# The Simulation of the Fatal Crash Involving Diana, Princess of Wales, and Implications for the Investigation of Loss of Control Incidents

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#### Abstract

To assist the Inquest held in the United Kingdom into the fatal road traffic incident which occurred within the Pont de l'Alma underpass on the Cours Albert 1<sup>er</sup>, Paris, on 31 August 1997, the Transport Research Laboratory (TRL) was commissioned by the Metropolitan Police to re-examine the physical evidence found at the scene. The investigations examined whether this evidence could have been created in a single sequence of motion involving both the Mercedes and another vehicle, this vehicle having previously been identified as a white Fiat Uno. The analysis of vehicle motion was undertaken using the Human Vehicle Environment (HVE) simulation environment, and specifically the SImulation MOdel Non-Linear (SIMON) vehicle dynamics program using a simulation vehicle constructed using manufacturer data sources, and with reference to validation tests.

Several scenarios relating to the movement of the Mercedes were considered, and in particular; whether the physical evidence found at the incident scene could have been created in one sequence of motion by the Mercedes; the range of speed at which this occurred; and, the location of the contact between the Mercedes and a Fiat Uno.

It was found that the tyre marks found at the incident site, which had been disregarded in previous investigations, could have been created by the Mercedes, allowing the vehicle to reach the impact with pillar at the correct orientation and heading at a speed of 96 - 104 km/h. This is highly consistent with the impact speed of 105 km/h estimated during the original investigation with reference to two impact tests performed by the vehicle manufacturer. This work has demonstrated a method of analysis for tyre mark sequences which fall outside of commonly accepted criteria for the calculation of vehicle speed from "critical speed" tyre marks, using vehicle dynamics simulation.

#### Background

On the 31 August 1997, a fatal road traffic incident occurred within the Pont de l'Alma underpass on the Cours Albert 1<sup>er</sup>, Paris. During the incident, control of the involved vehicle, a Mercedes 280 S passenger car, was lost and the vehicle struck a central support pillar within the underpass.

As a result of this incident, three of the occupants within the Mercedes sustained fatal injuries. These occupants were the driver, Mr Henri Paul, and the two rear seat occupants, Mr Dodi Al Fayed and Diana, Princess of Wales. A fourth occupant, Mr Trevor Rees-Jones, who was positioned in the front passenger seat, survived the collision. Following the opening of inquests into the deaths of Diana, Princess of Wales and Mr Dodi Al Fayed in the United Kingdom, the Transport Research Laboratory (TRL) were appointed by the Metropolitan Police to assist their investigations into the road traffic accident investigation aspects of the incident. In particular TRL were asked to review records of the physical evidence found at the incident site and to use vehicle dynamics simulation to analyse and demonstrate the incident sequence.

The primary aim of the computer simulation

analyses were to establish whether the tyre mark evidence found at the scene of the incident was consistent with having been created by a single vehicle and, specifically, a Mercedes 280 S. The analyses also investigated whether the sequence of vehicle movements which led to the creation of the type marks could be consistent with other physical evidence from the incident. The analyses demonstrated how the Mercedes moved as it approached and entered the underpass, and how it was being driven in terms of its speed, steering and braking in the moments before the collision. The simulation analyses relied on data relating to the physical characteristics of the Mercedes 280 S vehicle and specifically how this vehicle behaves when subject to sequences of severe steering inputs.

To assist with the development of a valid vehicle model for the incident simulation, information was provided by the vehicle manufacturer with respect to the vehicle characteristics and handling behaviour. Handling tests were also conducted with a Mercedes  $280\,\mathrm{S}$  at TRL to provide additional detailed dynamic data for the vehicle model validation. The physical characteristics of the incident site were measured and modelled in detail (using laser scanning and 3D modelling) to accurately reflect the road geometry on the approach to, and within, the Pont de l'Alma underpass. This geometry provided physical constraints on the sequences of simulated vehicle movements and provides an accurate macroscopic road profile for the simulation.

