A STUDY OF HUMAN KINEMATIC RESPONSE TO LOW SPEED 'REAR END' IMPACTS INVOLVING VEHICLES OF LARGELY DIFFERING MASSES

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ABSTRACT

Vehicle-to-vehicle front-to-rear end low speed collisions are a common type of accident configuration. Research has been conducted, especially in the United States of America, to investigate and to try to quantify the relationship between occupant movement and vehicle impact speed. The authors of this paper have been involved in research into "low speed change" collisions for a number of years in an attempt to demonstrate how impact speed and occupant movement relate to European vehicles.

In recent years, these types of low speed collisions have lead to an increase in litigation relating to occupant injuries allegedly caused by the whiplash mechanism. More recently, a large number of personal injury claims have resulted from occupants of large passenger carrying vehicles (PCV), like buses, being involved in low speed collisions that trigger the whiplash mechanism leading to soft tissue injury.

Because of the likelihood of there being a large number of occupants in such vehicles, it is common for a relatively minor event to escalate into a very high value claim.

There exists a lack of information in the UK relating to low speed impacts of larger passenger vehicles and specifically impacts between vehicles with largely differing masses. This paper therefore presents the results of physical tests conducted to establish the magnitude of occupant movement experienced during a low speed collision between a passenger car and a PCV (a single deck bus).

INTRODUCTION

The question to be addressed is 'what level of movement occurs in those involved in a rear end bus collision?'

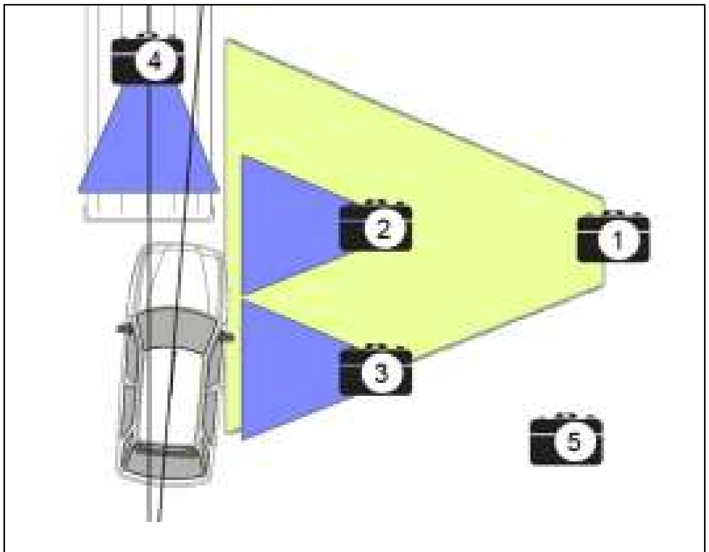
Dubois [1] performed 18 passenger car to bus collisions in their paper "Low Velocity Car-to-Bus Test Impact". With closing speeds between 1.47 and 9.34 mph, the changes in velocity for the bus were between 0.18 and 1.19 mph and the results, both in terms of vehicle and occupant behaviour, are comprehensive. However, the testing was conducted in the U.S.A and used North American vehicles built to specifications (and sizes) different from the vehicles typically encountered on UK roads.

Due to a lack of information available in the UK and faced with an increasing number of investigations involving large passenger carrying vehicles it was decided that a full scale physical test collision between a passenger car and a PCV would be conducted.

The impact speed was determined using a radar gun, from GPS and from integration of acceleration data recorded in the vehicle. The collision was also filmed using a high speed camera.

The recording equipment that was used consisted of two accelerometer units, one in each vehicle and external accelerometers placed on the head and chest of occupants of both vehicles.

Figure 1 indicates the collision configuration and shows the locations of the cameras used to record the impact;



Camera	Camera
1	Static. High tripod.
2	Static. Bumper level. High Speed. High Def.
3	Static. Medium tripod. Targeted at driver.
4	Internal. Wide Angle Lens.
5	Dynamic on tripod.

Figure 1 Diagram and details of test setup.

TEST DETAILS

Using the GBB test reference, this test is CT1-2009-1. The vehicles were set up to have a 50% overlap with the bullet vehicle being a 1996 Citroen ZX 1.9D Advantage with two adult male passengers (kerb weight: 1046kg, loaded weight: 1365kg) and the target vehicle being a 1994 Volvo B10B single deck bus with 18 male occupants and 2 females (kerb weight: 10161kg, loaded weight: 11807kg).

