CRASH SIMULATION FOR IMPROVING HIGHWAY SAFETY HARDWARE: STATUS AND RECOMMENDATIONS

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BACKGROUND AND PURPOSE

The Lawrence Livermore National Laboratory (LLNL) has been under contract to the DOT/FHWA's Turner-Fairbank Highway Research Center (TFHRC) since early 1992. Our work has focused on assisting TFHRC implement state-of-the-art vehicle crash simulation methodology for use in improving the design and evaluation of highway roadside safety hardware.

The impetus for LLNL involvement with TFHRC was born following the results from three independent studies contracted by TFHRC. All three recommended using finite element (FE) methodology and further that LLNL's DYNA3D, an explicit FE code that performs nonlinear large deformation dynamic analysis, was their code of choice. Essentially 100 percent of all vehicle crashworthiness analysis conducted by the automobile industry is performed using DYNA3D or one of its derivatives (e.g., LSDYNA, PAMCRASH).

LLNL's initial work was to assist TFHRC develop a comprehensive planning document that incorporated our DYNA3D*(1)* and NIKE3D*(2)* FE methodology as the basis for a multi-year program to develop the next generation computational tools for highway roadside design engineers and researchers. The resulting document is entitled *Vehicle Impact Simulation Advancement (VISTA): Planning Document (3)*. Major development tasks that were identified included: system architecture/user friendly interface; vehicle handling simulation program (NIKE3D); crash/impact simulation program (DYNA3D); vehicle, roadside hardware, and terrain models; and validation/correlation with crash test data. The plan suggests the development could take 7 years and cost as much as 7 million dollars.

Motivations for the VISTA planning document were numerous. Computational tools being employed at that time were inadequate to predict the interaction of vehicles and roadside structures. State-of-the-art computer hardware and software had evolved to the point where a powerful, versatile, user-friendly vehicle impact/handling simulation code could and should be produced. Full-scale crash testing of safety appurtenances such as longitudinal barriers, crash cushions, terminals, etc. are almost entirely limited to a few impact scenarios involving tracking vehicles. Most actual accidents bear little resemblance to these idealized conditions. Significant expense associated with full-scale testing, coupled with the practical limitations of crash testing technology, combine to limit the number and variety of impact scenarios which can be crash tested. An improved capability to accurately simulate vehicular dynamic responses and impacts with roadside features would result in more cost-effective roadway designs and roadside safety features. It would also permit a reduction in the number and expense of full-scale tests needed to develop new hardware. Most importantly, lives would be saved since a better understanding of hardware performance would improve hardware designs.

Along with the development of the VISTA planning document, TFHRC started to assemble a team of technical resources to assist them in the development and implementation of the program. Team members came from TFHRC, the National Crash Analysis Center (NCAC), and LLNL. In addition, LLNL contracted several consultants and formed a Technical Support Group (TSG) to provide advice and guidance. TSG members included experts from General Motors, University of Milan, Vanderbilt University, Momentum Engineering and University of Nebraska.

Over the last three and one-half years, as the result of assembling this team and the contributions of the TSG, TFHRC has made significant progress towards the implementation of FE methodology as the computational tool to perform vehicle crash simulation aimed at improving highway safety hardware.

The purpose of this paper is three-fold: (1) indicate major areas of progress made by TFHRC and their team; (2) identify areas where progress was slow; and (3) suggest how, with more focused management, progress could be accelerated even faster and in a more effective manner.

RECAP OF THE LAST 3-1/2 YEARS

Over the last three and one-half years TFHRC has made significant progress toward developing and establishing state-of-the-art finite element technology, using DYNA software, as a crash simulation tool for highway roadside hardware design engineers and researchers.

