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Mathematical Modelling and Simulation of Car Crash Test

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Abstract

The vehicle crash tests are complex and complicated experiments, so it is advisable to establish its mathematical models. This paper contains an overview of the kinematic and dynamic relationships of a vehicle in a collision. It contains basic mathematical model representing a collision together with its analysis. The main part of this paper is devoted to methods of establishing parameters of the vehicle crash model and to real crash data investigation i.e. – creation of a Spring Mass Model, Kelvin Model, Maxwell's Model, Hybrid Model 1, Hybrid Model 2, and Double Spring Mass Damper Model for a real experiment, its analysis and validation.

Keywords- Mathematical Modelling, Car Crash test, Maxwell's Model, Kelvin's Model, Hybrid Model, Double Spring Mass Damper Model.

Introduction- A crash test is a form of destructive testing usually per-formed in order to ensure safe design standards in crashworthiness and crash compatibility for various modes of transportation or related systems and components.

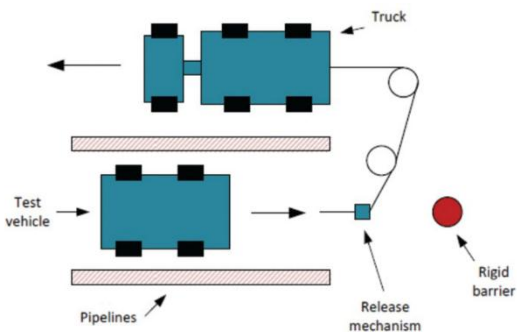
Crash tests are frequently used to help evaluate car safety. Different car safety programs and organizations (e.g. Euro NCAP, NHTSA, NCAC) specify how such tests should be performed, what factors should be investigated and how car safety should be assessed. Crash tests are not only performed when the car design is completed and a prototype is ready but also throughout the whole development and validation process. Car crash test standards and procedures designate detailed test procedures and requirements. Considerable re-sources are required to successfully conduct car crash tests. These involve skilled and trained personnel along with a large variety and quantity of sophisticated monitoring and measurement equipment and post-crash data analysis software.

Objectives-

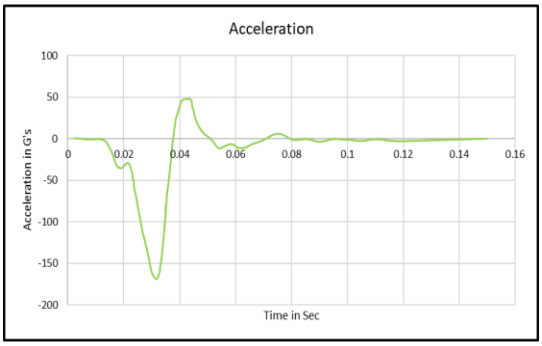
1. To predict the behaviour of the car after crash
2. To simulate the experiment of Car Crash virtually
3. To validate the results of Virtual Car Crash with the existing published experimental results.

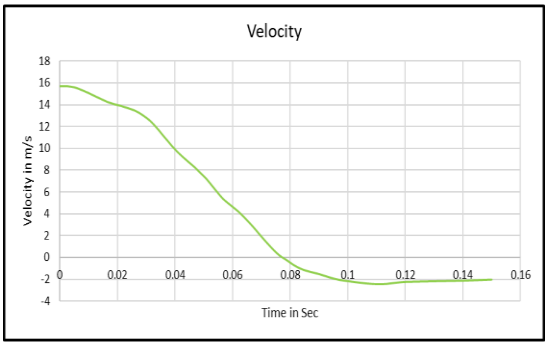
Experimentation-

Setup-



The Full Frontal Fixed Barrier Crash test (or Rigid Barrier test) represents a vehicle-to-vehicle full frontal engagement crash with each vehicle moving at the same impact velocity. A schematic of the test configuration is shown in Figure 2-4. The test is intended to represent most real world crashes (both vehicle-to-vehicle and vehicle-to-fixed object) with significant frontal engagement in a perpendicular impact direction. For FMVSS No. 208, the impact velocity is 0 to 48 Kmph (0 to 30 mph), and the barrier rebound velocity, while varying somewhat from car to car, typically ranges up to 10 percent of the impact velocity for a change in velocity of up to 53 Kmph. Note that although the rebound velocity varies somewhat from vehicle to vehicle, it is small compared to the impact speed, and the rigid barrier test therefore exposes the belted or unbelted occupant to approximately the same change in velocity (48 kmph plus the rebound velocity) for any vehicle. It is a full systems test which evaluates the protection provided by both the energy-absorbing vehicle structure and the occupant restraint system. Together with performance requirements, it ensures that the vehicle provides the same minimum level of protection in single vehicle crashes also regardless of the vehicles mass or size.