The PCV was a semi-automatic transmission vehicle which was stationary with the service brake applied and the gear lever in neutral mode. The vehicle was fitted with the Vericom VC 3000 data recorder, and a sample passenger was fitted with external 25g and 10g accelerometers at the head and chest respectively. The Vericom unit fitted to the target vehicle had a guaranteed accuracy of 0.003g within a dynamic range of ± 2g. Beyond that range the accuracy will decrease. The Vericom is limited in its ability to measure collision pulses given its operating range (±2g) and sampling frequency (100Hz), however it was sufficiently accurate to provide an indication of pre and post impact velocities. The sampling interval of the accelerometers was 0.01 seconds.

The Citroen was a manual transmission vehicle and was driven at a steady speed of around 9 mph as indicated upon the speedometer of the vehicle and GPS tracker (to allow an 8 mph impact). It was driven into the rear of the PCV and the brakes were not applied at any stage until the vehicle came to a complete stop after the collision.

The speed of the Citroen was checked by radar and GPS and was found to be 8 ± 1 mph. Accelerometer data from the Citroen indicated an impact speed of 8.0 ± 0.1mph. This was the value used in calculations.

OCCUPANT INSTRUMENTATION

Accelerometers were fitted on the forehead and chest of the rear seat passenger in the Citroen. Figure 2 below shows the positioning of the accelerometers and their orientation before and at a point during the impact.

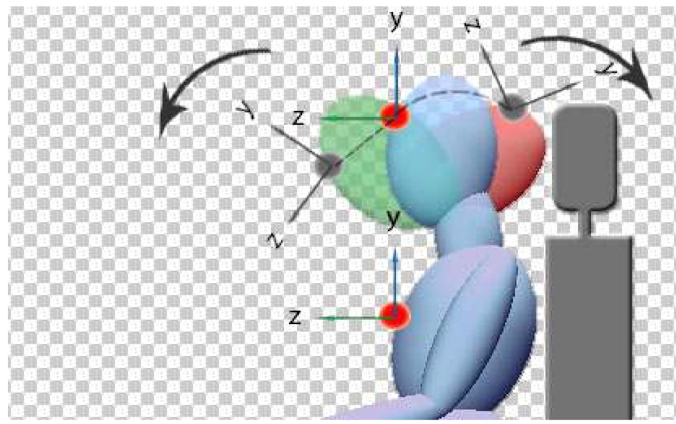


Figure 2 Movement of head and accelerometers during a collision. Head movement is dependent on impact direction.

The body of an occupant will experience an impact force through the seat. If this is sufficient, the body will accelerate under the action of this force but the motion of the head will lag behind that of the body during the early stages of a collision. This lag will cause the head to rotate and the orientation of the accelerometers to change as shown in figure 2.

In the striking vehicle, the major rotation of the head will be in the other direction as forces transferred to the head through the neck structure cause the head to accelerate past the body. It should be noted that the graphs of head accelerations shown in the results section of this paper have not been corrected for changes in orientation. The maximum acceleration experienced by the head will be the resultant acceleration calculated from the y and z components.

PRE-COLLISION CALCULATIONS

From knowledge gathered from previous collision testing (and in accordance with Newton's Second Law of

Motion) the lower mass vehicle will always experience the greatest speed change in a collision with a higher mass vehicle.

Whilst the acceleration of the PCV and subsequently the occupants therein was the main focus of the test, it was important to understand the likely effects upon the bullet vehicle and its occupants.

From observations of previous ‘car-to-car’ collisions, an estimated figure for restitution was obtained at the desired impact; however no data exists for a car-to-PCV collision.

Consideration of the car-to-car restitution figures was based upon an amalgamation of GBB data drawn from previous testing and research by Malmesbury and Eubanks [2]. Restitution values were plotted and a line of best fit was calculated. The resulting graph is show in Figure 3.

