The Use of the DRACR Airbag Simulation Model as a Design Tool

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Abstract

The airbag simulation program DRACR has been revised to include belt routines. The amended program is used to indicate optimal choice of parameters for a driver supplementary airbag system. As a validation, results from sled tests are given and compared with the computer runs. A good agreement is found for the values of the most essential protection criteria such as chest g's and HIC's. The model has proven to be useful in the engineering process of an airbag restraint system. The interrelationship between important input variables is easily studied. Further validation of the model by other teams is encouraged.

Introduction

The use of computers as design tools in high-tech companies is today a matter of course. Mathematical simulations of complex systems give many possibilities to study important parameters at early design stages and avoid extensive development tests, which in many cases take the form of a trial-and-error testing.

The engineering of an airbag system is a good example of where such an approach is suitable. Such a system consists of a large number of parameters, and an efficient way to handle these variables is to use a mathematical model. An early system analysis of bags, inflators, and steering system will shorten the time of development and make the process more efficient.

With this in mind, Volvo decided to start a project directed at the development and installation of a new computer model for the simulation of a driver airbag system. The model should be able to simulate the airbag inflation phase, different bag parameters, belts, different occupant sizes, etc. The DRACR model was chosen among available models to form a platform for the work. This report describes briefly the model and, more deeply, the parameter sensitivity studies and validations that have been made.

History

Volvo has been using computerized mathematical simulation models for airbag systems since 1975. The first model used a preinflated bag and in 1979 was improved to describe the inflator mass flow characteristics. In 1983 Volvo and Fitzpatrick Engineering developed a shell routine and updated the DRACR model, which was then to become the Volvo DRACR model (VDRACR) described in this paper.

The VDRACR Project

The project included—

- Updating the DRACR model
- Installation, input data preparation, and debugging
- Parameter sensitivity analysis
- Design of different airbag systems for testing

Updating the DRACR Model

As the existing DRACR model did not include all capabilities required by Volvo, the model had to be improved. For example, a belt routine was added for simulation of an airbag in combination with belts. The H-point was allowed to move also in the vertical plane and the model was changed to allow chest contact with the steering wheel through the airbag.

VDRACR Model Description

To understand the nature of the model and the results from the computer simulations, a short description of the model and its capability is presented below.

VDRACR is an acronym for Volvo DRiver Air Cushion Rotation. The model is a two-dimensional, lumped-mass computer model of a vehicle driver interacting with an airbag with or without a belt restraint system. The airbag is mounted in the steering wheel. The rotation suffix in the title means that the model simulates the rotation of the steering wheel with respect to the steering column as well as the rotation of the steering column with respect to the compartment. Different compartment geometries and occupant sizes and positions can be modeled easily. A schematic of the VDRACR model is depicted in Figure 1.

The driver is modeled by four masses: the head, the main torso, the sternal, and the lower body (pelvis and legs). The H-point is free to move in the vertical plane as well as the horizontal plane. The model simulates the pelvic girdle and torso compliance for belt interaction and sternal and chest compliance for airbag interaction. The abdomen compliance for steering wheel rim interaction is computed.

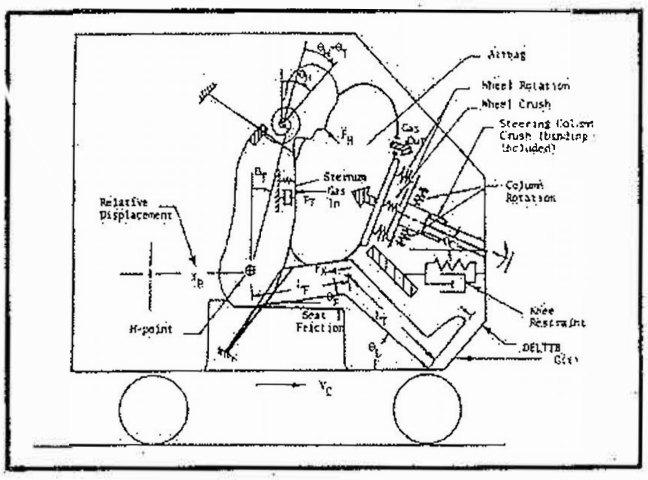

Figure 1. Schematic of VDRACR model

The airbag is modeled as an ellipsoid (actually an oblate spheroid), which is the most realistic shape of the driver airbag. The bag transmits forces from the driver head/chest to the steering wheel/column. The program uses a tabular input for the inflator gas mass flow-time properties.