Below is a list of progress:

- TFHRC appears to have abandoned, for the most part, the use of dated computer codes such as HVSOM, BARRIER IV, GUARD, and NARD.
- The TFHRC team is using state-of-the-art finite element analysis codes such as DYNA and LSDYNA and input/output software packages such as INGRID, LSINGRID, TRUEGRID, PATRAN, TARUS, LSTARUS, and GRIZ.
- TFHRC has purchased several workstations (IBM RS 6000 and Silicon Graphics) and have access to CRAY YMP computer time at the Universities of Mississippi and Alaska.
- TFHRC has assembled and funded a sizable team of technical resources to assist them. This includes: George Washington University (NCAC); faculty and graduate students from eight other Universities (via grants); consultants (e.g., Momentum Engineering, LS-Software and EASi Engineering) and LLNL.
- TFHRC has developed considerable experience applying the FE methodology to vehicle/roadside hardware crash simulation. Specific examples of accomplishments include: a Ford Festiva model for barrier impact studies; a digitizing procedure for vehicle surface definitions which was used to develop a C1500 truck model; numerous barrier models developed by Universities; enhanced features to DYNA3D; material evaluation for FE constitutive models; a Taurus model that was made available to Universities; a BCT barrier FE model; a U-channel FE model; and a MADYMO (occupant model) to DYNA3D linkage.
- TFHRC staff is starting to realize the advantages *and* limitations of FE analysis.
- TFHRC started developing closer collaborations with DOT/NHTSA.
- TFHRC is setting up an internet *crash simulation discussion group* where computer simulation problems, solutions, etc. are shared.

In contrast with the above achievements, below is a list of items and/or issues that did not progress as well as expected. In the future, more attention should be focused on these items.

- No specific overall implementation plan was adhered to. Changing plans brought considerable waste of time and effort. For example, the VISTA planning document was not implemented and more specifically, the plan to couple a real-time handling code to DYNA was suddenly funded without sufficient discussion.
- Crash simulation efforts performed by various resources are not being effectively coordinated and focused by the TFHRC team.
- The TRB Roadside Safety Features Committee (A2A04) and Subcommittee on Computer Simulation were underutilized.
- The quality and quantity of crash simulation work could be improved. TFHRC does not have resident staff that is sufficiently trained and experienced in FE analysis. The university collaborators are still in a learning mode and lack seasoned FE experience in vehicle and barrier model development and in simulation of actual crash events. In the near term, TFHRC could benefit greatly from associating more closely with institutions that possess experienced FE analysts.
- TFHRC's interpretation of what constitutes a "good" crash simulation calculation should be improved. Methods for measuring the success of a computer simulation application must be defined. Often insights and invaluable knowledge can be gained from crash simulation results using "not yet validated" vehicles and roadside hardware models. In general, the more simulation calculations made with various models and impact scenarios the more one gains.
- TFHRC must define a more efficient process to get validated vehicle and highway hardware models. All model development should be done within the context of the crash problems being addressed and should include an experienced code user (10+ years of FE code running experience) with a modeler who would provide model review during model development.
- Documentation available to the TFHRC team needs improvement. This includes: codes, vehicle, hardware and soil models; and crash analysis results. TFHRC could take a stronger role in encouraging more effective collaboration between experimenters and FE analysts to improve the simulation models and the physical test requirements.

THE NEXT 5 YEARS

Great opportunity exists for progress. TFHRC is only just beginning to tap the potential of finite element technology as a computer simulation tool. Our goal is still new state-of-the-art software evolved to the point, where a powerful, versatile, user-friendly vehicle impact/handling simulation code(s) can be performed routinely. This will reduce costly testing, and permit analysis of hardware systems for a wide variety of vehicles, speeds and impact scenarios (including nontracking) and post impact (i.e., trajectory simulation), provide hardware designers with a stress analysis and evaluation tool, permit evaluation of hardware designs and prototypes and the application of different materials.

