap of the front end, in: *Science and Engineering on Supercomputers*, E.J. Pitcher, ed., Springer, 1990, pp. 219–231.

[98] K. Gruber et al., Computer simulation of side impact using different mobile barriers, SAE Paper 910323, 1991.

[99] I. Hagiwara et al., Study of an analytical technique and system for conducting vehicle crash simulation, in: *Comp. Appl. in Automotive Industry*, M.A. Dorgham, ed., Interscience, 1989, pp. 203–221.

[100] I. Hagiwara et al., Simulation of automobile side member collapse for crash energy management, *Int. J. of Supercomputer Applications* **4** (1990), 107–114.

[101] I. Hagiwara et al., Dynamic analysis of thin-walled box columns subjected to axial crushing using the finite element method, *JSME Int. J.*, Series I, **33** (1990), 444–452.

[102] I. Hagiwara et al., Study of an analytical technique and system for conducting vehicle crash simulations, *Int. J. of Vehicle Design* **11** (1990), 564–577.

[103] E. Haug, FEM-CRASH: Berechnung eines Fahrzeugfrontalaufpralls, Verein Deutscher Ingenieure, Wurzburg, Germany, 1986.

[104] E. Haug et al., Static and dynamic finite element analysis of structural crashworthiness in the automotive and aerospace industries, in: *Structural Crashworthiness*, N. Jones, ed., Butterworth, 1983.

[105] E. Haug et al., Numerical crashworthiness simulation of automotive structures and components made of continuous fiber reinforced composite and sandwich assemblies, in: *Int. Congress and Exposition*, Detroit, SAE Paper 910152, 1991.

[106] E. Haug et al., Recent trends and developments of crashworthiness simulation methodologies and their integration into the industrial vehicle design cycle, in: *3rd Europ. Cars/Trucks Simulation Symp.*, ASIMUTH, 1991.

[107] E. Haug et al., Recent trends and advances in crash simulation and design of vehicles, in: *Crashworthiness of Transportation Syst.*, J.A.C. Ambrosio, ed., NATO ASI, 1997, pp. 401–417.

[108] R.J. Haydluk et al., Nonlinear structural crash dynamic analyses, *SAE Trans.*, 1980, Paper 790588.

[109] W. Jarzab, Mathematical modeling and applications in crash analysis, in: *Supercomputer Applications in Automotive Research and Engineering Development*, CMP, Southampton, 1986.

[110] W. Jarzab et al., Numerical simulation and experimental validation in crashworthiness applications, in: *Structural Design and Crashworthiness of Automobiles*, T.K.S. Murthy, ed., Springer, 1987, pp. 1–16.

[111] H. Jia et al., Crash simulation and parameters selection of typical thin walled beam-type vehicle structures, *Trans. Chinese Soc. Agricult. Mach.* **29** (1998), 24–28.

[112] J.P. Johnson and M.J. Skynar, Automotive crash analysis using the explicit integration finite element method, in: *Crashworthiness and Occupant Protection in Transportation Syst.*, **AMD 106**, ASME, 1989, pp. 27–32.

[113] A. Kaiser et al., Interaktionsprobleme auf dem Gebiet der Crashsimulation, VDI Tagung Berechnung im Automobilbau, Wurzburg, Germany, 1990.

[114] M.A. Kapadia and R.T. Eifert, Evolution of the new Ford aerostar impact extruded aluminum wheel, *SAE Trans.* **93** 1984, Paper 841694.

[115] T. Kashiwamura et al., Study on impact behavior of automobile seat, *Trans. of the Japan Society of Mechanical Engineers*, Ser. A, **63** (1997), 624–629.

[116] M. Kaufman et al., Integration of chassis frame forming analysis into performance models to more accurately evaluate crashworthiness, *SAE Spec. Publ.* **1321**, 1998, pp. 119–122.

[117] C.F. Kearns, Application of computational plasticity to the analysis of vehicle cab frames, *Engineering Computations* **4** (1987), 243–246.

[118] D. Kecman, Engineering approach to crashworthiness of thin-walled beams and joints in vehicle structures, *Thin-Walled Structures* **28** (1997), 309–320.

[119] D. Kecman and M. Sadeghi, The compound beam element with non-linear moment-rotation curves for the side impact and roof crush analysis using DYNA3D program, in: *8th Int. Conf. Vehicle Structural Mechanics*, SAE, 1992, pp. 85–97.

[120] R.W. Kent and C.E. Stroher, Wooden pole fracture energy in vehicle impacts, *SAE Spec. Publ.* **1321**, 1998, pp. 33–46.

[121] T.B. Khalil and J.A. Bennett, Nonlinear finite element analysis in crashworthiness of automotive shell structures. An overview, in: *Winter Ann. Meet.*, San Francisco, ASME, 1989, pp. 569–582.

[122] T.B. Khalil and D.A. Vander Lugt, Identification of vehicle front structure crashworthiness by experiments and finite element analysis, in: *Crashworthiness and Occupant Protection in Transport. Systems*, **AMD 106**, ASME, 1989, pp. 41–51.

[123] Y. Kitagawa et al., Development of a collapse mode control method for side members in vehicle collisions, SAE Paper 910809, 1991.

[124] Y. Kitagawa et al., Dynamic analysis of thin-walled columns with arbitrary section geometry subjected to axial crushing, *JSME Int. J.*, Ser. I, **35** (1992), 189–193.

[125] E. Larrode et al., Crash behaviour of components for the automotive industry: an application (Part 2), *Engineering Plastics* **9** (1996), 14–37.

[126] J.H. Leach, Practical tools for vehicle impact simulation, Part 1: Vehicle impact simulation in Rover group, *Proc. of the Institution of Mechanical Engineers*, D, **205** (1991), 13–16.

[127] J.E. Leland et al., Designing for impact resistance with new high strength PPS compounds, *SAE Trans.*, **98**, 1989, Paper 890444.

[128] D.A.V. Lugt et al., Passenger car frontal barrier simulation using nonlinear finite element methods, in: *7th Int. Conf. Vehicle Structural Mechanics*, **SAE P-210**, 1988, pp. 267–271.

[129] H.F. Mahmood and A. Paluszny, Analytical technique for simulating crash response of vehicle structures composed of beam elements, in: *6th Int. Conf. Vehicle Structural Mechanics*, Detroit, **SAE P-178**, 1986, pp. 277–287.

[130] H.F. Mahmood et al., On the front end design of automotive vehicle for crashworthiness, in: *Winter Ann. Meet.*, New Orleans, **AMD 169**, ASME, 1993, pp. 311–318.

[131] G.T. Mase and K.H. Lin, Probabilistic analysis of vehicle crashworthiness using a fast probability integrator, in: *Winter Ann. Meet.*, New Orleans, **AMD 169**, ASME, 1993, pp. 47–51.

[132] M. Mazurkiewicz and Y.L. Tien, Crash simulation of bumpers, *Computers & Structures* **26** (1987), 741–747.

[133] B.E. McClelland, Methodology for simulating roadwheel impact to a vehicle and determining an equivalent static load, *SAE Trans.*, 1984, Paper 841205.

