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CRASH ENERGY MANAGEMENT FOR OCCUPANT PROTECTION DURING VEHICLE CRASHES

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Abstract

Since design for crash energy management requires a system approach, severalmodels would be constructed in parallel to investigate synergy, if any, betweenthe major modes of frontal collisions, namely: 31 mph frontal, 35 mph frontal, and40 mph offset frontal impacts. At this stage, the desired crush sequence andmode will need to be selected and crush zones identified to assure that thestructural pulse parameter can be realized, that is, the force amplitude and themaximum crush distance, as determined in occupant model studies. Also, at thisstage in the design process, parametric studies are conducted in conjunctionwith other parallel design studies, such as packaging and vehicle dynamics toexplore various design alternatives.

Keywords: *Crash energy management, Crush zones, Occupant model, etc.*

Introduction: Crash energy management means controlling, by design, the dynamic behaviorof multiple systems in a very violent and complex environment of a collision. Toachieve this control over crash behavior, without sacrificing rigorous performanceand cost objectives, requires a very close interdisciplinary interaction. The designprocess of crash energy management must, for obvious reasons, begin with thebiomechanical considerations involving the interaction of the occupants withtheir restraint systems in response to a dynamic crash pulse generated in thevehicle by impact [1].Various occupant simulation models are used to study interactions betweendummy, restraint system and the vehicle. As a result, a family of crash pulses orsignatures that successfully meet specific injury criteria are easily defined. Thesepulses, in turn, define objective criteria for vehicle design. Using spring-massmodels, or any other simplified system modeling; these criteria are translated intodiscrete spring and mass elements to whatever degree of complexity the designeror analyst chooses. The logical choice would be to start with the simplest modelsand progressively increase their complexity as the design evolves[2].

There are two major considerations in the design of automotive structures forcrash energy management: absorption of the kinetic energy of the vehicle and thecrash resistance or strength to sustain the crush process and/or maintainpassenger compartment integrity. As for energy absorption, two basic modes ormechanisms are encountered in thin wall sheet metal beam-type structurescommonly found in automobiles: axial collapse and bending. Pure axial collapsecan be achieved only in the energy-absorbing structures and only during directfrontal/rear or slightly off-angle (5°-10°) impacts [3].Therefore, most of the structuralmembers, comprising the front and rear end structures, will be subject to mixedmodes comprised of axial collapse and bending. Higher order, more complex modes,which include torsion, are more likely to occur in the structural beam elementscomprising the passenger compartment and the structural interface, which supportthe energy-absorbing structures. In a well-designed and executed energyabsorbingstructure, the mixed modes will be avoided to assure predictableperformance during crash [4].

In crash energy management, thedesign criteria are different. The structure’s configuration, its mode of collapseand its resistance to crush (its crush strength), dictate the load magnitudecorresponding to that particular mode of collapse. Thus, an underestimate ofpeak crush load, generated by a collapsing structure, may trigger a premature

failure of its support structure, which is designed to carry the peak load. Thiscould result in an undesirable mode of collapse. Therefore, a very accurateestimate of the maximum crush load is imperative if predictable crash performanceand lightweight designs are to be achieved [5].

