Analysis of a Causal Model of Crash Test Pulses

Kieran Gockowiak[a], Dr Robert Anderson[b], Dr T. Paul Hutchinson[a]

[a]Centre for Automotive Safety Research, The University of Adelaide, [b]Hall Technical Pty. Ltd.

Abstract

This study first examines the theoretical basis for a differential equation model of vehicle crash response. It then describes the crash test data used to assess the validity of the differential equation, the criteria for selection of this crash test data, and the simple results that were obtained when the differential equation model was applied to this test data. These results are interpreted in terms of the theory, and the implications and limitations of this interpretation are discussed. Conclusions are drawn on the basis of this discussion, and possible future work related to the study is suggested.

Background

Crash testing in which a vehicle strikes a rigid barrier is common. However, published tests are usually limited to those performed for consumer programs or regulatory requirements, and crash performance at test velocities may not predict crash performance at other velocities (Searson, Hutchinson & Anderson, 2012). A differential equation model of vehicle behaviour can overcome some deficiencies of limited testing. Such a model is causal; vehicle behaviour may be extrapolated from starting conditions (impact velocity) and crash structure properties. It may therefore use published crash tests results to predict vehicle impact response at velocities not tested.

With the advent of primary safety technologies that modify crash velocities, assessment of overall vehicle crash safety should account for both secondary safety performance and active speed reductions. The model may therefore provide a basis for integrating the assessment of primary and secondary safety. Models in which crash performance is dependent on impact velocity have been applied in pedestrian crash analysis (Hutchinson, Anderson & Searson, 2012; Edwards, Nathanson & Wisch, 2014; Searson, Anderson & Hutchinson, 2014).

Theory

A differential equation (1) relating acceleration (x''), velocity (x') and deformation (x) may be used to model a deforming vehicle crash test structure (Hunt & Crossley, 1975; Herbert & McWhannell, 1977). For a given vehicle, m, k, b and n are constant. n describes the non-linearity of the vehicle crash structure's force-deformation function, and is investigated in this study.

$$mx'' - kx^n \left[1 + \left(\frac{b}{v_0}\right) x'\right] = 0 \tag{1}$$

Eqs. (2-4), relating impact velocity (v_0) to dynamic crush (C, maximum vehicle deformation), peak acceleration (a_{peak}) and time of dynamic crush (t_m) may be derived from Eq. (1). n may be determined from Eqs. (2-4) and known values of C, a_{peak} and t_m.

$$C \propto {v_0}^{2/(n+1)} \tag{2}$$
$$a_{\text{peak}} \propto {v_0}^{2.n/(n+1)} \tag{3}$$
$$t_m \propto {v_0}^{(1-n)/(n+1)} \tag{4}$$

Method

Tests were selected from the NHTSA crash test database. Vehicles were mid-size/full-size, transverse-front-engine passenger sedans from model years 2004 to 2014. Inclusion criteria required at least two tests conducted on each vehicle at significantly different impact velocities (11.1 ms-1 and 15.7 ms-1) with relevant accelerometer and video data. Crash pulse kinematics were resolved from accelerometer data. C, t_m and a_{peak} were calculated. Eqs. (2-4) were used to determine n from existing crash pulses by regressing known values of C, t_m and a_{peak} against v_0. C data was used to calculate n; t_m and a_{peak} were found to be ill-suited for determination of n. Due to the small number of crash tests that fulfilled the inclusion criteria, tests were aggregated and a common n was calculated for all vehicles.

Results

Values of n calculated for individual vehicles ranged from 0.09 to 1.61. Confidence intervals calculated for n were wide due to the small number of tests for each vehicle. Differences in n values between individual vehicles were marginally significant. When all tests were aggregated, the point estimate of a common n was 0.78, with a confidence interval of (0.62, 0.98). n for one vehicle varied significantly from the common n.

Conclusions

Aggregating data from all tests used in the analysis suggests that n may be approximately 0.78 for modern mid-size/full-size transverse-front-engine passenger sedans. This finding remains tentative due to the lack of available data.

References

Edwards, M., Nathanson, A., & Wisch, M. (2014). Estimate of Potential Benefit for Europe of Fitting Autonomous Emergency Braking (AEB) Systems for Pedestrian Protection to Passenger Cars. *Traffic Injury Prevention*, 173-182.

Herbert, R., & McWhannell, D. (1977). Shape and Frequency Composition of Pulses from and Impact Pair. *Journal of Engineering for Industry*, 513-518.

Hunt, K., & Crossley, F. (1975). Coefficient of Restitution Interpreted as Damping in Vibroimpact. *Transactions of the ASME*, 440-445.

Hutchinson, T., Anderson, R., & Searson, D. (2012). Pedestrian Headform Testing: Inferring Performance at Impact Speeds and for Headform Masses Not Tested, and Estimating Average Performance in a Range of Real-World Conditions. *Traffic Injury Prevention*, *13*(4), 402-411.

Searson, D., Anderson, R., & Hutchinson, T. (2014). Integrated Assessment of Pedestrian Head Impact Protection in Testing Secondary Safety and Autonomous Emergency Braking. *Accident Analysis and Prevention*, 1-8.

Searson, D., Hutchinson, T., & Anderson, R. (2012). From Crash Test Speed to Performance in Real World Conditions: A Conceptual Model and its Application to Underhood Clearance in Pedestrian Head Tests. *Stapp Car Crash Journal*, 485-496.