[134] R.J. Melosh, Computer resources for FEA of vehicle crash, in: *5th Int. Conf. Vehicle Structural Mechanics*, Detroit, 1984, pp. 1–21.

[135] D. Meravides and M. Turbin, Dynamic impact comparisons between experimental and theoretical results obtained with DYNA-3D, *FEN*, No 1 (1986), 16–19.

[136] J.C. Miles et al., Practical tools for vehicle impact simulation. Part 2: An integrated approach using OASYS DYNA3D, *Proc. of the Institution of Mechanical Engineers*, D, **205** (1991), 95–100.

[137] A. Miravete et al., Crash behaviour of components for the automotive industry: background (Part 1), *Engineering Plastics* **9** (1996), 1–18.

[138] C.W. Mousseau and G.M. Hulbert, An efficient tire model for the analysis of spindle forces produced by a tire impacting large obstacles, *Computer Methods in Applied Mechanics and Engineering* **135** (1996), 15–34.

[139] C.W. Mousseau and G.M. Hulbert, The dynamic response of spindle forces produced by a tire impacting large obstacle in a plane, *J. Sound Vib.* **195** (1996), 775–796.

[140] T.K.S. Murthy and C.A. Brebbia, eds., *Structural Design and Crashworthiness of Automobiles*, Springer-Verlag, Berlin, 1987.

[141] K. Nakagawa and T. Ootsubo, Crash simulation of a passenger car, in: *SAE Spec. Publ.*, No 820, Detroit, 1990, pp. 51–56.

[142] K. Nakamura and Y. Wakasa, Analytical technique for predicting crash response of car body structural components and its application, *SAE Trans.* **93** (1984), Paper 840450.

[143] E. Nalepa, Crash worthiness simulation of the Opel Vectra using the explicit FE-method, in: *Vehicle Design of Components: Comp. Appl. Automot.*, Geneva, 1989, pp. 191–201.

[144] E. Nalepa, Crash-worthiness simulation of Opel Vectra using the explicit finite element method, *Int. J. of Vehicle Design*, **11** (1990), 160–165.

[145] P. Ng and G.H. Tidbury, The development of a vehicle angled side collision computer simulation program, in: *6th Int. Conf. Vehicle Structural Mechanics*, Detroit, 1986, pp. 199–208.

[146] L. Nilsson, Computational crash analysis at the Saab Car Division, in: *12th Int. Tech. Conf. Expo. Safety Vehicles*, Gothenburg, Sweden, 1989.

[147] I. Nishimura and T. Sakurai, Prediction of the crashworthiness of vehicle body aided computer, in: *6th Int. Pacific Conf. Automotive Engineering*, Seoul, 1991, pp. 1111–1120.

[148] T.A. Omar et al., Crash analysis of two vehicles in frontal impact using adaptive artificial neural networks, in: *1998 ASME Int. Mechanical Engineering Cong. Expo.*, **AMD 230**, 1998, pp. 115–129.

[149] K.H. Park et al., Application of the finite element method for improvement of vehicle crashworthiness, in: *6th Int. Pacific Conf. Automotive Engineering*, Seoul, 1991, pp. 1123–1131.

[150] M. Philipps et al., Structural analysis and testing of composites in automotive crashworthiness application, *SAE Spec. Publ.* **1320**, 1998, pp. 97–101.

[151] A.B. Pifko and R. Winter, Theory and application of finite element analysis to structural crash simulation, *Computers & Structures* **13** (1981), 277–285.

[152] A.J. Regan and R. Winter, Nonlinear finite element crash analysis of a minivan, in: *Computational Mechanics '86*, G. Yagawa and S.N. Atluri, eds, Springer, 1986, pp. VI-223.

[153] J.D. Reid, Towards the understanding of material property influence on automotive crash structures, *Thin-Walled Structures* **24** (1996), 285–313.

[154] L.C.H. Ricardo, The use of plasticity theories to understand the behavior of automotive crash analysis, in: *5th Int. Conf. on Computational Plasticity*, D.R.J. Owen, ed., CIMNE, 1997, pp. 1949–1956.

[155] M. Riesner et al., Computer simulation of wheel impact test, in: *6th Int. Conf. Vehicle Structural Mechanics*, Detroit, **SAE P-178**, 1986, pp. 269–275.

[156] N.K. Saha et al., Frontal offset pole impact simulation of automotive vehicles, in: *1992 ASME Int. Computers in Engineering Conf. Exhib.*, San Francisco, 1992, pp. 203–207.

[157] R.K. Sarkar, Strategies for calculation car-crash, in: *XVth Int. FEM Cong.*, IKOSS, Baden-Baden, Germany, 1986.

[158] T. Scharnhorst and Schettler-Kohler, FEM-CRASH experiences at Volkswagen research, in: *Supercomputer Applications in Automotive Research and Engineering Development*, Comp. Mech. Publ., Southampton, 1986, pp. 75–86.

[159] E. Schelkle, Die Berechnung eines Fahrzeuglangstragers mit Hilfe des nichtlinearen Finite Element Programms ABAQUS, in: *Konf. Finiten Elementberechn. Automobil.*, Frankfurt, Germany, 1983.

[160] R. Schettlerkohler et al., Finite element model of lateral collisions as a tool for motor-vehicle design, in: *Development of Modern Automobile Body Construction*, VDI Ber., **818**, 1990, pp. 121–142.

[161] K. Schweizerhof et al., Crashworthiness analysis in the automotive industry, *Int. J. of Computer Applications in Technology* **5** (1992), 134–156.

[162] V. Sharma et al., Mathematical modeling of bus rollover crashes, in: *1998 ASME Int. Mechanical Engineering Cong. Expo.*, **BED 39**, 1998, pp. 9–10.

[163] M.Y. Sheh et al., Vehicle crashworthiness analysis using numerical methods and experiments, in: *8th Int. Conf. Vehicle Structural Mechanics*, SAE, 1992, pp. 119–128.

[164] M.B. Shkolnikov et al., On analytical approaches in crash simulation, *SAE Trans.*, **98**, 1989, Paper 891975.

[165] K. Shoshida et al., Rear crash simulation of car, *FEN* (1986), 18–22.

[166] J. Sielaff and L. Recke, Simplified finite element model of the crashworthiness of a car in the pre-design stage, in: *Development of Modern Automobile Body Construction*, VDI Ber., **818**, 1990, pp. 187–208.

[167] P. Smolinski, Recent developments in finite element methods for the analysis of automobile crashworthiness, in: *108th Winter Annual Meet.*, ASME, Boston, 1987.

[168] J. Stanger et al., A numerical simulation of the proposed European side impact test procedure, in: *Supercomputer Applications in Automotive Research and Engineering Development*, C. Marino, ed., CMP, Southampton, 1988.

[169] J.G. Thacker et al., Experiences during development of a dynamic crash response automobile model, *Finite Elements in Analysis and Design* **30** (1998), 279–295.

[170] G.H. Tidbury, Structural impact analysis in design for safety, in: *Structural Design and Crashworthiness of Automobiles*, T.K.S. Murthy, ed., Springer, 1987, pp. 17–33.