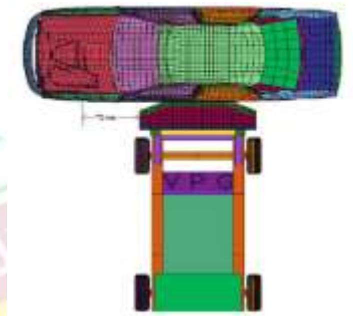
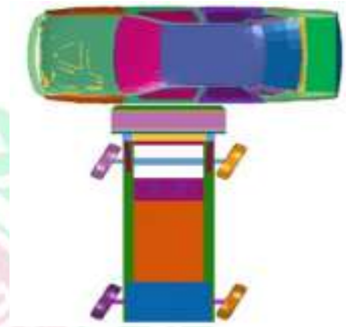
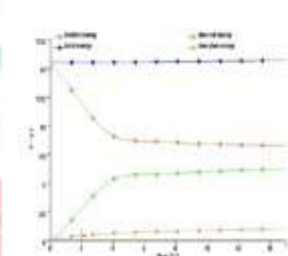
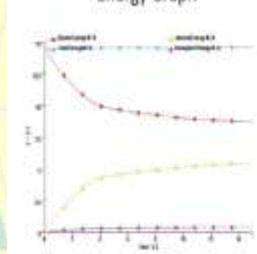
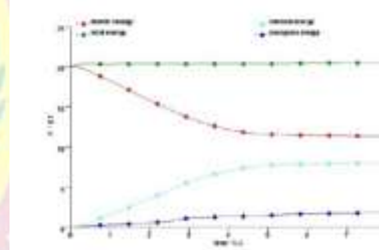
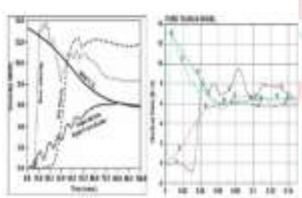
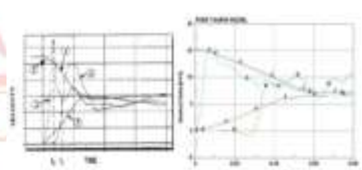
Related Work On Energy Management: Repeated full frontal crash-tests werecarried out with a load-cell barrier to determine the locallongitudinal stiffness with increasing crush. Repeated offset tests were run to determine shear stiffness. Two single high-speed tests (full frontal and offset) were carriedout and compared to the repeated tests to determine therate sensitivity of the front structure. Four repetitions at33.4 km/h provided equivalent energy absorption to a single 66.7 km/h test, when rebound was considered.Power-train inertial effects were estimated from high speed tests with and without power-train.Speed effects averaged 2% per [m/s] for crush up topower-train impact, and post-crash measurements werea reasonable estimate of front-structure stiffness. Power train inertia significantly increased the barrier force in thehigh-speed crashes [6]. The multi-body mathematical model consisted of a compartment, dash-panel and toepan-area and a front structure. The front structure was subdivided in 12 segments and a power-train, which were connected to the firewall by kinematic joints. The joints used local stiffness obtained from load-cell barrier crash-tests, and enabled local deformation of the vehicle front Similarly, the dash-panel and toepan were connected to the compartment, which enabled local intrusion into the compartment. A vehicle interior was modeled to enable contact-interactions with occupants, and the firewall geometry was included for interactions with the power-train. The vehicle-model was validated with full frontal and 50% offset data and predicted vehicle acceleration, crush profile and local intrusion well. The validity of the model indicates its applicability in a wide range of frontal (non-distributed) collisions. Due to the use of local stiffness data, the model can greatly improve accident reconstruction research especially in frontal offset and pole impacts at both high and low speeds. The vehicle-model can be easily adjusted by changing vehicle-mass, size, or local stiffnesses of the front structure, and is a useful tool in compatibility research to estimate trends in car crash compatibility [7]. A recently developed mathematical model was used to study the individual effects of fleet mass distribution, impact speedreductions and inherent vehicle protection on averageinjury and fatality rates for downsized fleets. A baselinefleet of 700-2000 kg was downsized by a) reducing allvehicle masses by 10% or 20% and b) by removing allcars heavier than 1400 or 1200 kg. The results showed that the safety can be maintained ifthe vehicle masses are reduced proportionally to theiroriginal mass. A higher safety level can be achieved byremoving the heavier vehicles. Traffic safety can be further enhanced by impact speed reductions or by improvements of restraint systems and vehicle compatibility. Thesafety level would rise more by implementation of radar activated brakes or controlling city speed limits than byintensified highway patrols, to eliminate crashes withimpact speeds over 140 mph or with an average velocitychange of 70 mph [8]. Massive moving barrier (MMB) testing is introduced as atool to obtain additional and accident specific stiffnesscoefficients applicable for reconstruction. The MMBimpacts a stationary vehicle of similar structure as theaccident vehicle under accident-specific conditions likeimpact location, angle, over-ride / under-ride, offset anddamage energy. A rigid or deformable structure ismounted to the front of the MMB, representative of theimpacting structure in the accident.Four illustrative tests are presented. A 1984 Honda Civicfrontal impact (2x), a 1988 Dodge Caravan rear impactand a 1992 Isuzu Rodeo frontal offset / over-ride impactwere conducted using the MMB. The tests demonstratedthat the MMB testing method is an efficient means toattain stiffness, crush energy and acceleration data forspecific accident conditions [9]. The accident severity of the collision pair of interest would be reconstructed more efficiently if the damage energy method were applied to only this collision pair. This method, however, entails the concernthat the observed damage of these two vehicles hasbeen enhanced by the subsequent collisions. An analysis is presented to specify the conditions underwhich initial vehicle damage of a collision pair is not enhanced