## Evidence from the incident scene

During the investigation of the incident scene immediately following the incident, a number of observations and measurements were made of physical evidence on the approach to and in the vicinity of the point of impact with the underpass pillar by the investigating authorities. This evidence included;

 clear and red fragments of vehicle light unit debris – these were found within the right lane of the west bound carriageway close to the entrance to the underpass;

- the cowling of the right door mirror and front right indicator lens debris from the Mercedes – these were found close to the end of the first tyre mark found at the scene, around 15 – 20 m from the entrance to the underpass;
- a sequence of tyre marks: the first starting close to the entrance of the underpass in the left lane curving from left to right; a second starting in the left lane before entering the right lane and curving from right to left; and, a third parallel to the second mark travelling from right to left, within the left lane (the second mark terminated in the vicinity of the pillar which was struck by the Mercedes, and the third mark terminated after a number of metres within the left lane);
- marks and abrasions consistent with a wheel impact with the central kerb of the westbound carriageway a short distance in advance (to the east) of the point of collision;
- damage to the pillar which was struck by the Mercedes; debris in the vicinity of the impact; and the rest position and orientation of the Mercedes following the collision;
- and, damage to the Mercedes indicating a significant frontal impact with the central pillar and evidence of contact with another vehicle on the front right wing

# Vehicle Data and TRL Tests

The construction and validation of the Mercedes 280 S vehicle model was greatly assisted by the provision of vehicle specifications and test data by the vehicle manufacturer. Information was also provided by the manufacturer in relation to the specific incident vehicle; this included the full vehicle equipment specification.

Detailed specifications relating to the Mercedes 280 S together with both specifications and test data relating to the 500 S (test data was not available for the 280 S), although the construction, specifications and handling performance of the 280 S and 500 S models are very similar with the only slight differences being in mass, inertia and suspension stiffness. Obtaining specifications for these vehicles assisted in the construction of simulation vehicle models, and for preliminary validation tests to be undertaken using test data for the Mercedes 500 S.

The 500 S test data consisted of static, open loop and closed loop tests in the form of steady state cornering, step steer and double lane change tests. In addition to data supplied by the vehicle manufacturer, TRL undertook a series of performance tests with the comparison 280 S vehicle which was obtained for a limited period by the Metropolitan Police in May 2006.

These tests largely duplicated those for which test data had been provided for the 500 S and involved steady state cornering, step steer and a series of closed loop tests specifically intended to provoke similar responses from the vehicle as would have occurred during the incident. These tests involved rapid sequences of steering inputs of varying severity at speeds of 92 - 100 km/h (57 - 62 mph). The test vehicle instrumentation is shown in figures 1 and 2.

## Simulation Software & SIMON overview

The computer simulation software used to develop the validated Mercedes 280 S model and to perform the simulations of the incident sequence was Human Vehicle Environment (HVE) [1, 2] developed by the Engineering Dynamics Corporation (EDC), Oregon, USA. In the analysis of this incident the Engineering Dynamics SImulation MOdel Non-linear (SIMON) [3, 4, 5, 6], a vehicle dynamics algorithm which runs within the HVE simulation environment was used to simulate the motion of the Mercedes 280 S. SIMON is one of a suite of analysis models designed to simulate vehicle movements and collisions within HVE.

The SIMON analysis engine is a mathematically constrained simulation program which uses physical laws to determine the result of vehicle/road-environment interactions. In the analysis of any simulation event the dynamic response of a vehicle is modelled by the SIMON



Fig. 1: The Mercedes 280 S test vehicle

program in response to: the initial conditions of a simulation (the vehicle's positioning, orientation, heading, speed and rotation); the driver controls on the vehicle (steering, acceleration, gear selection and braking); and the geometry and physical characteristics of the road environment (horizontal and longitudinal gradients, vertical features such as kerbs, and the frictional characteristics of different surfaces within the model). The SIMON engine allows a vehicle sprung mass with six degrees of freedom (x, y and z position, roll, pitch and yaw rotation) and multiple axles with three degrees of freedom per wheel for independent suspension systems (steer, z position and wheel spin). Suspension kinematics are simulated with user defined tables or data for camber angle, half-track change and roll steer at each wheel for suspension compression and extension.

