

Validation Study of a Generalized Minor Rear Vehicle Crash MADYMO Model Utilizing Real World Data

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ABSTRACT

A generalized MADYMO minor rear crash vehicle model with BioRIDII ATD was developed and validated using the mean response of previously published 12 km/h delta-V rear crash tests. BioRIDII simulation pelvis, thorax and head x-axis accelerations, as well as head y-axis angular acceleration, fell within corridors defining +/- one standard deviation of the mean BioRIDII crash test responses. Peak sagittal plane BioRIDII upper neck forces and moments in the simulation were on par with the mean values observed from the crash tests. After the model was validated for 12 km/h delta-V, the model was further exercised by performing simulations with (1) a Hybrid III 50th percentile occupant and (2) by reducing the pulse by 40% of its original value. Results indicate that this generalized minor rear crash model could be useful in accurately estimating occupant kinematics and kinetics in minor crashes up to at least 12 km/h delta-V as an alternative to expensive and time consuming crash testing.

INTRODUCTION

Minor rear crashes, where the struck vehicle longitudinal velocity change, or delta-V, is less than 15 km/h, are a potential source of injury complaints, expensive vehicle repairs and litigation. Occupant kinetics, kinematics and injury risk in these crashes can be evaluated through (a) costly vehicle crash tests or (b) use of computational crash models. MADYMO (MATHematical DYnamic MOdels, TASS-SAFE, Livonia, Michigan, USA) is a dynamic modeling package that has been extensively

used in motor vehicle crash safety design and analysis. The development and validation of a generalized minor rear crash passenger vehicle MADYMO model would allow for accurate and cost-effective evaluation of accelerations, forces and moments acting on occupants in real world minor rear crashes.

The objectives of this study were to (1) validate a generalized minor rear crash MADYMO model using the mean of impact data from minor rear crash tests with an instrumented BioRIDII, (2) use this validated MADYMO model to observe and compare BioRIDII and Hybrid III 50th percentile minor rear crash responses and (3) evaluate model kinetics and kinematics in response to a 40% reduced input pulse approximating a 7.3 km/h delta-V minor rear crash.

METHODS AND MATERIALS

The simulated minor rear crash acceleration pulse was taken from the mean of six (6) late model passenger vehicles weighing less than 4,536 kg involved in rear barrier minor crash tests with an instrumented BioRIDII ATD in the driver position. A summary of the crash tests is shown in Table 1 and the specifics of these tests have been previously published. (Siegmund et al., 2005) It should be noted that in these crash tests, the authors noted variance in vehicle response during repeated crash tests with the same vehicle, as well as when comparing similar crash severities across vehicle make, model and year.

TEST #	YEAR	MAKE/MODEL	Delta-V (km/h)
1.3	1997	Chevrolet/Cavalier	14.9
1.4	1997	Chevrolet/Cavalier	14.7
7.1	2002	Dodge/Caravan	12.7
11.1	2003	Volkswagen/Jetta	10.9
11.2	2003	Volkswagen/Jetta	10.9
19.1	1998	Chevrolet/Silverado	11.2
Mean from six (6) crash tests			12.1

Table 1. Passenger vehicle crash tests used as inputs to MADYMO minor rear crash simulation

From these six minor rear crash pulses, the mean vehicle x-axis, or longitudinal, acceleration pulse seen in Figure 1 was calculated for use in the MADYMO simulation for the first 225 milliseconds following barrier contact. Also shown is the mean longitudinal velocity change of the crash tests over this pulse duration. The mean crash test delta-V was 12.1 km/h.

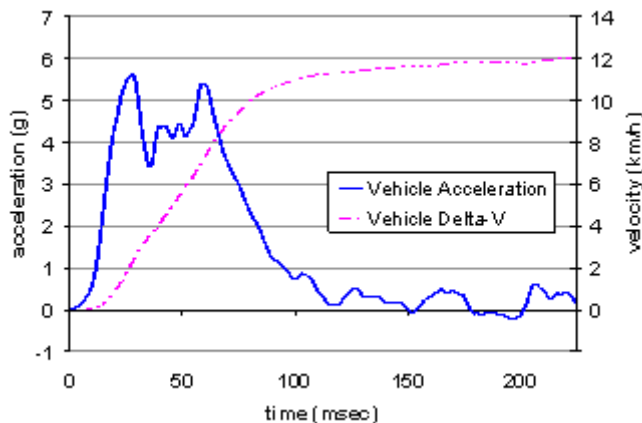


Figure 1. MADYMO longitudinal vehicle crash pulse and delta-V from the mean of six minor rear crash tests

The mean rear crash pulse was applied to a generic late model vehicle interior model in MADYMO V6.4 with a BioRIDII ATD seated in the driver and passenger seats as seen in Figure 2. Utilizing two BioRIDII ATD allowed for increased parametric changes in each simulation run, comparative analysis of BioRIDII side-by-side kinematics and likely decreased total simulation time required during the validation process.