by successive collisions, such that the initial delta-V of the vehicles of interest can be calculated usingonly the front and rear damage energy of that pair. The vehicles must have low restitution and sufficient space between them, such that the vehicle pile-up can be treated like a sequence of two-vehicle crashes (where the approaching vehicle may consist of a combination of the previously collided vehicles) [10]. Crash behavior in narrow object impacts was examined for the perimeter of a 4-door full size sedan. Additional test data was obtained for this vehicle by impacting four sedans with a rigid pole mounted to a massive moving barrier (MMB) in the front, right front oblique, right side, and rear. The vehicles were stationary when impacted by the MMB. Two of the four cars were repeatedly impacted with increasing closing speeds in the front and side, respectively. Each test was documented and the resulting deformation accurately measured. The stiffness characteristics were calculated for the perimeter of car and were presented using the power law damage analysis model. The vehicle's crash performance in these pole tests was compared to that of NHTSA's flat fixed barrier tests (deformable and non-deformable) for the front, side, and rear of this vehicle [11]. Real world statistics indicate that the ratio of occupant fatalities between two vehicle types can range from 1.6:1 (cars and light trucks in frontal collisions) to 23:1 (cars struck in the side by large vans). The mix of vehicle types and potential impact conditions present a challenge when designing crash protection strategies for motor vehicles and the transportation network. Mass is a predominant incompatibility factor. However, incompatibilities due to stiff front-structures and high bumper-heights in some vehicles may reflect greater safety consequences than mass alone. Historically, crash-testing legislation has focused on occupant protection of the tested vehicle [12]. Crush reaching into the stiff firewallmay cause vehicle peak accelerations to rise aboveexpected levels in low overlap and high speed,especially in case the engine enhances firewalldeformation. Furthermore, far-side intrusions may reachsimilar levels as near-side intrusions in offset collisions(>33% overlap), due to induced damage and the loaddistributing effect of the engine.Vehicle average acceleration and local intrusionlevels may reach injurious levels for the far-sideoccupant in offset collisions. Vehicle crashworthinessimprovements with a sole focus on near-side occupantsmay result in reduced protection of the far-sideoccupant [13].This paper presents an efficient algorithm for developing vehicle structures for crashworthiness, based on the analyses of *crash mode*, a history of the deformation of the different structural zones during a crash event. It emulates a process called crash mode matching where structural crashworthiness is improved by manually modifying the design until its crash mode matches the one the designers deem as optimal. Given an initial design and a desired crash mode, the algorithm iteratively finds a new design whose crash mode is increasingly closer to the desired one. At each iteration, a new design is chosen as the best among the normally distributed samples near the current design, whose mean and standard deviation are adjusted by a set of fuzzy rules. Each fuzzy rule encapsulates elementary knowledge of manual crash mode matching, as a mapping from the differences between the current and desired crash modes, to the changes in mean and standard deviation for sampling a sizing parameter in a structural zone. A case study on a vehicle frontal crash demonstrated the algorithm outperformed the conventional methods both in design quality and computational time [14]. An alternative approach to vehicle crashworthiness improvement by inserting add-on nonstructural energy absorbing (EA) devices in the unutilized space in series with existing load paths is studied conceptually. Vehicle-barrier impact simulations are conducted to determine the energy absorption and crushable space requirements for the add-on devices. Based on the experimental data available in the literature, a number of materials are identified as being capable of meeting these requirements. Simple tubes and honeycombs in axial crushing mode are found to be more effective as add-on EA devices than complex devices such as inversion tubes. Foam filling of primary structural members in bending mode is found to be less effective in increasing energy absorbing capacity than add-on EA devices. While the study indicates a theoretical assessment of