[171] A. Toyama et al., Numerical analysis of vehicle frontal crash phenomena, in: *Int. Congr. Expos.*, SAE Tech. Paper, Detroit, 1992, pp. 143–154.

[172] B.D. Walker et al., Vehicle crashworthiness from lumped parameter to continuum models, in: *Winter Ann. Meet.*, New Orleans, **AMD 169**, ASME, 1993, pp. 67–82.

[173] C. Wang et al., Study of crashworthiness of vehicle frame by using finite element methods, *Automotive Eng.* **19** (1997), 336–341.

[174] R.G. Whirley and B.E. Engelmann, Automatic contact in DYNA3D for vehicle crashworthiness, in: *Winter Ann. Meet.*, New Orleans, **AMD 169**, ASME, 1993, pp. 15–29.

[175] R. Winter and A.B. Pifko, Finite element crash analysis of automobiles and helicopters, in: *Structural Impact Crashworthiness*, G.A. Davies, ed., Elsevier, 1984, pp. 278–309.

[176] R. Winter et al., Finite element crash analysis of a rear-engine automobile, in: *4th Int. Conf. Vehicle Structural Mechanics*, Detroit, 1981.

[177] R. Winter et al., Front crash analysis of a steel frame auto using a finite-element computer code, in: *5th Int. Conf. Vehicle Structural Mechanics*, Detroit, 1984.

[178] H. Yamaoka et al., Computer simulation of automotive body crash response, *SAE Trans.*, **94**, 1985, Paper 851685.

[179] K.S. Yeung et al., A simplified approach for non-linear impact analysis of vehicle bumpers, in: *5th Int. Conf. Vehicle Structural Mechanics*, Detroit, 1984, pp. 23–44.

[180] Z.H. Zhong, Crashworthiness analysis of shell structures using the finite element method, in: *Struct. Shock Impact*, Comp. Mech. Publ., Southampton, 1989, pp. 289–300.

Vehicle rail structures crashworthiness

[181] C. Andersson and T. Dahlberg, Wheel/rail impacts at a railway turnout crossing, *Proc. of the Institution of Mechanical Engineers*, Part F, **212** (1998), 123–134.

[182] R.J.M. Dodd and G.A. Scott, Elastic-plastic collapse of a rail vehicle body end, in: *Structural Impact Crashworthiness*, G.A. Davies, ed., Elsevier, 1984, pp. 771–782.

[183] R.G. Dong and S. Sankar, Characteristics of impact loads due to wheel tread defects, in: *1994 Int. Mechanical Engineering Cong. Expo.*, **RTD 8**, ASME, 1994, pp. 23–30.

[184] H.A. Lupker, LPG rail tank cars under head-on collisions, *Int. J. Impact Engng.* **9** (1990), 359–376.

[185] A. Marissal et al., Crash behavior of guided vehicles, *GEC ALSTHOM Tech. Rev.*, No 9 (1992), 55–62.

[186] M.S. Pereira et al., Crashworthiness analysis and design using rigid-flexible multibody dynamics with application to train vehicles, *Int. J. for Numerical Methods in Engineering* **40** (1997), 655–687.

[187] G.A. Scott, Development of a theoretical technique for rail vehicle structural crashworthiness, *Proc. of the Institution of Mechanical Engineers*, Part D, **201** (1987), 123–128.

[188] M.Y. Sheh and T.B. Khalil, The impact response of a vehicle rail structure by experiments and finite element analysis, in: *Crashworthiness and Occupant Protection in Transport. Systems*, Atlanta, 1991, pp. 195–206.

Aircraft-birdstrike impact problems

[189] T.V. Baughn and L. W. Graham, Simulation of a birdstrike impact on aircraft canopy material, *J. of Aircraft* **25** (1988), 659–664.

[190] R.R. Boroughs, High speed bird impact analysis of the Learjet 45 windshield using DYNA3D, in: *39th Structures, Structural Dynamics and Material Conf. Exh.*, Long Beach, CA, 1998, pp. 49–59.

[191] R.A. Brockman, Finite element analysis of soft-body impact, Flight Dynam. Lab., AFWAL-TR-84-3035, WPAFB, 1984.

[192] R.A. Brockman, Computational methods for soft-body impact problems, in: *Computational Mechanics '88*, S.N. Atluri and G. Yagawa, eds, Springer, 1988, pp. 6vi.

[193] Y. Crutzen, Bird impact on aircraft windshield using ABAQUS, *FEN* (1984), 28–31.

[194] C.J.L. Florie et al., General 3-dimensional fluid-structure interaction applied in airbag and birdstrike analyses, in: *18th MSC NASTRAN User Conf.*, 1991.

[195] A. Letellier et al., Bird impact on fan blade analysis using smooth particle hydrodynamics coupled with finite elements, in: *1997 ASME Pressure Vessel and Piping Conf.*, **PVP 351**, 1997, pp. 191–195.

[196] N.F. Martin, Nonlinear finite element analysis to predict fan-blade damage due to soft-body impact, *J. Propulsion Power* **6** (1990), 445–450.

[197] R.E. McCarty, Finite element analysis of F-16 aircraft canopy dynamic response to bird impact loading, in: *21st Structures, Structural Dynamics and Material Conf.*, Seattle, 1980.

[198] R.E. McCarty, Aircraft transparency bird impact analysis using the MAGNA computer program, in: *Conf. Aerospace Transparency*, British Aerospace Co., London, 1980.

[199] R.E. McCarty, Finite element analysis of a bird-resistant monolithic stretched acrylic canopy design for the F-16 A aircraft, WPAFB, Ohio, 1981.

[200] R.E. McCarty, MAGNA computer simulation of bird impact on the TF-15 aircraft canopy, in: *14th Conf. Aerospace Transp. Mater. Encl.*, Scottsdale, 1983.

[201] R.E. McCarty, Aircraft transparency bird impact analysis using the MAGNA computer program, in: *Conf. Train Wildlife Hazards Aircraft*, Charleston, 1984.

[202] R.E. McCarty and J.L. Hart, Validation of the MAGNA computer program for nonlinear finite element analysis of aircraft transparency bird impact, in: *14th Conf. Aerosp. Transp. Mater. Encl.*, Scottsdale, 1983.

[203] E. Niering, Simulation of bird strikes on turbine engines, in: *J. of Engineering for Gas Turbines and Power* **112** (1990), 573–578.

[204] R.P. Nimmer and L. Boehman, Transient, nonlinear response analysis of soft bodied impact on flat plates including interactive load determination, in: *22nd Structures, Structural Dynamics and Material Conf.*, 1981, pp. 0621-CP.

[205] W. Schuette, Blade behaviour during birdstrike, in: *Science and Engineering on Supercomputers*, E.J. Pitcher, ed., Springer, 1990, pp. 145–157.

[206] F. Stoll and R.A. Brockman, Finite element simulation of high-speed soft-body impacts, in: *38th Structures, Structural Dynamics and Material Conf.*, Kissimmee, 1997, pp. 334–344.

[207] A.F. Storace et al., Analytical and experimental investigation of bird impact on fan and compressor blading, in: *24th Structures, Structural Dynamics and Material Conf.*, Lake Tahoe, 1983, pp. 457–465.