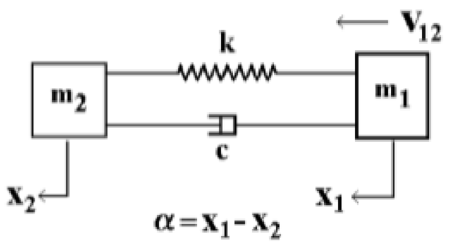
Data captured form Test report-

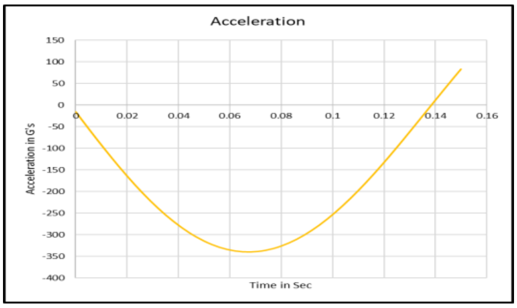
1. Test No.: 2320
2. Study Title: 1996 DODGE NEON INTO FLAT FRONTAL BARRIER
3. Test Type: NEW CAR ASSESSMENT TEST
4. Test Configuration: VEHICLE INTO BARRIER
5. Closing Speed (Kmph): 56.5

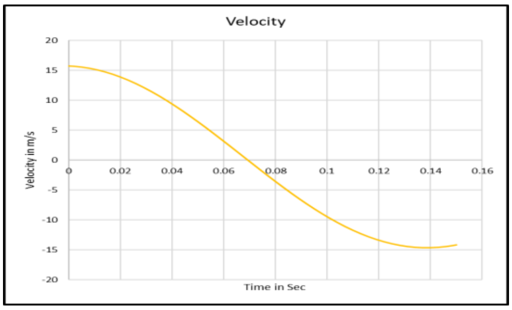
Mathematical Models-

Kelvin's Model-

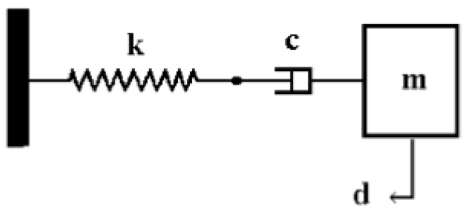
Kelvin's Model is developed using one Spring and one Damper in parallel as shown in figure. M is mass, C is Effective Damping Coe., K is Effective Stiffness and V is initial velocity of the Vehicle. The constants K and C are determined by initial conditions like dynamic crush and velocity at time equal to zero. To get the behavior of the car after crash Matlab Simulink model is developed.