The belt system in VDRACR can be used in combination with an airbag or as a stand-alone restraint system. A 2-point or 3-point belt can be simulated.

The system is described by the force-deflection properties of the webbing, the coefficient of friction between belt and latch plate, initial slack, and the amount of webbing that may stretch in each of the torso and lapbelts.

VDRACR models the steering wheel/column crush and rotation. An accurate simulation of this is important to achieve an overall simulation realism. The program calculates in each time integration interval the airbag forces and pressure before it proceeds with the steering wheel/column calculations, and in each time step the program uses a minimum energy method to determine which crush mode (steering wheel/column-rotation/crush) will occur. VDRACR models the column in a way that can be representative of most current car designs.

The model also has the capability to—

- Simulate the out-of-position driver
- Compute all the conventional protection criteria such as HIC's, chest g's, head g's, femur load, peak chest g's with 3ms clip

As a design tool, the program is oriented toward the hardware actually encountered in most design situations.

In addition, the program modules describing the performance of the various hardware components are designed to be complementary to one another. VDRACR is structured to provide balanced treatment of all the various restraint components that make up the total model.

Installation

The installation of the VDRACR model required—

- Changing the Fortran code to fit the mainframe computer at Volvo
- Creating an input file consisting of over 150 different parameters
- Building up knowledge inside Volvo of how the model was structured and how the program parameter interaction adds up to an overall system performance. It is the interaction of the major parameters affecting the driver airbag, as they vary over the range of interest, that many times has a greater effect on the results than the variation of any single parameter.

Parameter Sensitivity Analysis

The program input file consists of many different parameters. Some of these are more suitable for parameter studies and are used to optimize the airbag system, e.g., bag parameters as volume, ratio of axis, and ventilation area. Other parameters are more or less fixed because they depend on what can be delivered or developed by suppliers—for example, inflators—or are related to the vehicle. To form a basis for the sensitivity analysis, the vehicle-dependent parameters were decided and plugged into the model. The parameter sensitivity analysis was made for the overall system, and interesting parameters were varied.

For example, the interaction between chest g's, steering wheel plus steering column stroke, bag geometry and ventilation, occupant size, and inflators were varied. This is shown in Figures 2 to 4.

Figure 2 shows a plot of chest g's along with total stroke (steering wheel plus column) versus vent area for a

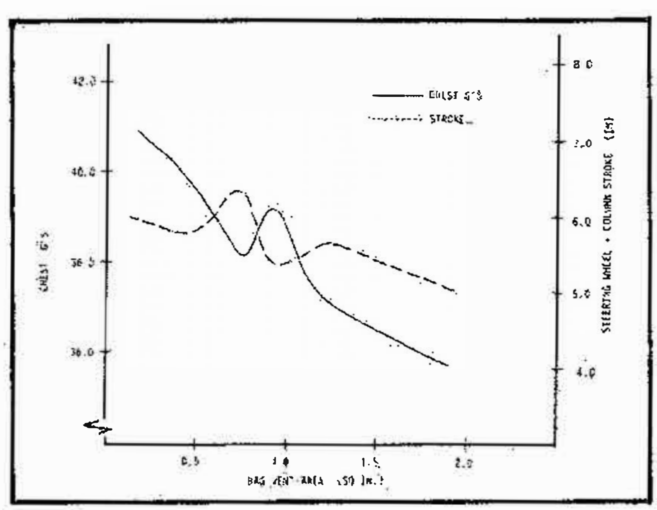

Figure 2. Chest g's and steering wheel plus column stroke versus bag vent area

67 liter bag with 280mm straps (internal straps to maintain the shape of the airbag) restraining a 50th percentile man in a 30mph barrier crash. Of interest is that chest g's and the total stroke are good mirror images of each other. Dips in the chest g's curve are matched with maxima in the total stroke and vice versa.