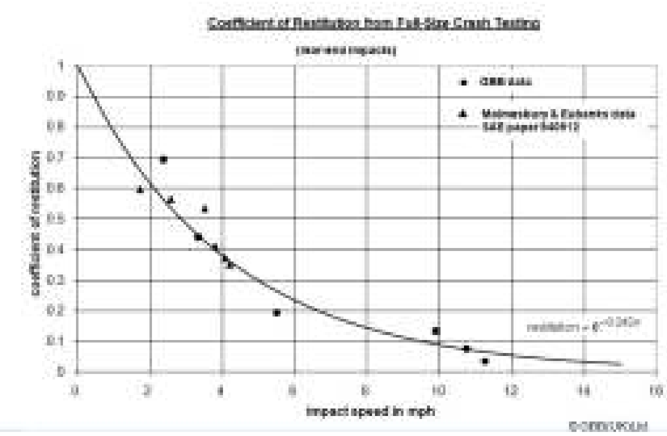


Figure 3 *Graph of restitution from Eubanks and GBB research.*

Figure 3 indicated a typical value of restitution for an 8 mph impact was 0.14. That value was incorporated into a momentum exchange calculation to provide values for the anticipated speed change of the PCV and of the car.

$$M = \frac{m_1}{m_2} = \frac{1046}{10161} = 0.1$$

$$v_1 = \frac{u_1(M - r)}{(M + 1)} + \frac{u_2(1 + r)}{(M + 1)} = \frac{8 \times (0.1 - 0.14)}{(0.1 + 1)}$$

$$= -0.3\, mph$$

$$\Delta v_1 = -0.3 - 8 = -8.3\, mph$$

$$v_2 = \frac{u_1(M + r)}{(M + 1)} + \frac{u_2(1 - Mr)}{(M + 1)} = \frac{8 \times 0.1(1 + 0.14)}{(0.1 + 1)}$$

$$= 0.8\, mph$$

$$\Delta v_2 = 0.8 - 0 = 0.8\, mph$$

A speed change of 8.3 mph was anticipated for the car and a speed change of 0.8 mph was anticipated for the bus based upon the unladen mass for each vehicle.

It would be unsafe for live human occupants to be placed in a target vehicle with anticipated speed changes in the 9mph region. The risk of injury would be too great.

By translating knowledge gathered from previous research it was estimated that for the bullet car in a 5 to 6mph speed change collision the positive disparity between peak head and chest accelerations should be in the region of 0.3g (z axis), whilst in the target vehicle it should be around 3.6g (z-axis).

It was therefore on this basis that the experienced volunteer investigator in this test was satisfied that the consequent accelerations (less than 3.5g) would be comfortably tolerated with minimal risk of injury.