[208] A.F. Storace et al., Analytical and experimental investigation of bird impact on fan and compressor blading, *J. of Aircraft* **21** (1984), 520–527.

[209] H.C. Teichman and R.N. Tadros, Analytical and experimental simulation of fan blade behavior and damage under bird impact, in: *Int. Gas Turbine Aeroengine Cong. Exp.*, Brussels, 1990, pp. 1–15.

[210] B.S. West, Development of bird impact resistant crew enclosures for aircraft, in: *Structural Impact Crashworthiness*, G.A. Davies, ed., Elsevier, 1984, pp. 696–709.

[211] M.R. Wisnom, Prediction of penetration of curved metal stiffened panels due to birdstrike, *Aeronautical J.* **94** (1990), 313–317.

Impact-induced injuries

[212] T.S. Atkinson et al., Impact-induced fissuring of articular cartilage: an investigation of failure criteria, *J. of Biomechanical Engineering, ASME* **120** (1998), 181–187.

[213] F.A. Bandak, On the mechanics of impact neurotrauma: a review and critical synthesis, *J. Neurotrauma* **12** (1995), 635–649.

[214] F.A. Bandak, Biomechanics of impact traumatic brain injury, in: *Crashworthiness of Transportation Systems*, J.A.C. Ambrosio, ed., NATO ASI, 1996, pp. 53–93.

[215] F.A. Bandak et al., An imaging-based computational and experimental study of skull fracture: finite element model development, *J. Neurotrauma* **12** (1995), 679–688.

[216] M. Beaugonin et al., Numerical model of the human ankle/foot under impact loading in inversion and eversion, in: *40th Stapp Car Crash Conf.*, No P-305, Albuquerque, 1996, pp. 239–249.

[217] P.G. Bedewi, The biomechanics of human lower extremity injury in the automotive crash environment, Ph.D. Thesis, The George Washington Univ., Washington, DC, 1998.

[218] P.G. Bedewi and N.E. Bedewi, Modeling of occupant biomechanics with emphasis on the analysis of lower extremity injuries, *Int. J. Crashworth.* **1** (1996), 50–72.

[219] F. Bermond et al., A finite element model of the pedestrian knee joint in lateral impact, in: *1993 Int. IRCOBI Conf. Biomech. Impacts*, Eindhoven, 1993, pp. 117–129.

[220] I.S. Bush and S.A. Challener, Finite element modeling of non-penetrating thoracic impact, in: *Int. IRCOBI Conf. Biomech. Impacts*, Berg Gladb, 1988, pp. 227–238.

[221] D.L. Camacho et al., Experimental flexibility measurements for the development of a computational head-neck model validated for near-vertex head impact, in: *41st Stapp Car Crash Conf.*, P-315, 1997, pp. 473–486.

[222] L.M.M. Careme, Thoracao-abdominal impact tolerance levels in side impact accidents – collection of field data and mathematical models, SAE Paper 890385, 1989.

[223] L.Y. Cheng et al., Finite element analysis of diffuse axonal injury, in: *Vehicle Crash Occupant Protection in Frontal Collision*, SAE, 1990, pp. 141–154.

[224] M. Claessans et al., Modeling of the human head under impact conditions: a parametric study, in: *41st Stapp Car Crash Conf.*, P-315, 1997, pp. 315–328.

[225] F. Dauvilliers et al., Development of a finite element model of the neck, in: *Proc. Stapp Car Crash Conf.*, SAE, 1994, pp. 77–91.

[226] M. De Jager et al., Three-dimensional head-neck model: validation for frontal and lateral impacts, in: *Proc. Stapp Car Crash Conf.*, SAE, 1994, pp. 93–109.

[227] M. De Jager et al., Global and detailed mathematical model for head-neck dynamics, in: *40th Stapp Car Crash Conf.*, Albuquerque, 1996, pp. 269–281.

[228] F. DiMasi et al., Simulated head impacts with upper interior structures using rigid and anatomic brain models, in: *Finite Elements in 90's*, E. Onate et al., eds, Springer, 1991, pp. 333–345.

[229] F.P. DiMasi, Three-dimensional finite element modeling of head impacts with vehicle upper interiors, Tech. Memo. No. TSC-HS-876-4, 1988.

[230] F.P. DiMasi et al., Computational analysis of head impact response under crash loadings, in: *Stapp Car Crash Conf.*, Coronado, CA, 1995, pp. 425–438.

[231] R.H. Eppinger, On the development of a deformation measurement system and its application toward developing mechanically based injury indices, SAE, Paper 892426, 1989.

[232] G.R. Erickson et al., Validated dynamic continuum finite element model representing a simplified cervical spine motion segment, in: *1997 Bioengineering Conf.*, **BED 35**, ASME, 1997, pp. 231–232.

[233] J.J. Garcia et al., Comparison of stresses in human and rabbit knees as they pertain to injuries observed during impact experiments, *1997 Bioengineering Conf.*, **BED 35**, ASME, 1997, pp. 315–316.

[234] J.J. Garcia et al., Approach for the stress analysis of transversely isotropic biphasic cartilage under impact load, *J. of Biomechanical Engineering, ASME* **120** (1998), 608–613.

[235] V.K. Goel and Y.E. Kim, Effects of injury on the spinal motion segment mechanics in the axial compression mode, *Clinical Biomechanics* **4** (1989), 161–167.

[236] V.K. Goel et al., Interlaminar shear stresses and laminae separation in a disc. Finite element analysis of the L3-L4 motion segment subjected to axial compressive loads, *Spine* **20** (1995), 689–698.

[237] S. Hayashi et al., Experimental and analytical study of knee fracture mechanisms in a frontal knee impact, in: *40th Stapp Car Crash Conf.*, No P-305, Albuquerque, 1996, pp. 161–171.

[238] R.R. Hosey, A homeomorphic finite element model of impact head injury, Ph.D. Dissertation, Tulane Univ., New Orleans, LA, 1980.

[239] R.R. Hosey and Y.K. Liu, A homeomorphic finite-element model of impact head and neck injury, in: *Int. Conf. Finite Elements in Biomechanics*, Tucson, 1980, pp. 851–870.

[240] R.R. Hosey and Y.K. Liu, A homeomorphic finite element model of the human head and neck, in: *Finite Elements in Biomechanics*, R.H. Gallagher, ed., Wiley, 1982, pp. 379–401.

[241] R.R. Hosey et al., A finite element analysis of crown impact using an initially straight head cervical spine body alignment, in: *Biomedical Engineering II*, C.W. Hall, ed., Pergamon Press, 1983, pp. 139–142.

[242] H. Hu et al., Modeling human brain movability effect on brain response during impact, in: *1998 ASME Int. Mechanical Engineering Cong. Expo.*, **AMD 230**, 1998, pp. 267–280.

[243] S.S. Jung, Development of translational head injury model (THIM) and translational energy criteria (TEC) of child, Ph.D. Thesis, The Ohio State Univ., 1992.

[244] H.S. Kang et al., Validation of a 3D anatomic human head model and replication of head impact in motorcycle accident by finite element modeling, in: *41st Stapp Car Crash Conf.*, P-315, 1997, pp. 329–338.