This appears to be the result of the program using a minimum energy approach to determine the collapse load during the program iterations. The chest g's and total stroke decrease for larger vent areas, which means that the bag dissipates energy. If the vent area is increased more than is shown in the plot, a point is reached where the chest g's raise again because there is not enough gas in the bag to prevent the occupant from bottoming out against the steering wheel.

This is actually shown in Figure 3: A 95th percentile male restrained by a 64 liter bag with 270mm straps, in a 30mph barrier test.

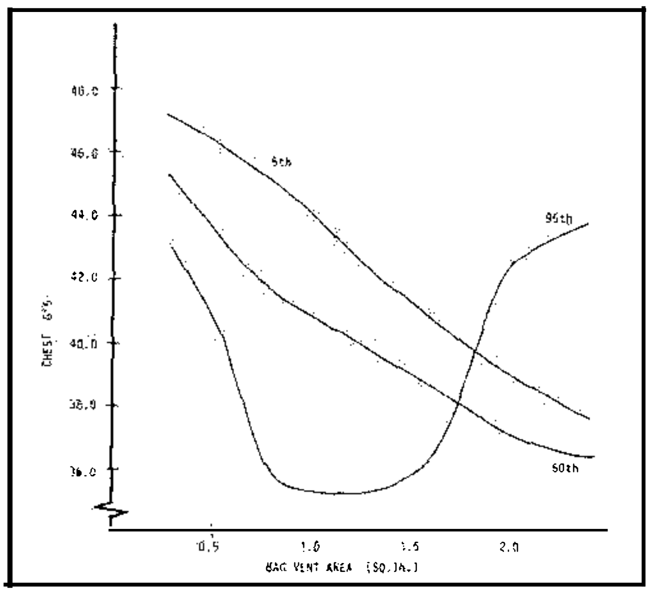

Figure 3. Chest g's versus bag vent area for a 95th, 50th, and 5th percentile driver restrained by a 64-liter airbag in a 30mph barrier crash

If the vent size is less than 0.8in², the bag is too stiff for the 95th percentile which results in high chest g's. Around 1in² the vent area is an optimum to get low chest g's, and above 1.5in² the driver bottoms out against the steering wheel and the chest g's raise again. The 50th percentile male and the 5th percentile female are also shown in Figure 3. In these cases, the smaller driver does not bottom out as the 95th, because there is a sufficient amount of gas in the bag to protect the driver.

Figure 4 shows the chest g's versus bag vent area for a 35mph barrier crash with the driver, a 50th percentile male, restrained by a 67 liter bag with 280mm straps and a 3-point belt. Two sizes of inflator are used, 75 and 80g.

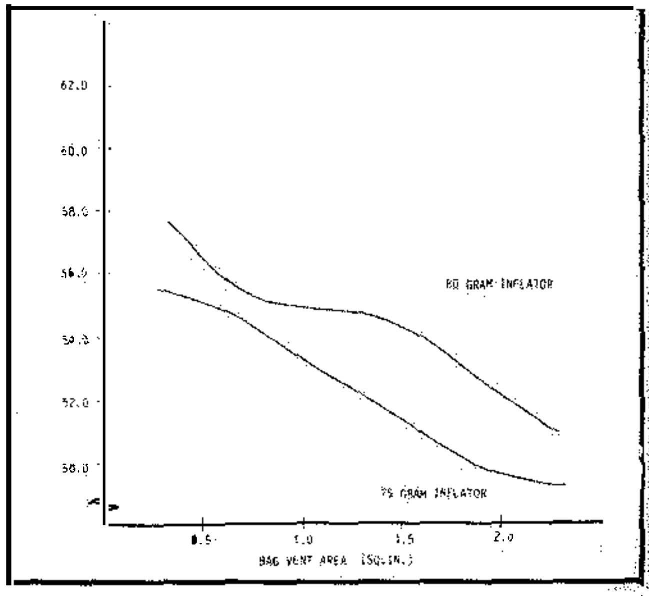

Figure 4. Chest g's versus bag vent area for a 50th percentile driver restrained by a 67-liter bag and 3-point belt in a 35mph barrier crash