The "best" way to maximize progress towards the incorporation of FE/DYNA-like methodology would be for TFHRC to hire a full-time in-house staff of 10 to 12 experienced FE code experts 10+ years DYNA-like code experience. Supplement this staff with vehicle modeling experts from auto industry and expert highway roadside hardware design engineers and researchers. This approach does not appear to be feasible. The "next best" approach, might be to contract a *single* organization that has the FE code expertise. Supplement that organization with the experts from the auto industry and highway community. A third approach, the one chosen by TFHRC, is to develop an external "team" to assist them. This approach can work provided that careful management controls are put into place to assure that "team" members are qualified to perform the functions assigned; that "team" member assignments are part of a well-defined action plan; that "team" members work together; and that the quantity and quality of work produced is high.

Below are four critical management issues that need attention if TFHRC wishes to speed progress towards the development and implementation of improved computer tools to address vehicle/roadside hardware crash simulation. Following these recommendations should help eliminate most of the concerns expressed in the previous section.

1. *TFHRC computer simulation efforts need stronger management.* Establish a single point-of-contact in the Design Concepts Research Division at TFHRC to be responsible for the development and implementation of improved computer tools for highway design engineers and researchers. This person needs to balance and coordinate design, testing and computer analysis activities in the Division and must recognize that the most practical, cost-effective way to improved roadside safety hardware is through computer simulation. The goal should be to limit vehicle crash testing only to validate computer simulation.

2. *TFHRC should develop a detailed 5-year crash simulation program development plan and be committed to the plan.* The 5-year program plan might use the VISTA planning document as a starting point and update it by incorporating insights gained over the past 3-1/2 years.

The plan should be consistent with the underlying philosophy of NCHRP 350*(4)*: (a) ensure structural adequacy (i.e., contain, redirect, permit controlled penetration of impacting vehicle or permit a controlled stop in a predictable manner), (b) minimize occupant risk (i.e., the degree of hazard to which the impacting vehicle occupant is subjected), and (c) predict after-collision vehicle trajectory (i.e., probable involvement of other traffic).

Technical issues for consideration in the plan could include

- Identify code development needs;
- Identify targeted computer hardware for both vector and parallel computational machines;
- Define type of impact analysis and simulation to be addressed: impact speeds and approach angles, frontal and side impact, rollover, pre-impact, and post-impact;
- Select vehicle types to be modeled: mini-compact and subcompact passenger cars, standard 3/4 ton pickups, single unit trucks, and tractor-trailer cargo trucks;
- Select highway hardware to be modeled: longitudinal barriers, crash cushions, breakaway or yielding supports for signs and luminaries, breakaway utility poles, truck mounted attenuators, and work zone traffic control devices;
- Define parameters for measuring success of computer simulation applications; and
- Define "validation" for vehicle and roadside hardware models.

The documentation should include a comprehensive implementation plan that (1) establishes tasks, (2) identifies specific TFHRC team member work, (3) includes schedule and costs associated with each task, and (4) and overall plan as to how all tasks will be coordinated to meet program goals and objectives. A prioritization of technical issues will be required as part of the implementation plan.

3. *Establish Crash Simulation Technical Review Committee (CSTRC).* CSTRC's charter should include (a) review and validation of the TFHRC's 5-year plan and (b) semi-annual reviews of all TFHRC contractor work (model development and crash simulation analysis) and report quality level to TFHRC management.

The CSTRC should report to the single point of contact identified in the Design Concepts Research Division at TFHRC. The CSTRC members should be made up of acknowledged technical experts in FE modeling and analysis, highway safety hardware design and regulatory issues. Experts could be sought from organizations such as the automobile industry, roadside hardware manufacturers, TRB Roadside Safety Features Committee (A2A04) and/or Subcommittee on Computer Simulation, NHTSA, and FHWA Engineering.

4. *Explicitly define roles of various TFHRC technical resources and a process that ensures that all work activities are integrated into a focused effort.*

SUMMARY

Significant progress has been made by TFHRC and their team in adapting state-of-the-art FE methodology towards vehicle-roadside hardware crash simulation. A more focused and coordinated effort would expedite future progress and lead to vastly improved simulation results and a new level of computational tools. Recommendations are presented herein as to how to provide this improved focused and coordination.

REFERENCES

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