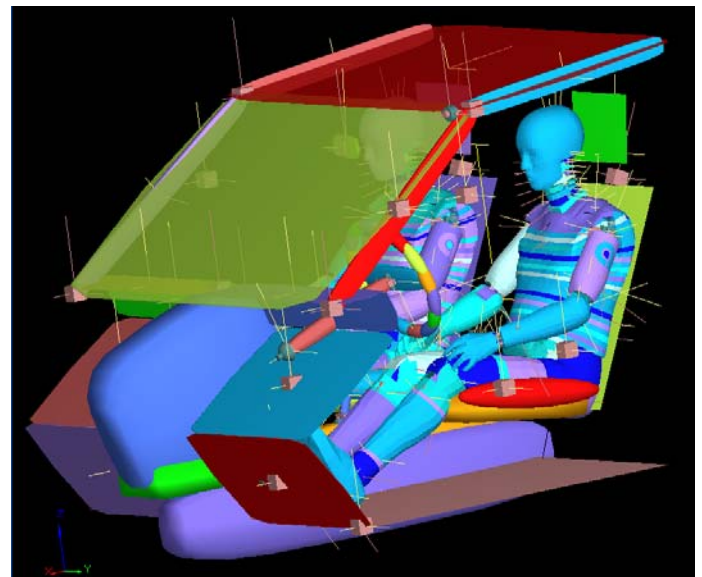


Figure 2. Initial position of BioRIDII facet ATD

(1) VALIDATION – The BioRIDII initial seating position was determined via a 500 millisecond settling simulation. In this pre-simulation, the BioRIDII was positioned five millimeters above the seat cushion and in front of the seat back and allowed to move into a neutral position in response to a gravitational acceleration field acting on the BioRIDII. The final BioRIDII position in the pre-simulation served as the initial position during validation runs.

Each validation simulation lasted 725 milliseconds. The gravitational acceleration field was applied to the BioRIDII for the first 500 milliseconds of this time period to fully settle any minor contact loading discontinuities due to initial position. The crash test pulse acceleration field was applied to the vehicle in the forward direction during the next 225 milliseconds. Because the acceleration, force and moment magnitudes the BioRIDII experienced during the forward rebound phase, after the vehicle and BioRIDII achieved a common velocity, were small or insignificant after the 225 millisecond rear pulse period, occupant loading during rebound was ignored.

Important model parameters such as BioRIDII initial position, seat cushion and head restraint rigidity, seat back and head restraint joint stiffness and seat back and head restraint orientation, and less vital parameters such as BioRIDII contact friction and damping, were parameterized over the course of one hundred forty-two simulation iterations. Finite element three-point belt restraints were initially applied to the BioRIDII driver and passenger. The belts were subsequently removed since these restraints imparted no appreciable accelerations, forces or moments on the BioRIDII during the simulation that affected kinematic or kinetic response and their presence reduced computational efficiency.

The model was considered valid when important BioRIDII acceleration outputs, involving pelvis, thorax and head x-axis linear accelerations and head y-axis angular acceleration traces fell generally within corridors defined by $\pm$ one standard deviation of the real world crash test BioRIDII mean responses. Secondary validation measures, including peak upper neck x- and z-axis forces, y-axis bending moment, pelvis and head z-axis accelerations, head and thorax y-axis angular velocities, FMVSS208 frontal crash neck injury criterion, N_{ij} , potential rear crash neck injury criterion #1, N_{km} , and potential rear crash neck injury criterion #2, NIC, were compared with the crash test maxima and provided further confirmation that the model adequately represented the BioRIDII crash test response.

(2) COMPARISON WITH HYBRIDIII ATD - After the MADYMO minor rear crash model was validated for the 12.1 km/h delta-V minor rear crashes, a 50th percentile HybridIII ATD replaced the BioRIDII in the passenger seat and the simulation was re-run. The HybridIII initial position was similar to the BioRIDII initial position. This ATD response comparison was performed since the HybridIII is a more widely used ATD in vehicle crash testing but has been shown to have a different response than the BioRIDII in rear crashes.