[245] A.I. King et al., Recent advances in biomechanics of brain injury research: a review, *J. Neurotrauma* **12** (1995), 651–658.

[246] M. Kleinberger, Application of finite element techniques to the study of cervical spine mechanics, in: *37th Stapp Car Crash Conf.*, San Antonio, TX, 1993.

[247] A.H. Kuijpers et al., The influence of different boundary conditions on the response of the head to impact: a two-dimensional finite element study, *J. Neurotrauma* **12** (1995), 715–724.

[248] S. Kumaresan and S. Radhakrishnan, Importance of partitioning membranes of the brain and the influence of the neck in head injury modelling, *Medical and Biological Engineering Computing*, **34** (1996), 27–32.

[249] E.A. Laabs et al., Fast path system: simplifying the task of identifying successful material/design combinations for energy management for automotive head impact requirements, *SAE Spec. Publ.* **1351**, 1998, pp. 85–92.

[250] E.S. Lee, A large-strain, transient-dynamic analysis of head injury problems by the finite element method, Ph.D. Thesis, Georgia Inst. of Technol., 1990.

[251] M.C. Lee et al., Finite element analysis of traumatic subdural hematoma, in: *31st Stapp Car Crash Conf.*, No 872201, SAE, 1987, pp. 67–77.

[252] S.P.G. Madabhushi et al., Finite element analyses of impacted allografts for total hip arthoplasty, in: *BIOSIM 96*, Merida, 1996, pp. 165–174.

[253] K. Mendis, Finite element modeling of the brain to establish diffuse axonal injury criteria, Ph.D. Thesis, The Ohio State Univ., 1992.

[254] W.N. Newberry and R.C. Haut, Effects of substructure impact loading on the patellofemoral joint in a rabbit model, in: *40th Stapp Car Crash Conf.*, No P-305, Albuquerque, 1996, pp. 149–159.

[255] T. Nishimoto and S. Murakami, Correlation between disturbance of consciousness and impact stress concentration of brain, *Trans. of the Japan Society of Mechanical Engineers*, Ser. C, **63** (1997), 715–722.

[256] T. Nishimoto et al., Stress distribution of brain under rotational impact (finite element analysis of diffuse axonal injury), *Trans. of the Japan Society of Mechanical Engineers*, Ser. A, **62** (1996), 2109–2115.

[257] G.S. Nusholtz and Y. Shi, Physical reality in FE head models: rotation and strain, *SAE Spec. Publ.*, **1355**, 1998, pp. 37–54.

[258] L.J. Ovenshire, Towards finite element crash injury analysis, in: *Int. Conf. Finite Elements in Biomechanics*, Tucson, 1980, pp. 69–82.

[259] H.S. Park and Y.S. Yoon, Application of linear biphasic theory to finite element analysis of head impulse loading, *Proc. of the Institution of Mechanical Engineers*, Part C, **211** (1997), 153–165.

[260] G. Plank and R. Eppinger, Computed dynamic response of the human thorax from a finite element model, in: *12th Int. Tech. Conf. ESV*, Goteborg, Sweden, 1989, pp. 665–672.

[261] G. Plank et al., FE modeling and analysis of thorax/restraint system interaction, in: *14th Int. Tech. Conf. ESV*, 1994, pp. 210–219.

[262] J.W. Plummer et al., Parametric finite element studies on the human pelvis: the influence of load magnitude and duration on pelvic tolerance during side impact, in: *40th Stapp Car Crash Conf.*, No P-305, Albuquerque, 1996, pp. 17–28.

[263] J.W. Plummer et al., Parametric tests of the human pelvis: the influence of load rate and boundary condition on peak stress location during simulated side impact, in: *1998 ASME Int. Mechanical Engineering Cong. Expo.*, **BED 39**, 1998, pp. 165–166.

[264] E. Privitzer and T. Belytschko, Impedance of a three-dimensional head-spine model, *Mathematical Modelling* **1** (1980), 189–209.

[265] M.M. Reddi et al., Computer simulation of human thoracic skeletal response, in: *Int. Conf. Finite Elements in Biomechanics*, Tucson, 1980.

[266] Renaudin et al., A 3-D finite element model of the pelvis in side impact, SAE Paper 933130, 1993.

[267] D.A. Renfroe et al., Modeling of vehicle rollover and evaluation of occupant injury potential using MADYMO, *SAE Spec. Publ.*, **1319**, 1998, pp. 33–50.

[268] J. Ruan et al., Study of the influence of the neck restraint on the human head impact response, in: *1997 Bioengineering Conf.*, **BED 35** ASME, 1997, pp. 457–458.

[269] J.S. Ruan and P. Prasad, Head injury potential assessment in frontal impacts by mathematical modeling, in: *Proc. Stapp Car Crash Conf.*, SAE, 1994, pp. 111–121.

[270] J.S. Ruan and P. Prasad, Coupling of a finite element human head model with a lumped parameter Hybrid III Dummy Model: preliminary results, *J. Neurotrauma* **12** (1995), 725–734.

[271] J.S. Ruan et al., Human head dynamic response to side impact by finite element modeling, in: *Winter Annual Meet.*, Dallas, **BED 17** ASME, 1990, pp. 399–401.

[272] J.S. Ruan et al., Brain injury in direct impact, in: *1994 Int. Mechanical Engineering Cong. Expo.*, **BED 28** ASME, 1994, pp. 313–314.

[273] J.S. Ruan et al., Dynamic response of the human head to impact by 3D finite element analysis, *J. of Biomechanical Engineering, ASME* **116** (1994), 44–50.

[274] J.S.T. Ruan et al., Human head dynamic response to side impact by finite element modeling, *J. of Biomechanical Engineering, ASME* **113** (1991), 276–283.

[275] A.A. Sauren and M.H.A. Claessens, Finite element modeling of head impact: the second decade, in: *Int. IRCOBI Conf. Biomech. Impacts*, Eindhoven, 1993, pp. 241–254.

[276] D.I. Shreiber et al., In vivo threshold for mechanical injury to the blood-brain barrier, in: *41st Stapp Car Crash Conf.*, P-315, 1997, pp. 277–291.

[277] J.H. Stuhmiller et al., Computer modeling of thoracic response to blast, *J. of Trauma* **28** (1988), S132–39.

[278] R.E. Tannous et al., Three-dimensional finite element model of the human ankle: development and preliminary application to axial impulsive loading, in: *40th Stapp Car Crash Conf.*, No P-305, Albuquerque, 1996, pp. 219–236.

[279] R.L. Taylor and J.L. Sackman, A computer program for crash injury simulations, in: *Int. Conf. Finite Elements in Biomechanics*, Tucson, 1980, pp. 817–828.

[280] B.H. Thacker et al., Probabilistic cervical spine injury analysis methods, in: *7th Spec. Conf. Probabilistic Mechanics and Structural Reliability*, Worcester, 1996, pp. 270–273.

[281] B.H. Thacker et al., Probabilistic injury analysis of the cervical spine, in: *38th Structures, Structural Dynamics and Material Conf.*, Kissimmee, 1997, pp. 2093–2103.