In this configuration the driver receives higher chest g's with the 80g inflator as he will be more restrained. The simulations show that when a belt and an airbag are used together, the total forces on the chest are higher than if a separate system, either airbag or belt, was used. However, HIC values are decreased in tests with airbags combin with belts compared to belt-only systems due to the favorable ride down of the head.

Figures 2 to 4 demonstrate how the model gives the user the opportunity to optimize the sytem for best restraint performance.

Design of Different Airbag Systems for Testing

A number of candidate airbag systems were investigated using the optimizing procedure described above. It is important to have in mind that the objective of this work was to develop an airbag that would give protection for a 5th as well as a 95th percentile occupant and at the same time perform satisfactorily for the 50th percentile with and without a belt.

It will sometimes be easy to optimize the chest g's and HIC's for the belted 50th percentile male driver, but an unbelted 95th percentile driver may bottom out against the steering wheel with such a configuration. Also the 5th percentile female driver with belt can be overrestrained with high chest g's as a consequence. A suitable combination that meets all desirable requirements has to be found.

Over 1,000 computer analysis runs have been done, and some of the most promising combinations, depending on the availability of components and materials, were chosen for testing and served as a basis for validation of the model.

Validation

A series of HYGE sled tests with driver airbag systems was conducted to validate the VDRACR model against experimental data. Four different test series were conducted.

General Test Conditions

50th percentile dummy, 75g inflator, bag vent area 2.65in^2.

Test Matrix

A: 35mph, 64 liter bag/280mm straps, 3-point belt
B: 35mph, 52 liter bag/220mm straps, 3-point belt
C: 30mph, 64 liter bag/280mm straps, no belt
D: 30mph, 52 liter bag/220mm straps, no belt

Results

HIC's, chest g's, head g's belt forces, chest displacements, and femur forces resulting from simulation and sled tests are compared below. Table 1 shows an overview of the results.

Figure 5 compares chest g's and HIC's from sled tests and simulations.

Examples of plots of other parameters from the tests are shown in Appendix 1.

The results show a good overall correlation. Important parameters such as chest g's, HIC's, and belt forces correlate satisfactorily.

There is a difference between simulated and experimental knee forces. This may be a result of a too stiff knee pad characteristics in the program data input.

It is important to point out that it is difficult to have an exact correlation between model input parameters and testing conditions. Some of the input parameters are results from static component tests. Dummy-related parameters such as neck and chest parameters are also