RESULTS

Bullet Vehicle – Citroen ZX

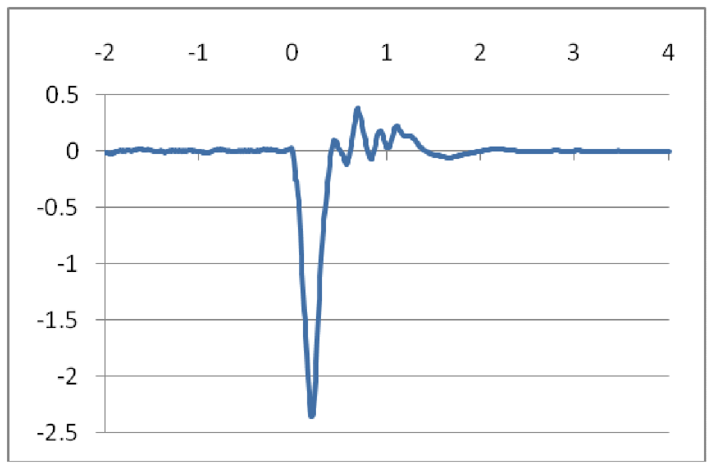


Figure 4 *ZX Vehicle acceleration (g)*

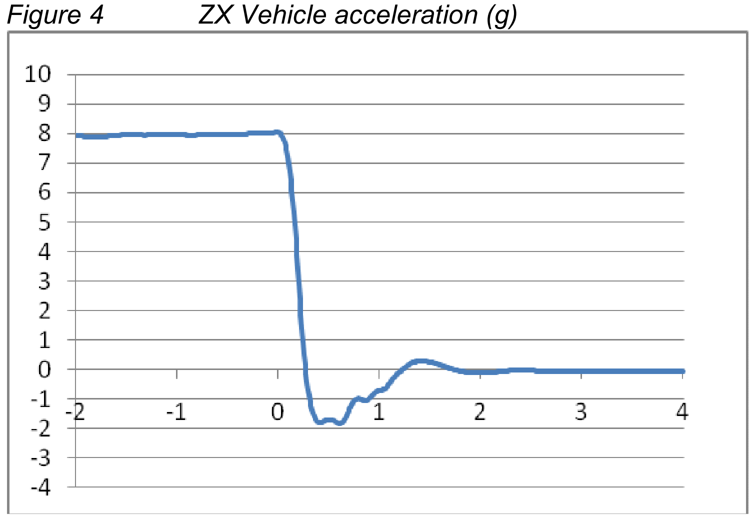


Figure 5 *ZX Vehicle Speed (mph)*

The timescale of the accelerometer was adjusted so that the collision started at 0 seconds. The start of the collision was defined to be when the acceleration became negative and stayed negative. Peak deceleration of 2.4g occurred at 0.19 seconds. The initial deceleration phase took 0.4 seconds, rebound then occurred.

From integration of the acceleration pulse, it was calculated that the impact speed was 8.0 ± 0.1 mph, and that the delta v (Δv) was 9.7 ± 0.1 mph.

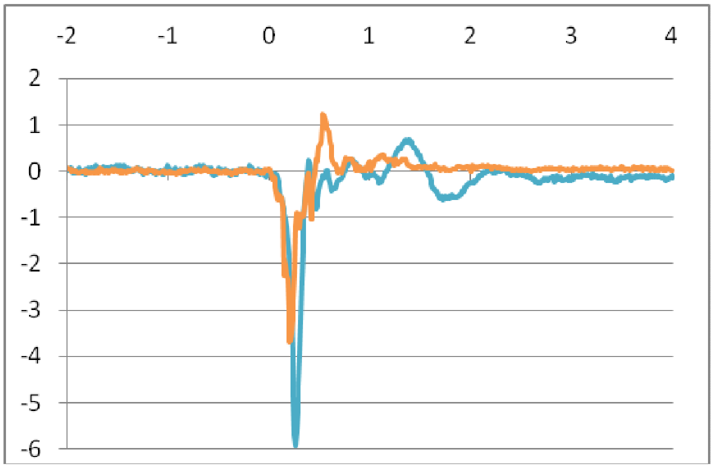


Figure 6 ZX Occupant Y Axis Acceleration (g). Blue = Chest, Orange = Head.

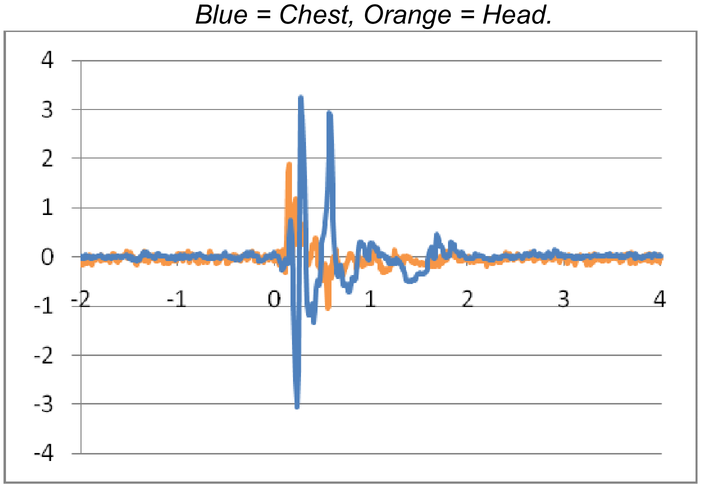


Figure 7 ZX Occupant Z Axis Acceleration (g). Blue = Chest, Orange = Head.

The occupant acceleration is expressed in two components; "Y" which denotes the vertical axis, and "Z" which denotes the longitudinal.

Y Axis - Peak vertical (Y) chest and head acceleration of 3.68g and 5.91g occurred at 0.2 and 0.26 second respectively.

At 0.26 second, the chest acceleration was 1.21g allowing for a maximum disparity of 4.7g.

Z Axis - A peak g of 1.9g occurred at the chest at 0.15 second. At this point, a head acceleration of 0.7g was experienced. (Peak 0.8g occurring at 0.17 second.). This first maximum disparity of 1.2g occurred.

A peak head acceleration of –3.06g occurred at 0.24 second. At this point the chest acceleration was 0.3g. The disparity was 3.36g.