[282] K.L. Thibault et al., Effect of the age-dependent properties of the braincase on the response of the infant brain to impact, in: *ASME Int. Mechanical Engineering Cong. Expo.*, **BED 36**, 1997, pp. 137–138.

[283] P. Tong et al., Finite element modeling of head injury caused by internal loading, in: *12th Int. Tech. Conf. ESV*, Goteborg, Sweden, 1989, pp. 617–627.

[284] S. Tsutsumi et al., Impact analyses of whiplash neck behaviors in rear-end collisions, *Trans. of the Japan Society of Mechanical Engineers*, Ser. C, **63** (1997), 791–796.

[285] F. Turquier et al., Validation study of a 3D finite element head model against experimental data, in: *40th Stapp Car Crash Conf.*, No P-305, Albuquerque, 1996, pp. 283–294.

[286] K. Ueno et al., Two-dimensional finite element analysis of human brain impact responses: application of a scaling law, in: *Crashworthiness and Occupant Protection in Transport. Systems*, **AMD 106**, ASME, 1989, pp. 123–124.

[287] K. Ueno et al., Development of tissue level brain injury criteria by finite element analysis, *J. Neurotrauma* **12** (1995), 695–706.

[288] K.H.C. Wang and K.H. Yang, The development of a finite element human thoracic model, in: *5th Injury Prevention Through Biomechanics Symp.*, Detroit, 1995, pp. 129–135.

[289] C.C. Ward et al., Simulation of brain injury test using a finite element primate brain model, in: *Int. Conf. Finite Elements in Biomechanics*, Tucson, 1980, pp. 829–850.

[290] R. Willinger et al., Modal and temporal analysis of head mathematical models, *J. Neurotrauma* **12** (1995), 743–754.

[291] A. Wittek and J. Kajzer, Modelling of muscle influence on the kinematics of the head-neck complex in impacts, *Mem. School Eng.*, Nagoya Univ., **49** (1997), 155–205.

[292] N. Yoganandan et al., Mathematical and finite element analysis of spine injuries, *Critical Rev. Biomedical Engineering* **15** (1987), 29–93.

[293] H. Yoshida et al., Impact analysis of whiplash injuries in rear-end collisions, in: *1998 ASME Int. Mechanical Engineering Cong. Expo.*, **BED 39**, 1998, pp. 147–148.

[294] C. Zhou et al., Shear stress distribution in the porcine brain due to rotational impact, in: *Proc. Stapp Car Crash Conf.*, SAE, 1994, pp. 133–143.

[295] C. Zhou et al., New model comparing impact responses of the homogeneous and inhomogeneous human brain, in: *39th Stapp Car Crash Conf.*, Coronado, 1995, pp. 121–137.

[296] Q. Zhou et al., Analytical study of system variables for meeting FMVSS 201 head impact requirements, in: *1998 ASME Int. Mechanical Engineering Cong. Expo.*, **AMD 230**, 1998, pp. 131–139.

Human surrogates

[297] A. Buijk, Crash simulation of side impact with occupant interaction, in: *20th MSC NASTRAN Europ. Users Conf.*, Vienna, 1993.

[298] A.J. Burton, Explicit large strain dynamic finite element analysis with applications to human body impact problems, Ph.D. Thesis, Univ. of Wales, Swansea, 1996.

[299] L.R. Dharani and F.S. Ji, Dynamic analysis of normal impact of occupant head in laminated glass, *SAE Spec. Publ.*, **1320**, 1998, pp. 49–54.

[300] M. Fountain et al., Mathematical modelling of the BioSID Dummy, in: *Proc. Stapp Car Crash Conf.*, SAE, 1994, pp. 309–323.

[301] L. Fredriksson and L. Nilsson, The Hybrid III Dummy finite element model, in: *Structural Dynamics-EURODYN '93*, T. Moan et al., eds, Balkema, Rotterdam, 1993, pp. 529–537.

[302] L.A. Fredriksson, A finite element data base for occupant substitutes, Dissertation, Linköping Studies Sci. Tech., No 447, 1996.

[303] L.A. Fredriksson and L. Nilsson, An advanced finite element data base of the Hybrid III Test Dummy: Phase I model generation and sled test validation, in: *SAE Int. Congress and Expo.*, SP-1045, 1994, pp. 37–51.

[304] J.P. Gourret et al., Modeling of contact deformations between a synthetic human and its environment, *Computer-Aided Design* **23** (1991), 514–520.

[305] M.N. Hamilton et al., Adult to child scaling and normalizing of laterial thoracic impact data, *SAE Trans.*, **95**, 1986, Paper 861883.

[306] R.N. Hardy and G.D. Suthurst, Simulations to assess the influence of car lateral impact characteristics on occupant kinematics, *Proc. of the Institution of Mechanical Engineers*, Part D, **199** (1985), 97–104.

[307] E. Haug, Biomechanical models in vehicle accident simulation, in: *Crashworthiness of Transportation Systems*, J.A.C. Ambrosio, ed., NATO ASI, 1997, pp. 237–259.

[308] E. Haug et al., Finite element models of dummies and biomechanical applications using PAM-CRASH, in: *PAM-User's Conf. Asia, PUCA '93*, Shinyokoham, 1993, pp. 123–158.

[309] R.H. Hollamby et al., An advanced EuroSID 1 occupant model, *Int. LS-Dyna3 Conf.*, 1993.

[310] M. Howard et al., The simulation of real world car to pedestrian accidents using a pedestrian humanoid finite element model, *Int. J. of Crashworthiness* **3** (1998), 347–357.

[311] Y. Huang et al., Finite element modeling of gross motion of human cadavers in side impact, in: *Proc. Stapp Car Crash Conf.*, SAE, 1994, pp. 35–53.

[312] H. Jamshidiat et al., Airplane size effects on occupant crash loads, in: *Aerotech '92*, Anaheim, SAE, 1992, pp. 1–17.

[313] T.B. Khalil and T.C. Lin, Simulation of the Hybrid III Dummy response to impact by nonlinear finite element analysis, in: *Proc. Stapp Car Crash Conf.*, SAE, 1994, pp. 325–343.

[314] T.B. Khalil et al., On developing a finite element model of the Hybrid III Dummy, in: *Winter Annual Meet.*, New Orleans, **AMD 169**, ASME, 1993, pp. 205–206.

[315] T.B. Khalil et al., Hybrid III thoracic impact on self-aligning steering wheel by finite element analysis and mini-sled experiment, in: *35th Stapp Car Crash Conf.*, SAE, 1991, pp. 73–83.

[316] T.B. Khalil et al., Integrated vehicle–dummy–airbag model for frontal crash simulation by FE analysis, in: *Symp. Crashworthiness and Occupant Protection in Transport. Systems*, J. Ried, ed., 1995, pp. 355–383.

[317] S.W. Kirkpatrick et al., Finite element modeling of the Side Impact Dummy (SID), in: *Human Surrogates,* SAE No 945, 1993, pp. 75–86.

[318] G. Krabbel and H. Appel, Development of a finite element model of the human skull, *J. Neurotrauma* **12** (1995), 735–742.

[319] D.H. Laananen, Validation of SOM-LA occupant response, *SAE Trans.* **94** (1985), Paper 850850.