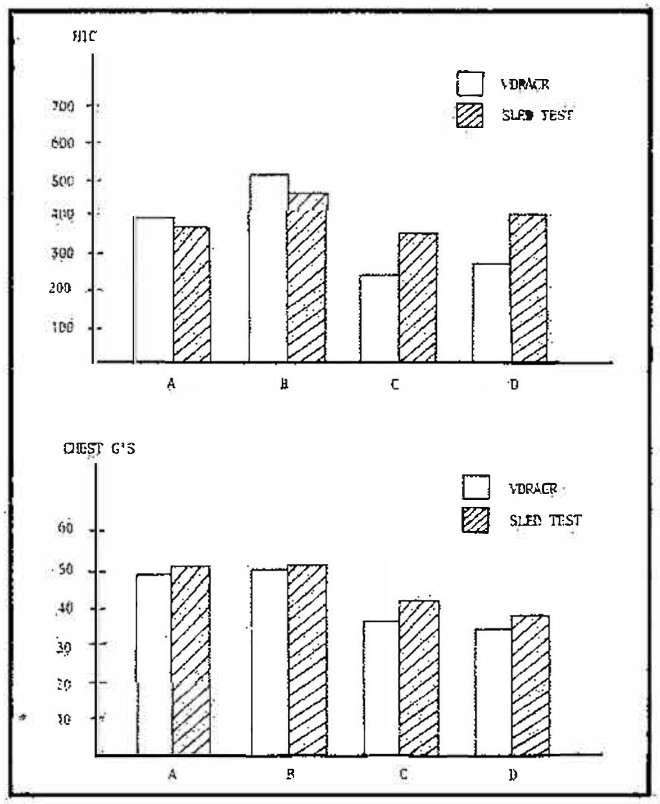

Figure 5. Chest g's and HIC from sled tests and simulations

		HIC	HEAD acc. (G)	CHEST acc. (G)	FEMUR Load (kN)	Lap Belt Load (kN)	Torso Belt Load (kN)	Chest Displ. (mm)
A	VDRACR	382	55	49	6.5	4./3	7.5	200
	Test	360	47	51	4.0/4.9	4.4	6.5	155
B	VDRACR	500	70	50	6.3	4.1	7.5	205
	Test	460	55	51	4.2/3.5	5.1	7.5	170
C	VDRACR	235	43	37	9.3	-	-	310
	Test	340	59	42	5.6/7.7	-	-	305
D	VDRACR	258	51	34	8.9	-	-	319
	Test	390	64	38	5.5/6.5	-	-	320

Table 1. Representative characteristics of structural components

hard to describe precisely. In the film, the bag shows a tendency to move up toward the windshield, which is not possible to describe in the model.

Conclusion

The VDRACR model has shown itself to be a good tool for design and development of a driver restraint airbag system. The model makes it easy to study several different airbag system parameters and their interrelationships.

Further validations should be done with different occupant sizes. Our validation is carried out against results from sled tests, and, of course, a validation against a barrier test is desirable. It is important to continue work with the model, refine the input parameters, and find methods to get improved input data for different systems guiding the event such as steering column bracket characteristics, seat cushion friction, etc.

Even if the results from sled tests and mathematical simulations are not always comparable in absolute figures, the trends suggested by the model are confirmed with the sled experiments.

The model seems capable of detecting changes in restraint system parameters and predicting trends in HIC's and chest g's, both in airbag-only exposure as well as in airbag and belt exposure.

Recommendations

A refinement of the description of the occupant is recommended. An improvement of the force balance between bag and chest is needed for simulation of a bag moving up toward the windshield, which occurred in the sled tests.

Sometimes minor algorithmical errors appear when the value of a parameter is changed. A more extensive error interrupt routine is needed. The model appears to be sensitive to changes of the integration time step, which perhaps is not relevant. The user of the model must have a good understanding of the function and capability of the model to be able to make full use of its possibilities.

Acknowledgments

The authors would like to thank the U.S. Department of Transportation, National Highway Traffic Safety Administration, for making the DRACR model available and also Fitzpatrick Engineering for their excellent work in improving the model.

References

1. Fitzpatrick Engineering, "DRACR user's manual," 1982.

2. B. Biss et al., "A systems analysis approach to airb design and development," ESV, 1980.

Appendix 1

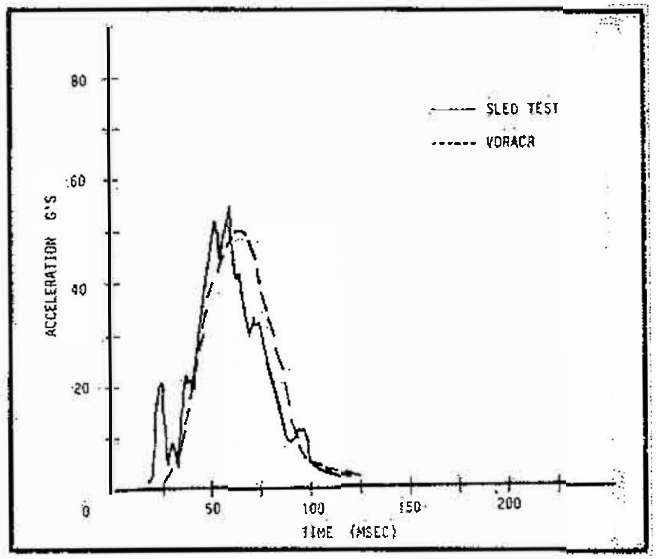

Figure 6. Chest g's versus time (35mph/50th percentile/64/64 liter bag/3-point belt)