Test	FMVSS-214	IIHS	NACP

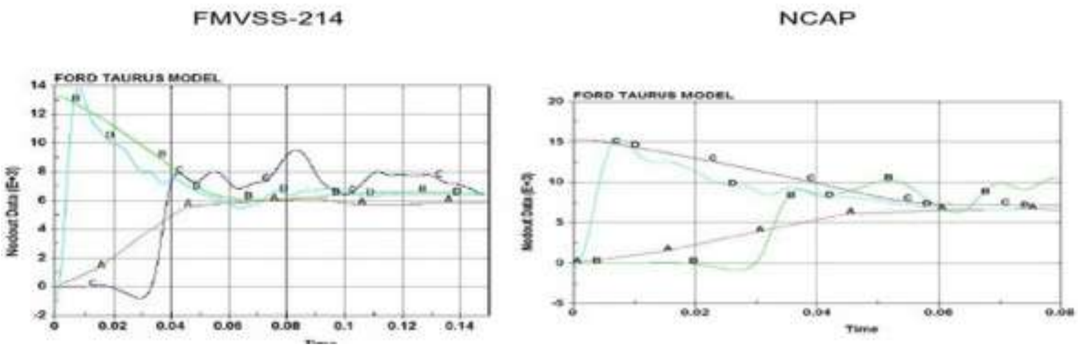
these devices, physical limitations may inhibit their usefullness. In particular, many of the devices are highly directional in nature [15]. The vehicle’s roll angle at the time of roof-impact dramatically affected the local DV at the point of head-to roof contact. Both roof-rail impacts may be injurious to far-side occupants, while near-side occupants are more likely to sustain head or neck injuries in roof impacts with the adjacent roof rail. Far-side occupants have a greater risk of compressive neck injury during impacts with the remote roof rail, while adjacent roof rail impacts subject occupants to primarily lateral head impacts with a higher head injury risk. Contoured roofs may reduce the opportunity and risk of head or neck injury in rollovers [16].

Discussions And Future Research Directions: In designing the vehicle structure for crash energy management, the designer isconcerned with its maximum strength (load capacity), its mode of collapse, theenergy absorbed and the residual strength. When a thin-walled structural component is subjected to a gradually increasing bending load, localized elasticbuckling initiates the collapse and the energy absorption processes. With the increasing moment capacity and starts tocollapse. In the plastic (deep collapse) region, the moment capacity decays exponentially with the collapse (increasing angle θ), which take the form of localizedfailure sites that constitute the “lastic hinge”. The energy absorbed is proportional to the area under the *M*-θ curve. The initial portion of the curve fromzero to the point of maximum bending capacity (segment O-M) usually can beneglected, since there is very little energy absorbed in that initial deformation.Most of the collision energy is converted into the plastic deformation energy ofthe hinge, which corresponds to the area under the tail segment of the *M*-θ curve, that is, after the maximum bending capacity has been reached. Today’s front-end structures of passenger vehicles are designed to be morecrashworthy by managing crash energy through effective use of available crush space. Sled tests and occupant model simulations indicated that crash pulsesover *ESW* of 20 g make it difficult to meet FMVSS 208 dummy performance criteria.Theoretically, when a square wave of 20 g is used, a crush distance of 24 in isrequired for a 35 mph frontal impact with a fixed barrier. However, a square wavecannot be achieved with today’s technology, and a vehicle is required to providean extra 20 to 25 percent deformation or 29 to 30 in overall for a better crashenergy management. Table 1 illustrates the comparison of Vehicle crashworthiness data with Side Impact Test using FMVSS-214,IIHS and NACP.

- Comparison of Vehicle crashworthiness data with Side Impact Test (FMVSS-214,IIHS,NACP)

Consist of	1.MBD of wheel rotates at 27 degree. 2.SID	1.MBD of 1500kg with velocity of 50 kmph	1.MBD of wheel base 27 degree. 2.SID
Test Procedure	Strike the MBD on the stationary vehicle at 90 degree with 4 wheels rotates at 27 degree.	MBD of 1500kg with velocity of 50 kmph strikes the vehicle at drivers side at 90 degree	Same as FMVSS-214 except velocity of MBD changes from 33.5 miles/hr to 38.5 miles/hr. Accelerators are introduced at different positions
Setup			
Energy Graph	Energy Graph  Velocity v/s time graph for FMVSS-214	Energy Graph 	Energy Graph for NCAP  Velocity v/s time graph for NCAP
Velocity Vs Time Graph		-------	

Comparison of Velocity curves



Reference

Winnicki, John and Eppinger, Rolf, ”A Method for Estimating the Effect of Vehicle Crashworthiness Design Changes on Injuries and Fatalities”, NHTSA Technical Report, pp. 1-30, 1998.