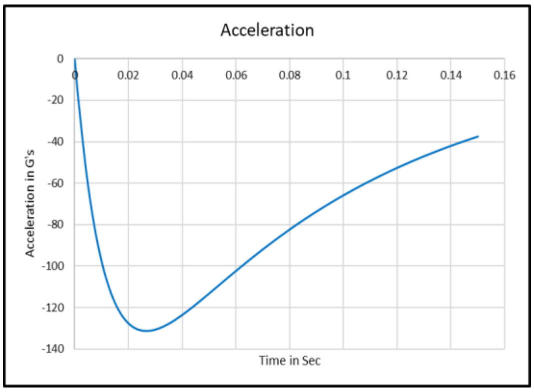


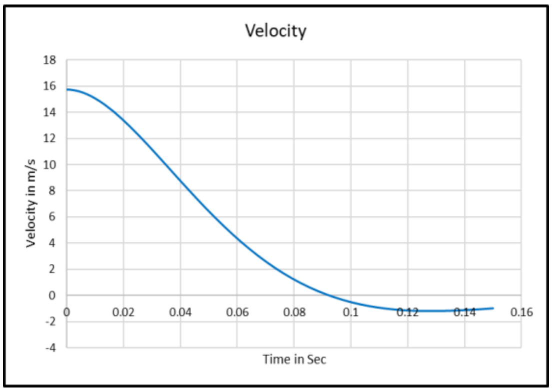


Maxwell's Model-

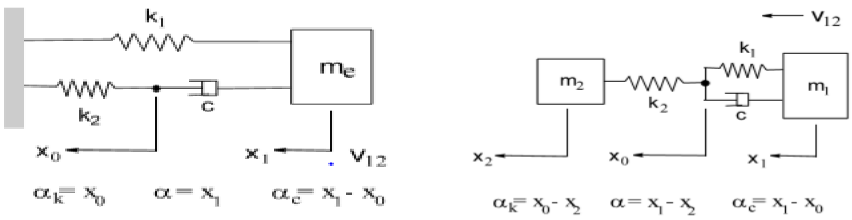


The Maxwell element consists of spring and damper elements connected in series, as shown in Fig. The element, massless and uni-axial, does not take into account the bending or torsion stiffness. The end points of the element can be attached to any bodies. The Maxwell model is suitable for modeling material responses that exhibit relaxation and creep, a time dependent phenomena. In vehicle impact modeling, it is suited for the localized impact where the vehicle effective stiffness is low. Maxwell's Model is developed in Matlab Simulink.



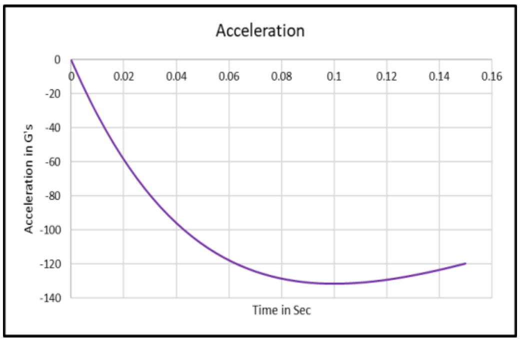


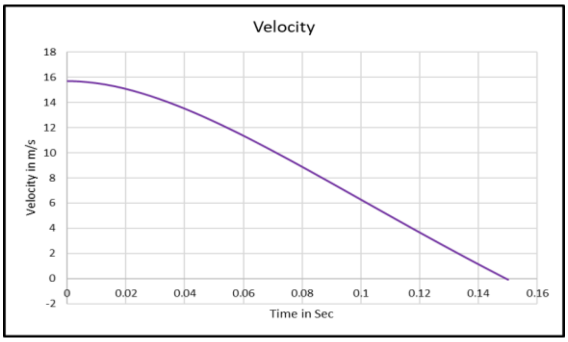
Hybrid Model 1&2-



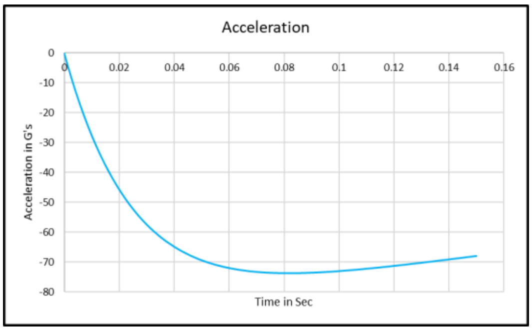
There are two types of Hybrid Models are developed which are shown above. It is the combination of Maxwell's and Kelvin's Model. It contains two springs and one Damper. These three elements are connected in such a way that the two hybrid models are structurally and functionally different (non-isomorphic). In impact analysis, each hybrid model has two mass systems with a closing speed of V12. To simplify the two-mass system analysis, the concept of an effective mass system is introduced.