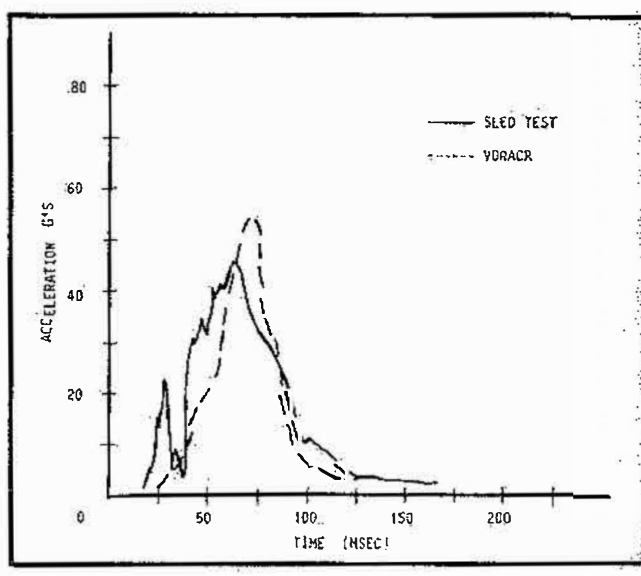

Figure 7. Head g's versus time (35mph/50th percentile/64 liter bag/3-point belt)

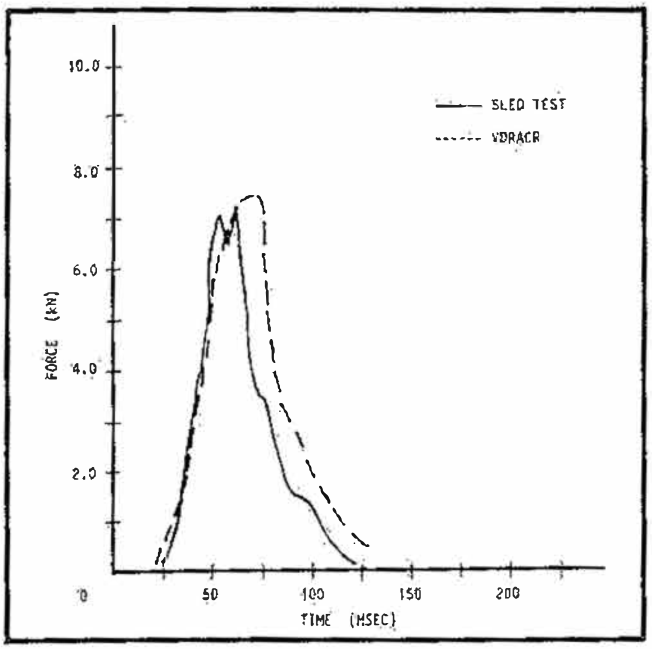

Figure 8. Torso belt load versus time (35mph/50th percentile/64 liter bag/3-point belt)