[320] H.M. Lankarani et al., Occupant dynamic responses for evaluation of compliance characteristics of aircraft bulkheads, in: *18th Annual ASME Design Automation Conf.*, **DE 44**, 1992, pp. 377–382.

[321] H.M. Lankarani et al., Multibody dynamics of aircraft occupants seated behind interior walls, *Nonlinear Dynamics* **6** (1994), 237–246.

[322] H.M. Lankarani et al., Kinematics of SID on side-facing aircraft seat, *Int. J. of Crashworthiness* **3** (1998), 393–403.

[323] D. Lasry et al., Mathematical modeling of the Hybrid III Dummy chest with chest foam, in: *35th Stapp Car Crash Conf.*, SAE, 1991, pp. 65–72.

[324] D. Lewis et al., Comparison of the dynamic response of a Hybrid III ATD restrained by an inflataband in a sled test with the computer simulation results, in: *35th Ann. SAFE Symp.*, Phoenix, 1997, pp. 145–155.

[325] T.C. Lin et al., Evaluation of the Hybrid III Dummy interactions with air bag in frontal crash by finite element simulation, in: *39th Stapp Car Crash Conf.*, Coronado, 1995, pp. 37–49.

[326] D. Ma and H.M. Lankarani, A multibody/finite element analysis approach for modeling of crash dynamic responses, *J. of Mechanical Design, ASME* **119** (1997), 382–387.

[327] D.E. Midoun et al., Dummy models for crash simulation in finite element programs, in: *35th Stapp Car Crash Conf.*, SAE, 1991, pp. 351–367.

[328] P. Prasad and C.C. Chou, A review of mathematical occupant simulation models, in: *Crashworthiness and Occupant Protection in Transport. Systems*, **AMD 106**, ASME, 1989, pp. 95–112.

[329] P. Prasad and C.C. Chou, Biodynamics simulation models, in: *Shock and Vibration Computer Programs*, W. Pilkey, ed., SAVIAC, 1995, pp. 105–181.

[330] J.S. Ruan and P. Prasad, Coupling of a finite element human head model with a lumped parameter Hybrid III Dummy model: preliminary results, *J. Neurotrauma* **12** (1995), 725–734.

[331] J. Ruckert et al., A finite element of the EuroSID Dummy, in: *36th Stapp Car Crash Conf.*, 1992, pp. 255–260.

[332] E. Schelkle and R. Remensperger, Integrated occupant–car crash simulation with the finite element method: the Porsche Hybrid III-Dummy and airbag model, in:*Front Crash Safety Tech. 90's*, SAE, 1991, pp. 1–8.

[333] C. Steyer et al., Numerical simulation of the proposed European Side Impact test procedure, in: *Crashworthiness and Occupant Protection in Transport. Systems*, **AMD 106**, 1989, pp. 53–58.

[334] R.M.V. Sturt et al., Modelling the occupant in a vehicle context – an integrated approach, in: *ESV*, Paris, 1991, Paper 91-S9-0-19.

[335] A. Tilakasiri and P. Du Bois, A simulation of an automobile side impact with finite element dummies included in the analysis, in: *Science and Engineering on Supercomputers*, E.J. Pitcher, ed., Springer, 1990, pp. 125–131.

[336] K. Tominaga et al., Numerical analysis of side impact phenomena using MADYMO-3D Dot-SID Dummy, in: *40th Stapp Car Crash Conf.*, P-305, 1996, pp. 51–61.

[337] K. Ueno and J.W. Melvin, Finite element model study of head impact based on Hybrid III head acceleration: the effects of rotational and translational acceleration, *J. of Biomechanical Engineering, ASME*, **117** (1995), 319–328.

[338] K.H. Yang and A.I. King, Development of a finite element based two dimensional human surrogate, in: *Bioeng. Ctr. 50th Anniv. Symp. Proc.*, Wayne Univ., 1989, pp. 52–57.

Injury protection

[339] J.A.C. Ambrosio et al., eds, *Crashworthiness of Transportation Systems: Structural Impact and Occupant Protection*, NATO ASI Ser. Vol. 332, Kluwer, Dordrecht, 1997.

[340] K. Digges et al., Effect of occupant position and air bag inflation parameters on driver injury measures, *SAE Spec. Publ.*, **1333**, 1998, pp. 9–14.

[341] M.U. Fitzpatrick and K.E. Thompson, PASSIM-PLUS, a multi-element, passenger airbag model, in: *Int. Cong. Expo.*, Detroit, SAE, 1991, pp. 1–12.

[342] C.J.L. Florie et al., General 3-dimensional fluid-structure interaction applied in airbag and birdstrike analyses, in: *18th MSC NASTRAN User Conf.*, 1991.

[343] E. Fraterman and H.A. Lupker, Evaluation of belt modelling techniques,in: *Frontal Impact Protection*, SAE No 947, 1993, pp. 1–14.

[344] N.P.M. Godfrey, Mathematical modelling of a helmet head under impact, Ph.D. Thesis, Brunel Univ., UK, 1991.

[345] M. Gopal and V. Anne, Performance evaluation of door and seat side impact airbags for passenger van and sport utility vehicles, *SAE Spec. Publ.*, **1333**, 1998, pp. 153–157.

[346] J.O. Hallquist et al., Efficiency refinements of contact strategies and algorithms in explicit FE programming, in: *3rd Int. Conf. Computational Plasticity*, D.R.J. Owen, ed., Pineridge, 1992, pp. 457–481.

[347] J. Hillmann and W. Rabethge, Computer aided development of a vehicle front-end structure to improve safety for car occupants in frontal collision, *Automobiltech. Z.*, **90** (1988), 641–646.

[348] R. Hoffmann et al., A finite element approach to occupant simulation – The PAM-CRASH airbag model, SAE Paper 890754, 1989.

[349] Y. Huang et al., Automotive side impact protection – finite element approach, in: *4th Injury Prevention in Biomechanics*, Wayne Univ., 1994, pp. 195–210.

[350] M. Igarashi and M. Atsumi, An analysis of 3 pt belted occupant impact dynamics in frontal collision and its application, *SAE Trans.* **94** (1985), Paper 850436.

[351] A. Kaiser, Some examples of numerical simulation in vehicle safety development, in: *8th Int. Conf. Vehicle Structural Mechanics*, SAE, 1992, pp. 107–117.

[352] T.B. Khalil and A.I. King, eds, *Crashworthiness and Occupant Protection in Transportation Systems*, ASME, **AMD 106**, 1989.

[353] T.B. Khalil and M.Y. Sheh, Vehicle crashworthiness and occupant protection in frontal impact by FE analysis – an integrated approach, in: *Crashworthiness of Transportation Systems*, J.A.C. Ambrosio, ed., NATO ASI, 1997, pp. 363–399.

[354] T.B. Khalil et al., Finite element simulation of airbag deployment and interactions with an occupant model using DYNA3D, in: *13th Exper. Safety Vehicle Conf.*, Paris, 1991.

[355] T.B. Khalil et al., Development of a 3-dimensional finite element model of air bag deployment and interactions with an occupant using DYNA3D, in: *35th Stapp Car Crash Conf.*, SAE, 1991, pp. 251–267.