SIMON uses the EDC semi-empirical tyre model [7] which is based upon the HSRI model developed at the University of Michigan Transportation Research Institute [8]. The semiempirical type model describes what is occurring at the tyre-road interface according to the current tyre-road conditions. The model assumes an adhesion region and a sliding region. The tyre model includes the following data groups: physical data, friction table, cornering stiffness table, camber stiffness table and slip vs roll-off. There exists within the model a parameter named "In use factor". This parameter acts as a multiplier for the longitudinal and slide friction values of the tyre.

## Construction of vehicle model

The 280 S and 500 S vehicle models were constructed for the SIMON model within HVE's vehicle editor using specifications provided by the vehicle manufacturer [9]. In addition to dimensional and inertia properties, information was provided for the front and rear suspension characteristics, the steering system, the braking system and the electronic traction system.

Manufacturer values were used for; camber angle, toe-in, front and rear spring stiffness and front and rear suspension damping rates. Camber angle against displacement can be entered directly into HVE as a table of values. The relationship of toe-in against vertical displacement is input into HVE as a third order polynomial. The polynomial describes the toe-in angle at the front wheels for extension and compression between 5 cm. Rear toe angle remains essentially fixed at  $\pm 0.25^{\circ}$ .

Manufacturer data was obtained for the (at wheel) front and rear spring deflection characteristics. The response is non-linear, but linear in the range of displacement relevant for vehicle handling. HVE assumes linear spring stiffness, hence front and rear values were adopted which reflected deflection levels observed during



Fig. 2: Test equipment fitted to the Mercedes 280 S

handling tests. Manufacturer data relating to suspension dampers in compression and extension and the lever ratios for conversion of these rates into "at wheel" damping was used to provide front and rear damping rates for the simulation vehicle. Since HVE assumes a linear damping rate at the front and rear wheels for both compression and extension, an average value of the compression/extension rates provided by the manufacturer was taken.

Sensitivity analyses of these variables have been undertaken to assess the magnitude of their influence on the path of the vehicle in the incident simulations, and the degree of corrective steering input required to correct for any changes in path. It is acknowledged that the simplification of damping characteristics within HVE would affect the vehicle's ride characteristics. However the effect on the fundamental dynamics of the simulation vehicle including path and oversteer characteristics was not significant.

Steering data from the manufacturer gave an overall steering ratio of 1:14 for the 280 S and 500 S vehicles. At higher levels of steering input, testing at TRL indicated that the steering ratio may become non linear (increasing), thus requiring lesser levels of steering input at the steering wheel of the simulation vehicle, although this observation may also reflect limitations of the tyre simulation model. Since it is not possible to change or adapt the effective steering ratio of the simulation vehicle during the course of a simulation, the validation tests investigated how much less steering input is required by the simulation vehicle model (as compared to the steering input to the test vehicle) when angles of steering input are relatively high, to compensate for the apparent higher steering ratios of the test vehicle.

It should be noted that the Mercedes 280 S and 500 S vehicles have particularly significant passive steering characteristics at the rear wheels, and that these are an important aspect of the vehicle's rear suspension kinematics. The passive steering characteristics at the rear wheels are such that they adapt the toe-in angle of the rear wheels in response to lateral force. This has the effect of reducing side slip at the rear wheels and thus reducing oversteer in severe handling situations.