(3) REDUCED INPUT PULSE - Finally, the 12.1 km/h delta-V crash test pulse was reduced by 40% and applied to the model for the BioRIDII to observe the occupant kinetics and kinematics representative of a 7.3 km/h delta-V minor rear crash. This delta-V was chosen since it was of similar magnitude to the mean delta-V found in a recently gathered real world minor rear crash data set.(Bartsch et al., 2008)

RESULTS

(1) VALIDATION – MADYMO BioRIDII pelvis, head and thorax x-axis acceleration-time curves, along with the head y-axis angular acceleration-time response, were compared with BioRIDII crash test corridors for the 225 millisecond crash pulse time period. These accelerations can be seen in Figures 3 through 6. The shaded areas on each figure define the corridors surrounding $\pm$ one standard deviation of the mean crash test values. As can be seen in the figures, the simulated BioRIDII accelerations generally fell within the crash test corridors and showed good correlation to the BioRIDII crash test response.

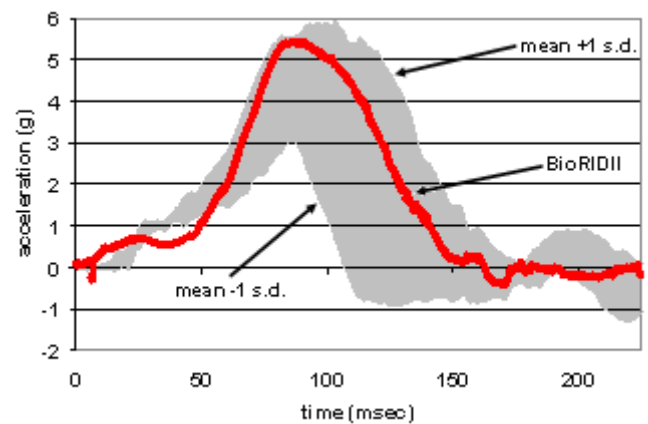


Figure 3. BioRIDII simulation pelvis x-axis acceleration response compared with crash test corridors

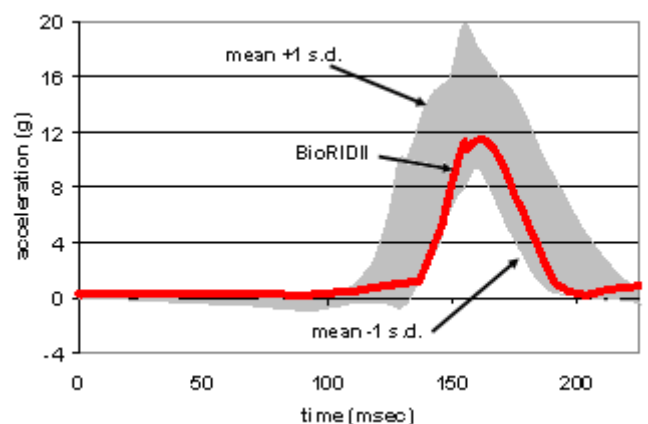


Figure 4. BioRIDII simulation head x-axis acceleration response compared with crash test corridors

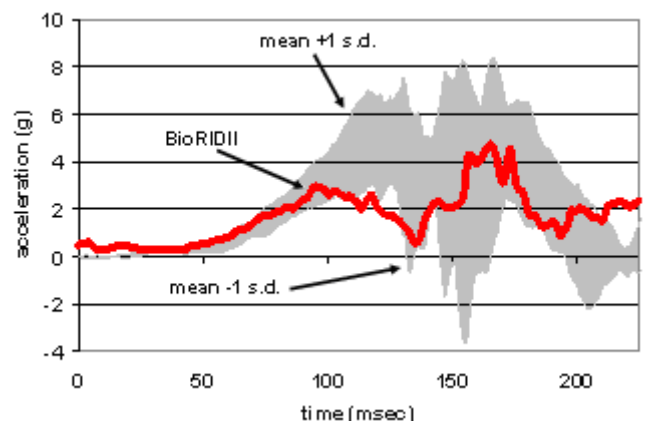


Figure 5. BioRIDII simulation thorax x-axis acceleration response compared with crash test corridors