William T. Hollowell, Hampton C. Gabler, Sheldon L. Stucki, Stephen Summers and James R. Hackeney, “Updated Review of Potential Test Procedures for FMVSS No. 208”, Office of Vehicle Safety Research, pp. 1-122, 1999.

D. Friedman and C E Nash, “Measuring Rollover Roof Strength for Occupant Protection”, International Journal of Crash, Vol.8, Issue No. 1, pp. 97-105, 2003.

M. Lindquist, A. Hall and U. Bjornstig, “Real World Car Crash Investigations- A New Approach”, International Journal of Crash, Vol.8, Issue No. 4, pp. 375-384, 2003.

Paul Du Bois, Clifford C. Chou, Bahig B. Fileta, Tawfik B. Khalil,, Albert I. King, Harold F. Mahmood and JacWismans, “Vehicle Crashworthiness and Occupant Protection”, Edited by Priya Prasad and Jamel E. Belwafa, American Iron and Steel Institute, Michigan, 2004.

Buzeman-Jewkes, D. G.; Viano, D. C.; Lövsund, P. (1999) Use of Repeated Crash-Tests to Determine Local Longitudinal and Shear Stiffness of the Vehicle Front with Crush.SAE Paper No. 1999-01-0637 in Proc. SP-1432.Presented at SAE Int. Congress, March 1-4 1999. Detroit, MI.

Buzeman-Jewkes, D. G.; Viano, D. C.; Lövsund, P. (1999) A Multi-body Integrated Vehicle-Occupant Model for Compatibility Studies in Frontal Crashes. Journal of Crash Prevention and Injury Control Vol. 1:2.

Jewkes, D. B.; Viano, D. C.; Lövsund, P. (1999) Safety of a Downsized Vehicle Fleet: Effects of Mass Distribution, Impact Speed and Inherent Protection in Car-to_Car Crashes.SAE

Paper No. 1999-01-0074 in Proc. SP-1442.Presented at SAE Int. Congress, March 1-4 1999. Detroit, MI.

Woolley, R. L.; Asay, A. F.; Jewkes, D. B.; Monson, C. (2000) Crash Testing With A Massive Moving Barrier As An Accident Reconstruction Tool.SAE Paper No. 00B-159. Presented at SAE International Congress, March 6-8 2000, Detroit, MI.

Jewkes, D. B. (2001) Reconstruction of Accident Severity in a Multiple Vehicle Collision.SAE Paper No. 2001-01-1283. Presented at SAE International Congress, March 5-8, 2001. Detroit, MI.

Asay, A. F.; Jewkes, D. B.; Woolley, R. L. (2002) Narrow Object Impact Analysis and Comparison with Flat Barrier Impacts. SAE Paper No. 2002-2B-0069. Presented at SAE International Congress, March 2002. Detroit, MI.

Buzeman-Jewkes, D., Thomson, R.W., and Viano, D.C., "Crash Compatibility." Chapter 28 in Crashworthiness: Energy Management and Occupant Protection, edited by Jorge Ambrosio, CISM Courses and Lectures No. 423, International Centre for Mechanical Sciences, Springer Verlag, New York, ISBN 3-211-83334-X, pp 447-463, 2001.

Jewkes, D. B. (2003) Vehicle Acceleration and Compartment intrusion for Far-Sided Occupants v. Near-Sided Occupants in Frontal Offset Collisions. SAE Paper No. 2003-01-0159.Presented at the SAE International Congress, March 2003, Detroit, MI.

KarimHamza and Kazuhiro Saitou, “Vehicle Crashworthiness Design Via a Surrogate Model Ensemble and a Co-Evolutionary Genetic Algorithm”, ASME 2005 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Paper No. DETC2005-84965, pp. 899-907.

Kuang-Huei Lin and G. Thomas Mase, “ An Assessment of Add-on Energy Absorbing Devices for Vehicle Crashworthiness”, Journal of Engineering Materials and Technology ,Volume 112, Issue 4 , 2008.

Jewkes, D. B. (2009) Effect of Roll Velocity and Roof-to-Ground Impact Angle on Injuries in Lateral Rollovers. SAE Paper No. 2009-01-0823.Presented at the SAE World Congress, April 2009, Detroit, MI.