In HVE an allowance has been made for the additional stability that the passive steering characteristic gives to the rear of the vehicle by adapting the lateral frictional characteristics of the rear types in the simulation. In a similar way to the slight adjustment of type angle in response to high lateral force allowed by passive steering (thus allowing increased cornering capacity and stability), increasing the lateral frictional characteristics of the rear tyres of the simulation vehicle allows higher levels of lateral force to be achieved at the rear before significant side slip and oversteer occur. Data was provided by the vehicle manufacturer in respect of the braking system. This included the front/rear braking ratio and an overview of the vehicle's anti-lock braking system (ABS). A simple type slip ABS model has been utilised to replicate an ABS effect where required



Fig. 3: The simulation environment



Fig. 4: The tyre mark locations as represented within the environment model

in the incident simulations. The incident vehicle was equipped with 235/60 ZR16 Michelin HMX tyres. The tests conducted at TRL were undertaken with Michelin Pilot 235/60 R16 tyres. A generic tyre model for 235/60 R16 tyres was used for the simulation. This tyre was obtained from the generic tyre data provided within the HVE tyre database which is populated with data generated by the Calspan Corporation. Sensitivity analysis of key tyre variables was undertaken to provide an indication of the likely magnitude of the effect of differing tyre parameters.

#### Vehicle validation

The detailed vehicle data described above was used to construct a preliminary Mercedes 500 S vehicle model in HVE for comparison against manufacturer 500 S test data. This data included static (steady state cornering), open loop (step



Fig. 5: Results of the first simulation run – Magenta curves = TRL test; blue curves = simulation



Fig. 6: Results of the third simulation run – Magenta curves = TRL test; blue curves = simulation

steer) and closed loop (double lane change) tests. The initial comparison of the HVE 500S model against this data provided a preliminary validation of the vehicle handling characteristics.

During the course of the validation exercise it was noted that the vehicle model over-steered following severe steering inputs, this was corrected through a modification to the rear tyre properties of the vehicle, and these are discussed below. After scaling the mass and inertia properties, the 500 S model was then used as a base for the 280 S model which was validated against TRL physical test data.

## **Review of validation**

Tests with a comparison Mercedes 280 S vehicle were undertaken on TRL's research track in May 2006 and provided an independent set of test data relating to the handling characteristics of the 280 S. The instrumentation fitted to the test vehicle provided a comprehensive record of the driving and vehicle response in each test. TRL physical tests included; steady state cornering (12 tests), step steer (26 tests) and severe steering (14 tests). The severe steering tests were undertaken in an attempt to provoke oversteer and to recreate, as closely as possible, the type of handling situation encountered by the incident vehicle during the loss of control in the Pont de l'Alma underpass. In running comparative simulations of the physical tests, sensitivity analyses of specific input parameters were undertaken to investigate the effects of variations on the speed and path of the vehicle. The results of two tests are presented in figures 5 and 6.

As can be seen from the results, the Mercedes 280 S simulation model generated data which closely matched that from the physical test vehicle. These results were obtained with only one significant modification to the vehicle model (which was initially made to the 500 S model) this being a modification of the lateral force verses slip relationship at the rear tyres. This modification was made in response to excessive rear tyre slip (causing oversteer) of the simulation vehicle, which was found during early sim-

ulation runs. The modification created a proxy for the influence of the test vehicle's rear passive steering characteristic. This modification was implemented by increasing the "in use factor" of the lateral friction characteristics at the rear wheels. The modification prevented excessive side slip developing at the rear tyres of the simulation vehicle and optimised the simulation results in comparison to the physical test data.

The steering and suspension systems within HVE could not simulate precisely the steering effect of each road wheel with respect to a particular level of steering wheel input from the driver (and in response to particular severities of cornering). This may have been due to a number of effects including, passive steering, non-linearity in the steering system and/or limitations of the simulation type model. These effects increased the effective steering input for the simulation vehicle in severe steering manoeuvres, and required that actual steering inputs to the simulation model were reduced in comparison to known test steering inputs. The degree of difference between the steering inputs to the Mercedes 280 S tested at TRL, and those to the simulation vehicle in the validation tests can be seen in figures 5c and 6c.