A peak forward chest acceleration of 3.2g occurred at 0.27 second. The chest acceleration was 0.6g.

At 0.41 second, the head acceleration was –1.4g the chest being 0.2g. The disparity was 1.6g.

A second forward peak acceleration of 2.9g occurred at 0.57 second. The chest acceleration was –0.4g. The disparity was 3.3g.

Target Vehicle – PCV (Volvo B10B)

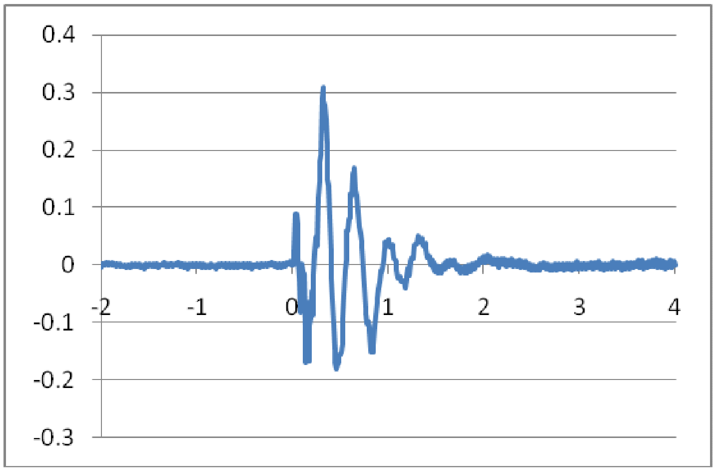


Figure 8 PCV Vehicle acceleration (g)

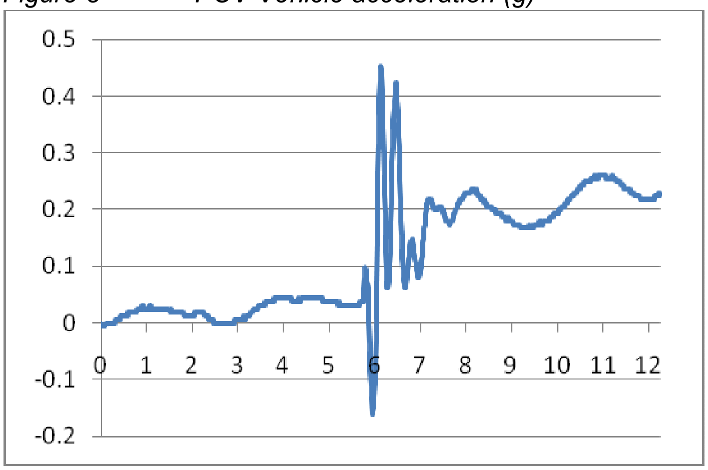


Figure 9 PCV Vehicle Speed (mph)

The timescale of the accelerometer was adjusted so that the impact started at 0 seconds. The acceleration reached a peak of 0.3g at 0.32 seconds. The speed change displayed oscillations as the vehicle's separated.

The wheels of the PCV were stationary and remained so throughout the collision phase. The sprung mass was accelerated to 0.43mph.

The un-sprung mass did not move as the acceleration applied was insufficient to overcome the frictional force between the tyres and road surface.

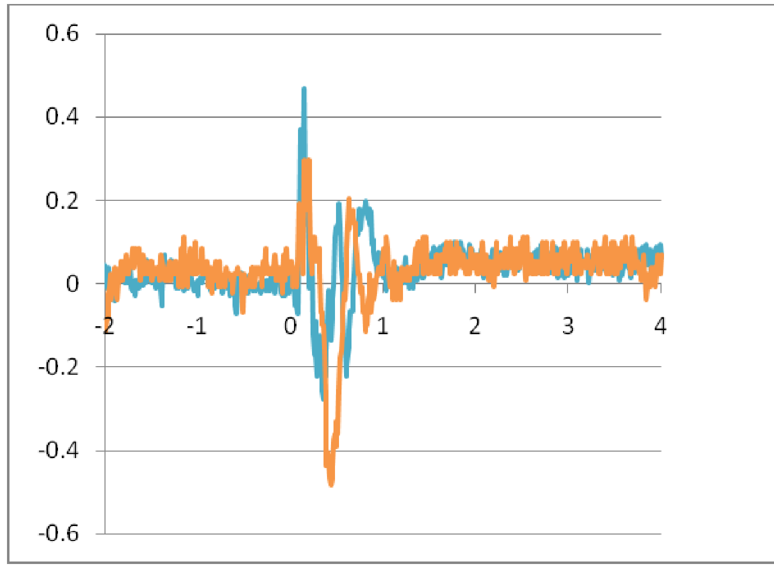


Figure 10 PCV Occupant Y Axis Acceleration (g). Blue = Chest, Orange = Head.