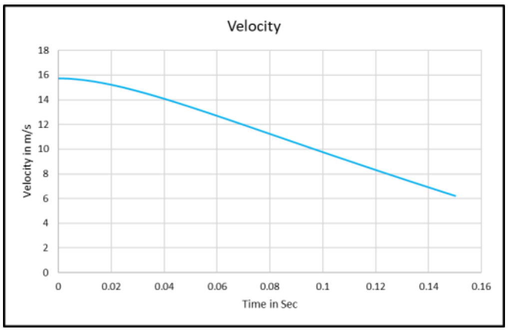
Hybrid Model 1 Results-



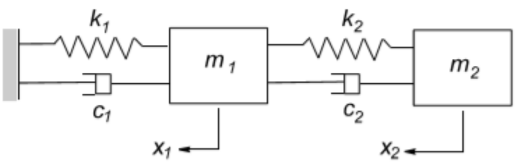


Hybrid Model 2 Results-

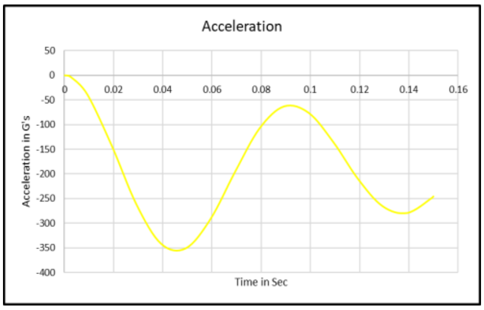


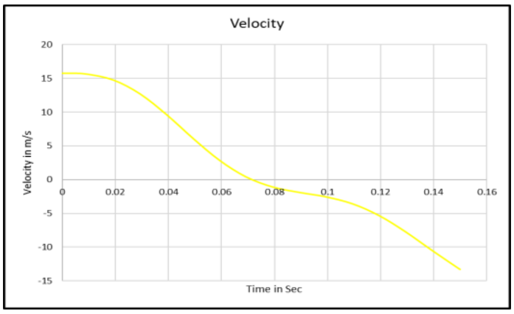


Double Spring Mass Damper Model-

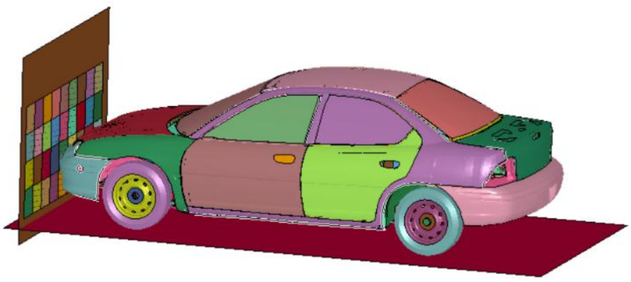


A numerical method based on semi-closed-form solutions of a two mass-spring-damper (2-MSD) model (shown in Fig.) is presented. Applications of the model solutions to the vehicle preprogram and post-crash structural analyses are described. The model in these applications simulates a rigid barrier impact of a vehicle where m1 and m2 represent the frame rail (chassis) and passenger compartment masses, respectively. In other cases, m1 may represent the vehicle structure with energy absorbers (spring and damper), and m2, the torso with a restraint system of spring, k2, and damper, c2.