Of particular importance to the validation is the ability of the simulation vehicle to follow the path of the test vehicle whilst also experiencing the same degrees of lateral acceleration, yaw angle (rotation) and side slip. This data (figures 5d and 6d) demonstrates a very close agreement between the paths followed by the test and simulation vehicles.

## **Event simulation**

In the analysis of the incident a series of simulations were developed to examine whether the validated Mercedes 280 S vehicle model could be "driven" within the road environment model of the Cours Albert 1<sup>er</sup> and the Pont de l'Alma underpass in such a way as to allow the simulation vehicle's tyres to pass over the locations of tyre marks found at the incident scene whilst also striking the kerb and, in particular, the pil-



Fig. 7: The entrance to the underpass and debris (note that the first tyre mark was identified in this area but is too light to be seen clearly)

lar within the underpass, in a position and orientation consistent with those reconstructed from the physical evidence and damage to the incident vehicle, figures 3 and 4.

Investigations conducted by the French Authorities in respect of the lens debris found close to the entrance of the underpass, and in the analysis of paint which was transferred to the Mercedes during contact with another vehicle, indicate that the Mercedes came into contact with a white Fiat Uno on the immediate approach to the underpass.

The physical evidence found by the investigating authorities, figures 7, 8, 9 and 10, identified



Fig. 9: The kerb strike and the area leading to the pillar impact

an initial tyre mark located within the left lane which was initially angled slightly towards left kerb of the carriageway, but which then curved right towards the nearside (right) lane. The implication of this mark being that the Mercedes would have travelled from right to left across the carriageway before being steered to the right, away from the central kerb. It was not known exactly where the contact occurred with the Fiat however the lens debris was found a short distance into the underpass and in the right-hand lane.

The positioning of the debris, relative to the tyre marks, would suggest that the collision must have taken place centrally or towards the right of



Fig. 8: The tyre marks leading toward the kerbstrike and the point of collision with the central pillar



Fig. 10: The vehicle in its rest position

the carriageway and a short distance from the entrance to the underpass. If the contact between the vehicles occurred in the left lane the debris would have been thrown laterally (to the right) from the point of collision before coming to rest. In the absence of a significant left to right impulse on this debris such movement is unlikely.

Simulations using the validated 280 S vehicle model in HVE have indicated that, for specific conditions of vehicle speed, driver steering input and allowing reasonable assumptions for road surface friction it is possible for the vehicle model to travel the path defined by the type marks, for the front left wheel to strike the kerb at the point of the wheel/kerb impact observed at the scene, and for the vehicle to reach a point of impact with the central pillar that is consistent with the location and orientation of damage sustained during the collision. Importantly, the areas where tyre marks were identified on the road surface coincided with the areas in which simulation model generated maximum lateral acceleration, type slip and weight transfer to the types on the side of the vehicle that created the marks, figures 11 and 12.

It was found that an initial approach speed of  $108 - 115 \,\mathrm{km/h} (67 - 71 \,\mathrm{mph})$  provided very strong agreement between the simulation vehicle path and the path of the type marks found at the incident site, the location of the kerb strike, the orientation of the vehicle at this point and the orientation and heading of the vehicle at the point of impact with the central pillar. The incident simulations predicted a pillar impact speed of 96 - 104 km/h (60 - 65 mph) which was highly consistent with the impact speed of  $105 \,\mathrm{km/h}$  $\pm 5 \text{ km/h}$  (65 mph  $\pm 3 \text{ mph}$ ) estimated during the initial investigation by the French investigators using data from two the impact tests performed by the vehicle manufacturer at test speeds of 95 and  $109 \,\mathrm{km/h}$  (59 and 68 mph). Since the simulation and the impact test techniques were independent in their means of speed estimation, they provide strong support of one another.