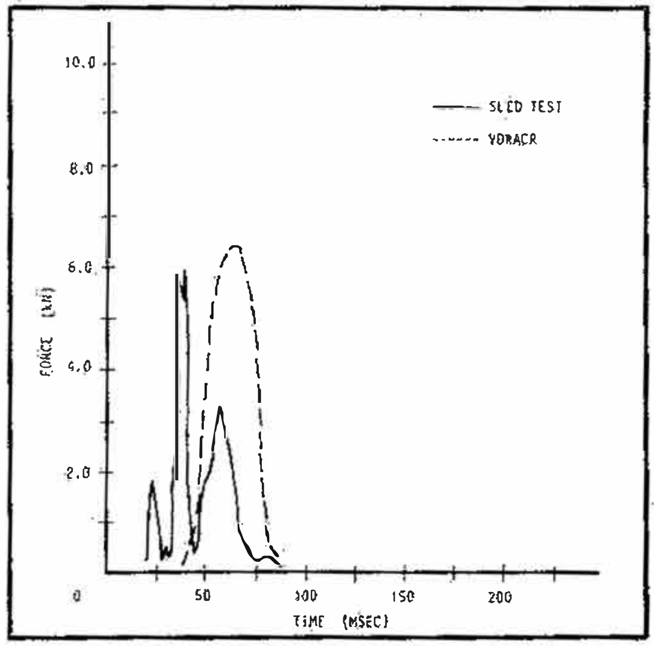

Figure 10. Femur force versus time (35mph/50th percentile/64 liter bag/3-point belt)

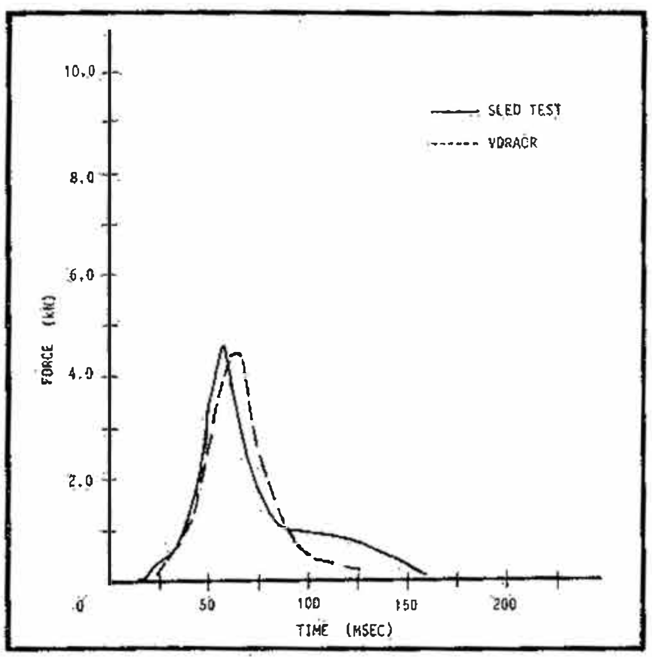

Figure 9. Lap belt load versus time (35mph/50th percentile/64 liter bag/3-point belt)

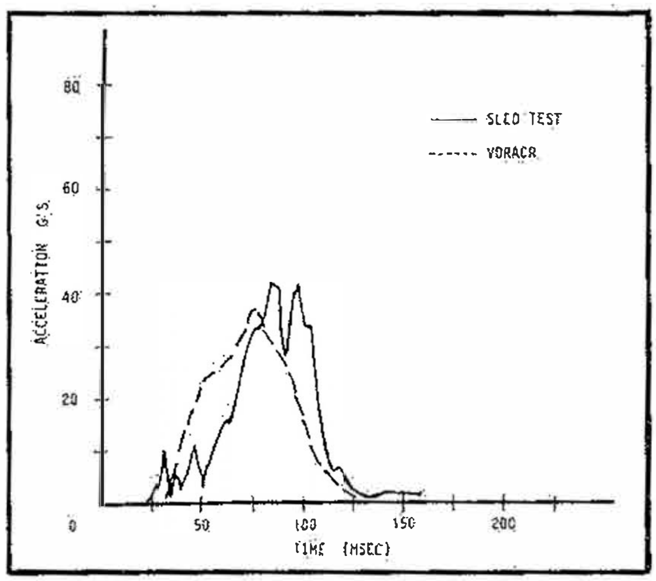

Figure 11. Chest g's versus time (35mph/50th percentile/64 liter bag/no belt)