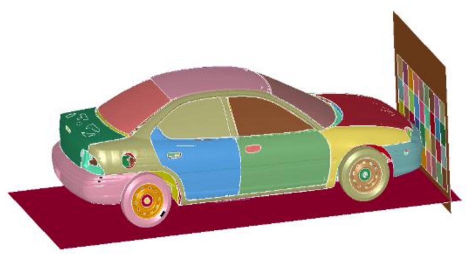


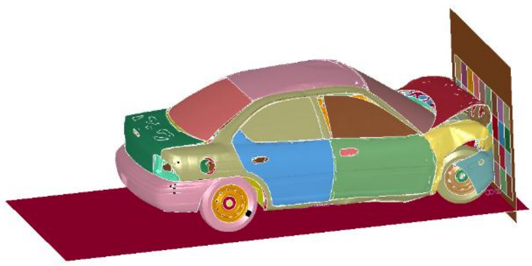
Simulation-

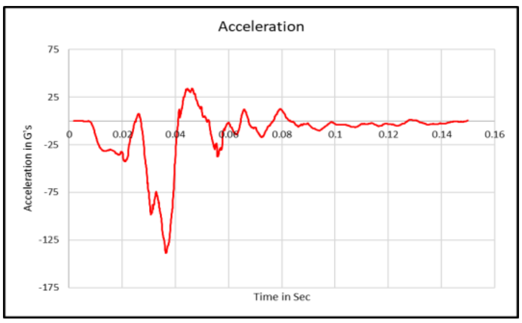


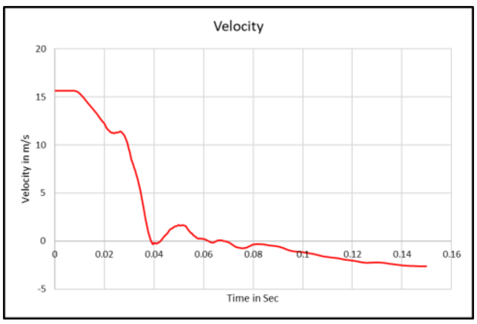
Simulation a frontal impact crash-test of a vehicle model moving at a velocity of 15.65m/s or 35mph (≈56.3kmph) in to a rigid immovable barrier is to be carried out and analyzed. It is assumed that the brakes are not applied during the crash event. The results obtained will then be validated and compared with the results of the same crash analysis performed by the NHTSA (National Highway Traffic Safety Administration). The reason for comparing with the NHTSA is that the institute has already conducted the same test under the same conditions by using a physical test vehicle. Then developed a finite element model of the vehicle by the process of reverse engineering. Then again carried out the same test under the same test conditions on the finite element model and validated their results by comparing with the results obtained from the physical test.

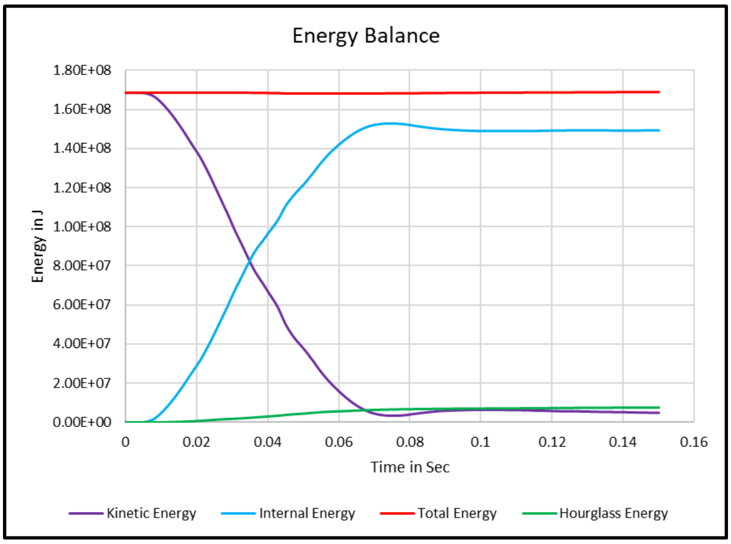
The energy balance of a system in an impact is governed by the law of conservation of energy. In case of an impact the kinetic energy possessed by the system in motion is converted into potential energy, sound energy and heat energy. The majority of the converted energy is the potential energy. In other words, the total kinetic energy is absorbed by the structure of the vehicle, since the energy must be conserved. Kinetic energy is the work input and internal energy is the work output. Internal energy is the energy absorbed by the system and is directly proportional to the product of force and deformation.