## **Discussion and conclusions**

The simulations of this incident sequence demonstrated that the tyre marks found at the incident site could have been created by the Mercedes in a sequence of motion which would be consistent with all of the physical evidence found at the scene.

The tyre marks had been disregarded in previous investigations due the apparent incompatibility between the path of a tyre mark which was assumed to have been created by vehicle's front right wheel and the positioning of the impact between the front left wheel and the kerb, i.e. the distance between the kerb strike and the tyre mark was too great to be consistent with the tyre mark being generated by the front right tyre.

The possibility that this tyre mark was generated by the rear right tyre was investigated by



Plan view showing evidential tyre marks overlayed (white)



Plan view showing simulated tyre marks (dark grey)

Fig. 12: Comparison of actual and predicted tyre mark location

TRL. This tyre, which would have been tracking outside the path of the front right could have followed the path of the mark whilst still allowing the front left wheel to strike the kerb at the known point.

The propensity for the Mercedes to generate rear wheel tyre marks was investigated and demonstrated during a series of physical tests with a duplicate vehicle. During these tests the vehicle was subjected to sequences of severe left, right, left steering input. The vehicle readily produced tyre marks from both rear wheels during heavy cornering, producing longer, darker rear marks from the rear tyres than the fronts.

This unusual characteristic appears to have led to the marks being disregarded during the initial investigation. It is quite possible that a third tyre mark identified at the incident scene, but insufficiently measured to allow plotting on a scene plan was created by the rear left wheel during the loss of control.

The mechanism for the formation of these marks is clearly demonstrated in the simulation of the incident sequence. The sequence is also consistent with the vehicle reaching the point of collision with the central pillar at the correct orientation and heading given the damage sustained by the vehicle during the collision.

This work has demonstrated a method of analysis using vehicle dynamics simulation for tyre mark sequences which fall outside of commonly accepted criteria for the calculation of vehicle speed from "critical speed" tyre marks, such as those described by Lambourn [11].

Vehicle path simulation can thus be of considerable value where evidence of a vehicle's path exits but is limited to short sections of mark, or where a mark is followed by an impact with a vehicle or object at a well defined point and alignment.

In undertaking the simulation of such sequences, numerical data should be examined to investigate simulated tyre slip, lateral acceleration, weight transfer and lateral force at the tyre/road contact, with respect to the location of the tyre mark. These factors should be at maximum for the particular manoeuvre (or part of the manoeuvre) when the simulation vehicle reaches the point at which the tyre mark was created.

Clearly, if the road on which such marks are found has significant three dimensional geometry then simulation using an accurate 3D model of the road surface is recommended, particularly where crossfall or superelevation may influence the cornering behaviour of the vehicle and/or where variations in the longitudinal road profile load/unload the suspension.

It is recognised that to some degree tyre mark formation may commence before a critical speed is reached for a curved path, and that the conditions for tyre mark formation will vary from location to location. Nevertheless, when considering cars and light goods vehicles, significant lateral force is required to generate tyre marks and an investigator should ensure that simulation data is consistent with severe cornering, and that these conditions peak at points where tyre marks are found.

In adopting this method of analysis for curved tyre marks, it is important for the investigator to consider the possibility of braking or throttle application, in combination with severe steering. Significant application of either over a sequence of marks may well be evident as significant variations in mark radius.

As demonstrated through the validation of the Mercedes 280 S vehicle model it is very important for rear wheel passive steering effects to be considered when preparing a vehicle model for the simulation of a severe steering sequence.

Preferably such effects should be accommodated within a vehicle dynamics model through a lateral force/steer angle relationship, however, where this capability does not exist it was found that a modification (increase) in rear tyre lateral friction characteristics provided results that matched physical tests. Failing to consider such effects will lead to the simulation of events in which the simulation vehicle would oversteer to a greater extent than a real vehicle, leading to inconsistencies in the path of the simulation vehicle and potentially inconsistencies with other physical evidence.