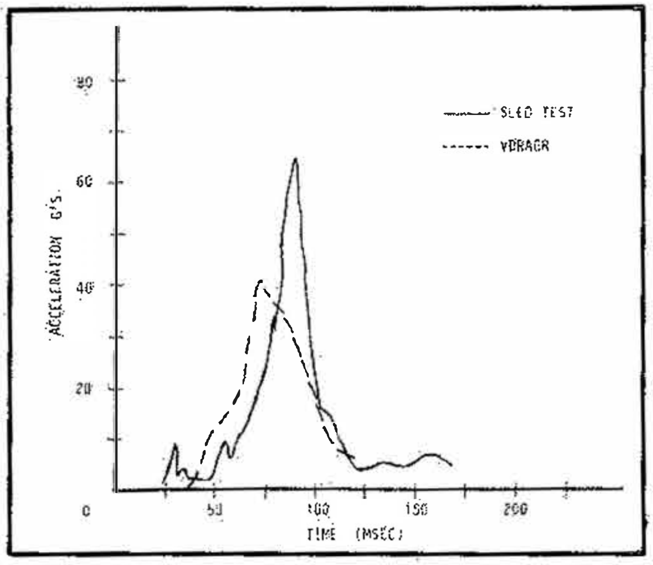

Figure 12. Head g's versus time (35mph/50th percentile/64 liter bag/no belt)

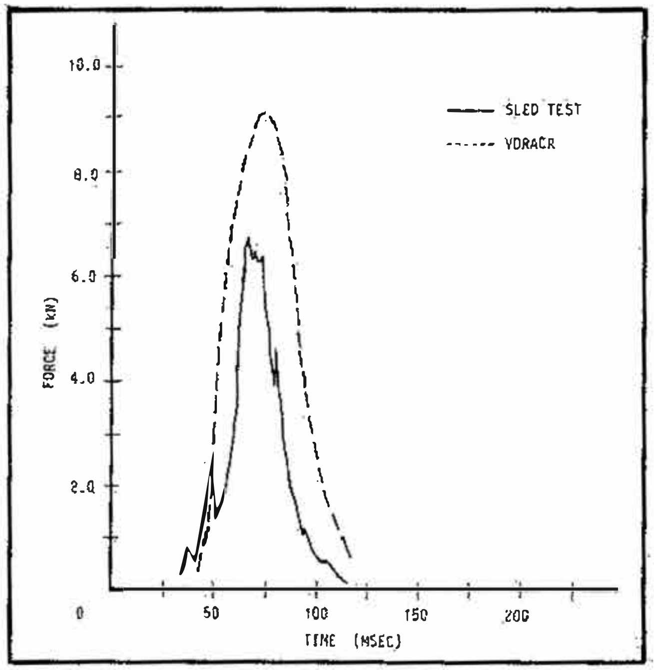

Figure 13. Femur force versus time (35mph/50th percentile/64 liter bag/no belt)

An Analytical Management of Frontal Crash Impact Response

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Abstract

The rotational behavior of the vehicle in the vertical plane at frontal collision against a flat barrier often plays an important role with respect to an evaluation of passenger compartment integrity and occupant protection.

An analytical method to examine the degree of influence of vehicle front end parameters, both on the behavior of the vehicle and its occupant, is presented, employing a two-dimensional finite element vehicle model and a two-dimensional lumped-mass occupant model.

The feasibility of the method is discussed by comparing the calculated results with the experimented ones, in relation to the behavior of passenger compartment and its occupant injury measure.

Preface

In high-speed frontal collisions, a rotation of passenger compartment in a vertical plane, often referred to as nose dive, is often observed. The effect of this rotation, especially on an occupant behavior restrained by a seatbelt, is not very well understood. This rotation may give rise to a substantial increase of crash space, or it may degrade restraint capability of a seatbelt system, due to an additional forward movement of the seatbelt anchorage points.

This paper describes the application of a computer model to simulate both the vehicle dynamics and its interaction with the occupant in the frontal barrier crash. The vehicle is assumed to be a small passenger car, and its occupant is assumed to be restrained by a conventional 3-point seatbelt system. Each behavior at collision is treated in the vertical, two-dimensional plane.

The object of this study is to assess a method of examining the effect of changes in vehicle front end parameters on the rotation of passenger compartment and, further, on its occupant injury measure in terms of the deceleration and displacement of the occupant head.