Figure 11 PCV Occupant Z Axis Acceleration (g). Blue = Chest, Orange = Head.

Y Axis – Peak vertical accelerations of 0.29g and 0.47g were observed simultaneously at 0.15 second. This suggests an instantaneous compression disparity of 0.18g.

A trough of –0.28g of the head occurred at 0.36 second, where the chest acceleration is –0.09g; a disparity of 0.19g.

A trough of –0.48g of the chest occurred at 0.44 second. The head acceleration was –0.14g demonstrating a disparity of 0.34g.

The time delay of 0.08 second may suggest an elongation of the neck structure.

Z Axis - The first head acceleration peak was found at 0.62g; the chest acceleration at that point being 0.1g. This occurred at 0.1 second and demonstrates a disparity of 0.52g.

At 0.14 second the peak head acceleration was –0.5g with the chest at –0.03g. The disparity is 0.47g.

By 0.52 second, the peak chest acceleration was –0.39g with the head at –0.21g. This is a disparity in favour of the chest of 0.18g.

CONCLUSION

Vehicle movement - The acceleration of the PCV peaked at 0.31g. The speed change was 0.43mph.

The acceleration of the car peaked at 2.4g. The speed change for the car was 9.7mph.

The time of the peak acceleration occurred at 0.19 seconds, considerably later than a typical rear end collision (0.1 seconds). This was due to the crumpling effect of the frontal components of the car.

The peak car acceleration was 7.7 times greater than the peak PCV acceleration.

The PCV was 9.8 times heavier than the car.

The calculated speed change figure for the bus was an over estimate of 0.42mph.

The speed change figure for the car was an under estimate of 1.39mph.

It was anticipated that the calculated speeds would have been over and under estimated respectively for the PCV and car due to the lack of true restitution results, the large mass vehicle being braked and a difference in figures between kerb mass and actual mass.

The estimated speed change to cause the damage to the vehicle in the photographs which prompted this experiment, was 9mph.

The speed change for the car in this experiment was 9.7mph. The damage is marginally greater in this experiment.

Injuries – The occupants on the PCV were asked to record any symptoms experienced after the tests for a period between 10 minutes and 7 days. No symptoms were recorded by any of the occupants.

Figure 12 Vehicle pre-impact

Figure 13 Impact Sequence

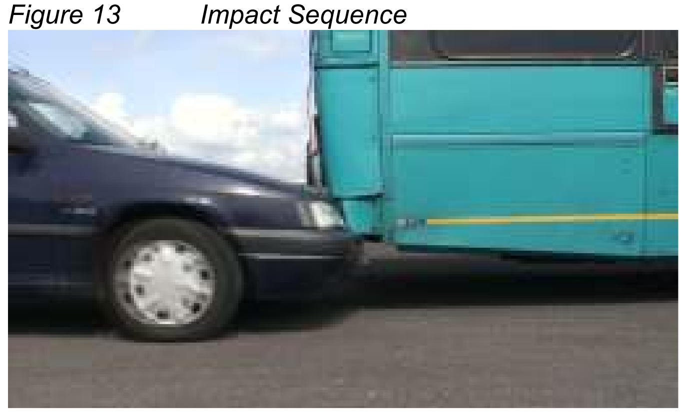


Figure 14 Impact Sequence

Figure 15 Impact Sequence

Figure 16 Impact Sequence (Max. Engagement)

Figure 17 Impact Sequence (Separation)

Figure 18 Impact Sequence (Final Position)

REFERENCES

1. *R Dubois, B McNally, J DiGregorio, G Phillips, "Low Velocity Car-to-Bus Test Impacts", Accident Reconstruction Journal, Volume 8, Number 5, September/October 1996.*
2. *R Malmsbury, J Eubanks, "Damage And/Or Impact Absorber (Isolator) Movements Observed in Low Speed Crash Tests Involving Ford Escorts", SAE Paper 940912, March 1994.*

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