In drawing conclusions from vehicle dynamics simulations in which sections of tyre mark have been used to estimate vehicle speed the authors take the view that results should be regarded alongside other sources of physical evidence in order to establish the level of consistency between these sources of evidence. Clearly, any inconsistencies should be investigated and explained.

In summary, TRL's investigations into the fatal crash within the Pont de l'Alma underpass on the Cours Albert 1<sup>er</sup>, Paris, on 31 August 1997 included an analysis of a sequence of tyre marks leading towards a kerbstrike and the point of impact with a central pillar within the underpass. The tyre marks were measured by the investigating authorities, but were later considered inconsistent with the location of a wheel strike with the central kerb, immediately prior to the impact with the central pillar.

TRL's investigations analysed these marks using a validated vehicle dynamics model. It was found that the tyre marks could have been created by a Mercedes 280 S in one sequence of motion leading to the kerb strike and pillar impact. The speed of the Mercedes at the point of collision was highly consistent with an impact speed estimate derived from impact tests conducted by the vehicle manufacturer. A full sequence of motion for the 280 S during the incident was identified and demonstrated. This sequence was consistent with all sources of physical evidence relating to the incident.

It is recommended that collision investigators consider vehicle dynamics simulation as an alternative method of analysis where tyre marks are found to indicate the path of a vehicle to a point of collision, but that these marks fall outside of commonly accepted criteria for the calculation of "critical speed".

## References

- Day, T. D.
   A computer Graphics Interface specification for Studying Humans Vehicles and their Environments SAE paper no. 930903, Society of Automotive Engineers, Warrendale, P.A. (1993).
- [2] Day, T. D.
   An Overview of the HVE Vehicle Model
   SAE paper no. 950308, Society of Automotive Engineers, Warrendale, P.A. (1995).
- [3] Day, T. D.; Roberts, S. G. SIMON: A New Vehicle Simulation Model for Vehicle Design and Safety Research SAE paper no. 2001-01-0503, Society of Automotive Engineers, Warrendale, P.A. (2001).
- [4] Day, T. D. Validation of the SIMON Model for Vehicle Handling and Collision Simulation – Comparison of Results with Experiments and Other Models SAE paper no. 2004-01-1207, Society of Automotive Engineers, Warrendale, P.A. (2004).
- [5] Parry, D. I.; Marsh, F. TRL Limited, Investigating the use of Simulation Model Non Linear (SIMON) for the "Virtual Testing" of Road Humps presented at Engineering Dynamics: Human Vehicle Environment Forum 2003, EDC WP-2003-4 (2003).
- [6] Parry, D. I.; Marsh, F.; Coley, G. TRL Limited, Validation Studies of the Human Vehicle Environment (HVE) Program Simulation Model Non-Linear (SIMON) Institute of Traffic Accident Investigators, 2005 Conference Proceedings.
- [7] Day, T. D.
   Differences between EDVDS and Phase 4
   SAE paper no. 1999-01-0103, Society of Automotive Engineers, Warrendale, P.A. (1999).
- [8] MacAdam, C. C.; Fancher, P. S.; Hu; Garrick, T.; Gillespie, T. D.
  A Computerized Model for Simulating the Braking and Steering Dynamics of Trucks, Tractor-semi-trailers, Doubles, and Triples Combinations
  Highway Safety Research Institute, University of Michigan, Ann Arbor, Report No. UM-HSRI-80-58, 1980.
- [9] Garvey, T. J.
   Building Vehicles for HVE
   Engineering Dynamics Corp. EDC WP-2000-6 (2000).
- [10] Day, T. D.; Hargens, R. L. Application and misapplication of Computer Programs for Accident Reconstruction SAE paper no. 890738, Society of Automotive Engineers, Warrendale, P.A. (1989).

 [11] Lambourn, R. F.
 Calculation of Motor Car Speeds from Curved Tyre Marks
 J Forensic Science Society, 29, 37 – 386 (1989).

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