[356] T.B. Khalil et al., Integrated vehicle–dummy–airbag model for frontal crash simulation by FE analysis, in: *Symp. Crashworthiness and Occupant Protection in Transport. Systems*, J. Ried, ed., 1995, pp. 355–383.

[357] V. Laksminarayan and D. Lasry, Finite element simulation of driver folded air bag deployment, in: *35th Stapp Car Crash Conf.*, SAE, 1991, pp. 227–235.

[358] H.M. Lankarani, Current issues regarding aircraft crash injury protection, in: *Crashworthiness of Transportation Systems*, J.A.C. Ambrosio, ed., NATO ASI, 1997, pp. 579–612.

[359] D.R. Lemmon, Pedestrian-safe automobile hood design using finite element analysis, Ph.D. Thesis, Univ. of Cincinnati, 1993.

[360] D.R. Lemmon and R.L. Huston, Automobile hood/fender design optimization for improved pedestrian head impact protection, in: *ASME Design Tech. Conf.*, Minneapolis, **DE 69/2**, 1994, pp. 569–577.

[361] D.S. Liu and S.Y. Chang, Design depowered airbag mass flow rate by using occupant simulation models and neural network, in: *1998 ASME Int. Mechanical Engineering Cong. Expo.*, **AMD 230**, ASME, 1998, pp. 141–148.

[362] J.K.H. Liu, SIR sensor closure time prediction for frontal impact using full vehicle finite element analysis, in: *Frontal Impact Protection*, SAE No 947, 1993, pp. 71–77.

[363] L. Lorenzo et al., Improving head-impact protection, *Automotive Eng.* **104** (1996), 49–53.

[364] F. Luan et al., Computer simulations of human neck loads in a car equipped with an airbag, in: *1998 ASME Int. Mechanical Engineering Cong. Expo.*, **BED 39**, 1998, pp. 159–160.

[365] H.A. Lupker and W.E.M. Bruijs, Gas jet model for airbag inflators, in: *Frontal Impact Protection*, SAE No 947, 1993, pp. 85–94.

[366] R. Maruthayppan et al., Comparison of thermoplastic composite vs conventional steel instrument panel system for side-impact energy management, in: *1998 Regional Tech. Meet.*, Soc. Plast. Eng., Detroit, 1998, pp. 1–9.

[367] J.J. Nieboer et al., Status of the MADYMO 2D airbag model, in: *32nd Stapp Car Crash Conf.*, SAE, 1988, pp. 223–235.

[368] J.J. Nieboer et al., Airbag modeling techniques, in: *34th Stapp Car Crash Conf.*, SAE, 1990, pp. 243–259.

[369] A. Noureddine et al., Analysis of airbag depowering and related parameters in out of position environment, *Int. J. of Crashworthiness* **3** (1998), 237–248.

[370] Y.S. Park et al., Optimum design of a steering column to minimize the injury of a passenger, *Int. J. of Vehicle Design* **17** (1996), 398–414.

[371] J.D. Reid, Tracking the energy in an energy absorbing guardrail terminal, *Int. J. of Crashworthiness* **3** (1998), 135–146.

[372] M.M. Sadeghi and H. Mellander, Alternative passenger car seat – seat belt design for crash safety, in: *7th Int. Conf. Vehicle Structural Mechanics*, SAE P-210, 1988, pp. 135–141.

[373] E. Schelkle and R. Remensperger, Integrated occupant–car crash simulation with the finite element method: the Porsche Hybrid III-Dummy and airbag model, in: *Frontal Crash Safety Tech. 90's*, SAE, 1991, pp. 1–8.

[374] E. Schelkle and H. Wandinger, Nichtlineare FE-Berechnung der Rucksitzlehne eines Autositzes mit integriertem Gurtsystem unter Crashbelastung, in: *14th Int. FE Cong.*, IKOSS, Baden-Baden, Germany, 1985, pp. 219–236.

[375] P.J. Schuster and B. Staines, Determination of bumper styling and engineering parameters to reduce pedestrian leg injuries, *SAE Spec. Publ.*, **1355**, 1998, pp. 93–103.

[376] M.B. Shkolnikov et al., Barrier impact test simulation using DYNA3D, in: *Crashworthiness and Occupant Protection in Transport. Systems*, **AMD 106**, ASME, 1989, pp. 33–39.

[377] A. Tabiei, Impact simulation of 850-kg pendulum into a guard rail test fixture, in: *Numerical Implementation and Application of Constitutive Models in FEM*, **AMD 213**, ASME, 1995, pp. 67–78.

[378] K. Uduma et al., Nonlinear dynamic analysis of an automotive knee bolster system, in: *8th Int. Conf. Vehicle Structural Mechanics*, SAE, 1992, pp. 155–164.

[379] S. Vaidyaraman et al., State-of-the-art side airbag modeling and its application in occupant safety in lateral collisions, *SAE Spec. Publ.*, **1333**, 1998, pp. 169–173.

[380] P.T. Vreede et al., Finite element analysis of tubular energy absorber in automobiles, in: *NUMIFORM '95*, S.F. Shen and P. Dawson, eds, Balkema, Rotterdam, 1995, pp. 893–897.

[381] B.D. Walker and P.R.B. Dallard, Integrated approach to the simulation of vehicle crashworthiness and occupant protection systems, in: *Int. Cong. Expo.*, Detroit, SAE, 1991, pp. 1–7.

[382] C.J. Wava et al., Implementation and validation of a finite element approach to simulate occupant crashes with airbags: Part II – Airbag coupling with crash victim, in: *Winter Annual Meet.*, New Orleans, **AMD 169**, ASME, 1993, pp. 287–309.

[383] C.J. Wawa et al., Implementation and validation of a finite element approach to simulate occupant crashes with airbags: Part I – Airbag model, in: *Winter Annual Meet.*, New Orleans, **AMD 169**, ASME, 1993, pp. 269–286.

[384] S.R. Wu et al., Airbag tire modeling by explicit finite element method, in: *15th Annual Meet. Conf. Tire Science and Technology*, Akron, OH, 1996.

[385] S.R. Wu et al., Airbag tire modeling by the explicit finite element method, *Tire Science and Technology* **25** (1997), 288–300.

[386] K.H. Yang and Y.Q. Li, Effects of the airbag folding pattern in out-of-position frontal impact with the airbag, in: *Winter Annual Meet.*, New Orleans, **AMD 169**, ASME, 1993, pp. 255–267.

[387] K.H. Yang et al., Computer simulations of contact forces for airbags with different folding patterns during deployment phase, *Shock and Vibration* **2** (1995), 237–245.

[388] F.Y. Yeh et al., Structural design and safety evaluation of highway guardrail systems, *MRL Bulletin on Reserach & Development* **6** (1992), 29–34.

[389] C.R. Yeich, Passenger airbag modeling, *Chilton's Automotive Ind.*, **174** (1994), 92–94.

[390] A.L. Yettram et al., Materials for motorcycle crash helmets – a finite element parametric study, *Plastics, Rubber and Composite Processing and Applications* **22** (1994), 215–222.