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Finite Element Crash Simulations and Impact-Induced Injuries: An Addendum. A Bibliography (1998–2002)

Jaroslav Mackerle

ABSTRACT—This paper gives a bibliographical review of finite element analyses and simulations of crashes and impact-induced injuries from the theoretical as well as practical points of view. The bibliography lists references to papers, conference proceedings and theses/dissertations that were published between 1998 and 2002. It is a continuation of the author's earlier bibliography with the same title published in 1999, Shock and Vibration, Vol. 6, 321–334. At the end of this paper 271 references are listed.

KEYWORDS: finite elements, contact-impact problems, crash simulations, impact-induced injuries, injury protection, bibliography.

1. Introduction

The output of scientific papers in general is fast growing and professionals are no longer able to be fully up-to-date with all the relevant information. The increasing specialization in various engineering fields has resulted in the proliferation of subject-oriented journals and conference proceedings directed to specialist audiences. The researchers have more channels for communicating the results of their research at their disposal, but on the other hand to find necessary information may be a time-consuming and difficult process. Another question is whether researchers/scientists are willing to spend time looking for information. It has been pointed out that in engineering, informal knowledge channels are 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.

In almost the last four decades, the finite element method (FEM) has become the prevalent technique used for analyzing physical phenomena in the field of structural, solid, and fluid mechanics as well as for the solution of field problems. The FEM is a useful tool also in biomechanics and biomedicine because it can be used to discover facts or study the processes in a way that no other tool can accomplish. The emphasis in research has been on applications to various areas such as orthopaedic and dental mechanics, cardiovascular and soft tissue mechanics, biological flow analysis, impact injury, etc.

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It is difficult for a single author to summarize the wide topic of this paper in a form of the state-of-the-art review paper; therefore a pure bibliography is presented here. Hopefully, this bibliography will save time for readers looking for information dealing with the subjects described below, not having access to large databases or not willing to spend time on uncertain information retrieval.

This bibliography provides a list of references on finite element simulations of contact-impact problems, crashes and impact-induced injuries. General solution techniques as well as problem-specific applications are included. The emphasis is to present papers published first of all in journals. This type of paper is relatively easy to obtain.

Conferences play an important role in scientific and technological communication by bringing together scientists, researchers and engineers, permitting informal exchange of ideas and information, and building up a network of personal contacts. The main criticism of conferences is that the material presented is often a repetition of what is published elsewhere in the literature. Also we often hear complaints of uneven quality of papers. Conference papers are also a source of never-ending bibliographical confusion. In the context of this paper two important conferences are exceptions and should be mentioned: the Stapp car crash conference, and the International Research Council on the Biomechanics of Impact (IRCOBI) conference on the biomechanics of impact (information about the proceedings can be found on the Internet at http://www.stapp.org/ and http://www.ircobi.org/, respectively).

The entries of this bibliography have been retrieved from the author's database, MAKEBASE, and are grouped into the following sections:

- crash and impact simulations where occupants are not included (aircraft and helicopter crashworthiness, automobile crashworthiness, and vehicle rail structure crashworthiness);
- 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 multibody dynamics codes have opened a new era in contact-impact biodynamic studies. The application possibilities of the FEM have been expanded in order to allow for the complex modeling of vehicle and integrated occupants.

The topics include:

- *aircraft and helicopter crashworthiness*—high-energy impact; energy absorption; impact damage prediction; impact on soft soil; airframe water impact; collision with space debris; penetration simulation; impact of aircraft engine into concrete walls; bird impact simulation; design of exit cone; earth entry vehicles; fan fuselage; composite fuselage; composite helicopter components; helicopter rotor blades; helicopter subfloor; seat system; wing panels; riveted join design; aircraft landing gears; engine fan cases;
- *automobile crashworthiness*—vehicle crashworthiness design; crush analysis; frontal impact problems; side impact problems; car-to-car impact; rollover simulation; energy absorption; crash visualization; crashworthiness for parallel environment; side door impact; steering wheel armature; hydroformed frames; front end design; bumper system; membrane floors; framed structures; crashworthiness of aluminum foams; smart material systems;
- *vehicle rail structure crashworthiness*—train crashworthiness analysis; wheel-rail impact; planetary gear trains; hydroformed frames; railroad passenger car; railway driver's cab.

3. Impact-induced injuries

Two main types of models in the 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.

Topics in this section list: vehicle impact and occupant biomechanics; frontal impact analysis; side impact analysis; vehicle rollover studies; skull fracture by direct impact; impact-induced fissuring of articular cartilage; human lower extremity injury; head and neck impact injury; whiplash injury; thorax injury; pelvis injury; shoulder injury; knee injury; eyeball injury; brain impact studies; car to pedestrian accidents; aircraft occupants and seat crashworthiness; pregnant women in vehicles crashes; high-speed passenger train crashworthiness and occupant safety.

4. 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 using experimental tests when exceeding injury levels and therefore, in some cases, 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 a human body contains head, neck and skeleton represented by bones, their joints, various soft tissues, and internal organs.

The following topics are handled: biomechanical dummies; hybrid III dummy; FAT dummy; SID dummy; dummy spine model; dummy head model; dummy measurement of chest injuries.

5. 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 the 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 analyze and simulate injury protection systems and this is the main subject of this last section.

Topics handled in this section: vehicle occupant safety; occupant head protection; airbag studies; door and seat side impact airbags; belt integrated seats; protective helmets; highway guardrail; W-beam guardrail; road safety barriers; sign support system.

Acknowledgment

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.

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