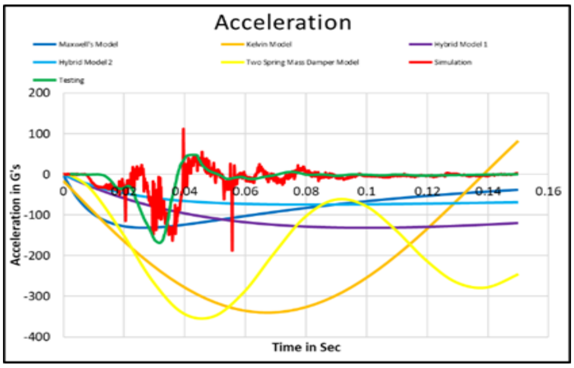


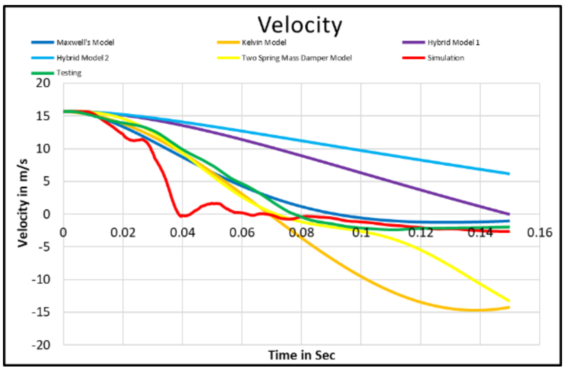




Result Analysis-

To represent vehicle to pole collision we established in total five models here (spring-mass model, Kelvin model, Maxwell model, Hybrid Model, Two Spring Mass Damper Model). Let us compare their responses with the car's behavior during the experiment analyzed. Characteristics which the best represents the overall car's behavior during the crash period belongs to the Maxwell model. Although Kelvin and spring-mass models give good approximation in the beginning of the crash (up to the time of maximum dynamic crush), they completely fail when it comes to the crash representation after the rebound. Therefore, the Maxwell model gives the best overall outcome. And the entire shape of the Maxwell model's response resembles closely the real car's crash data.

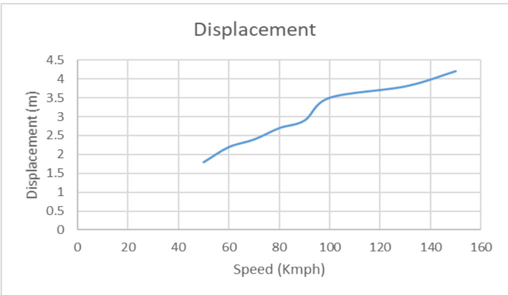


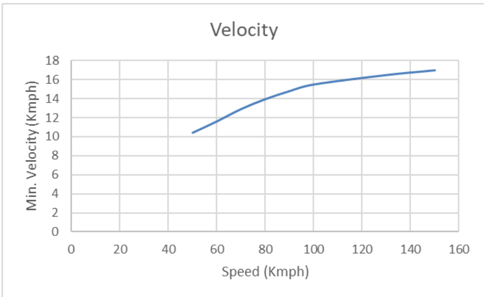


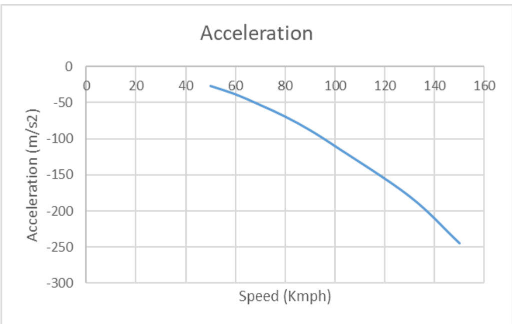
% Variation w.r.t. Testing-

Sr. No.	Model	% Variation in Velocity	% Variation in Acceleration
1	Maxwell's Model	51%	20%
2	Kelvin's Model	-610%	-46%
3	Hybrid Model 1	97%	50%
4	Hybrid Model 2	410%	64%
5	Two Spring Mass Damper Model	-565%	-61%
6	Simulation	-30%	16%

Behaviour of Displacement, Velocity and Acceleration w.r.t. change in Speed







From above graphs we can see that Displacement is increasing as speed of the car is increasing. Minimum Velocity of the vehicle is also increasing as speed is increasing. Acceleration of the vehicle is decreasing as speed of the car is increasing.

Conclusion-

Maxwell's Model, Kelvin's Model, Hybrid Model 1, Hybrid Model 2 and Two Spring Mass Damper Model compared with the testing data published by NHTSA. From the table of % Variation we can say that Maxwell's Model gives best results.

Average % Variation for Maxwell's Model is 51% for Velocity and 20 % for Acceleration.

With increase in Speed of Car Displacement, Minimum Velocity are increasing but at the same time Acceleration of Car is Decreasing.

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