Low Velocity Car-to-Bus Test Impacts (slightly abridged)

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INTRODUCTION

Low speed rear-end impacts resulting in minimal damage to the involved vehicles are common occurrences on our roadways. Claims, and/or litigation, involving neck and back injuries often result from these collisions. A surprising number of claims of injury result from impacts involving transit buses. Many transit bus collisions involve multiple claimants, who frequently claim whiplash-type injuries.

Because of the large number of often suspicious claims, the need for low speed car-to-bus collision data became apparent. The impact severities and the kinematics of the occupants involved in crash tests could be recorded and studied. This would help give the reconstructionist information needed to evaluate the injury potential from real-world accidents.

The authors have also investigated a number of transit bus collisions in the past several years. Some of these collisions have involved "jump in" passengers, who were not occupants of the bus when the collision occurred. Since a majority of these collisions occur while the bus is stopped to load or discharge passengers, the opportunity exists for uninvolved parties to enter the bus unnoticed. A few bus companies have recently installed cameras inside their buses to combat "jump in" passengers. These cameras are useful not only for the purpose of monitoring the activity of the passengers, but also for the accident reconstructionist in assessing the occupant kinematics of the passengers during a collision.

During our series of test impacts which took place in Newark, New Jersey, one of the police officers on the security detail was approached by an uninvolved pedestrian. The pedestrian, obviously unaware that the collision she had just heard was a test impact, asked the police officer for information regarding the number of injured passengers. When the police officer did not comply with her requests, the pedestrian wrote down the number of the bus and left the area. It is unknown at this time if the pedestrian has attempted to file a claim for injury in this incident.

TEST METHOD

The method selected for this study was to use a typical transit bus as the target vehicle. The vehicle selected for this purpose was a 1981 Flexible Model 870 transit bus. This vehicle had a curb weight of 26,500 pounds [12,020 kg] and a solid steel bumper on both its front and rear. This vehicle would be stationary with all its brakes either on or off, and then struck in the rear by either a passenger car or a light duty truck. A total of 18 tests were conducted. In all but one test, the bus was struck in the rear with at least a 40% overlap. In test number 16, the rear of the bus was struck severely offset to the passenger side, i.e., a sideswipe impact.

For each of the 18 tests, several volunteer test subjects occupied the bus. The number of test subjects varied from 3 to 15 for the different tests. Most of the test subjects were males. The approximate age range of the test subjects was 25 to 55 years. For the tests, some of the occupants were seated and others standing in the aisle. There were no seat belts or other restraint devices available to these occupants. Although all of the occupants knew that there would be an impact to the rear of the bus, they were unable to see the approach of the bullet due to the rear-engine design of the bus.

A utility vehicle and two automobiles were selected as striking vehicles. Each vehicle was used repeatedly for several tests. In tests numbers 1 through 8, the striking vehicle was a 1987 Chevrolet S-10 Blazer (VIN:1GNCT18REH0146117). Its curb weight was 3750 pounds [1700 kg]. For tests 9 through 13, the striking vehicle was a 1992 Dodge Spirit (VIN: 1B3XA463XNF198578). Its curb weight was 2800 pounds

[1270 kg]. For tests 14 through 18, the striking vehicle was a 1992 Plymouth Sundance (VIN: 1P3XP2401NN197578). Its curb weight was 2650 pounds [1200 kg]. For all 18 tests, the striking vehicle was controlled by a volunteer driver, a 41-year- old male. He was the only occupant of the striking vehicle and was wearing the available three-point seat belt.

One of the objectives of this study was to determine what effects, if any, the degree of bumper engagement had on occupant kinematics. The three striking vehicles had varying bumper heights, which allowed evaluation of both bumper-to-bumper impacts and bumper under-ride impact configurations. The Chevrolet pickup had a standard steel bumper face bar, which lacked an energy absorption system. The front bumper of the pickup was of sufficient height to make contact with the rear bumper of the bus. The Plymouth and the Dodge were both equipped with energy absorbing bumper systems. However, the lower heights of the front bumpers of these cars allowed their bumpers to under-ride the rear bumper of the bus. Instead, the grille/headlight areas of the cars engaged the bus bumpers.

All vehicles were free of damage prior to testing.

TABLE 1 - SUMMARY OF MOVING VEHICLE / STATIONARY BUS TEST DATA

Test #	Striking Vehicle	Car/UV Impact Speed	Delta V		Maximum Acceleration		Bus Brakes	Bus Movement (in.)	Duration of Movement (sec)
			Car/UV	Bus	Car/UV	Bus			
1	S-10 Blazer	1.47 mph 2.36 kph	2.15 mph 3.46 kph	0.18 mph 0.29 kph	-1.25g	0.26g	on	0.3	0.16
2		2.92 mph 4.70 kph	4.01 mph 6.45 kph	0.39 mph 0.63 kph	-2.59g	0.39g	on	0.8	0.16
3		5.57 mph 8.96 kph	7.05 mph 11.3 kph	0.79 mph 1.27 kph	-4.8g	0.73g	on	1.8	0.21
4		5.91 mph 9.51 kph	7.47 mph 12.0 kph	0.96 mph 1.54 kph	-5.65g	0.82g	on	1.9	0.20
5		7.46 mph 12.0 kph	9.53 mph 15.3 kph	1.16 mph 1.87 kph	-8.9g	1.25g	on	2.5	0.25
6		5.90 mph 9.49 kph	7.79 mph 12.5 kph	0.95 mph 1.53 kph	-7.1g	0.99g	on	2.6	0.30
7		4.90 mph 7.88 kph	5.5 mph 8.85 kph	0.79 mph 1.27 kph	-4.6g	0.56g	off	8.6	1.27
8		5.67 mph 9.12 kph	6.32 mph 10.2 kph	0.91 mph 1.46 kph	-4.9g	0.56g	off	11.8	1.62

9	Dodge Spirit	5.94 mph 9.08 kph	6.3 mph 10.1 kph	0.62 mph 1.00 kph	-3.4g	0.34g	off	6.2	1.18
10		5.70 mph 9.17 kph	6.68 mph 10.7 kph	0.69 mph 1.11 kph	-3.79g	0.43g	off	7.8	1.39
11		6.49 mph 10.4 kph	7.61 mph 12.2 kph	0.35 mph 0.56 kph	-3.45g	0.22g	on	0.7	0.23
12		5.68 mph 9.14 kph	6.93 mph 11.1 kph	0.44 mph 0.71 kph	-3.14g	0.30g	on	0.8	0.20
13		9.34 mph 15.0 kph	11.15 mph 17.9 kph	0.93 mph 1.50 kph	-6.51g	0.64g	on	2.12	0.25
14	Plymouth Sundance	3.9 mph 6.3 kph	4.73 mph 7.61 kph	0.44 mph 0.71 kph	-4.09g	0.30g	on	0.8	0.27
15		5.85 mph 9.41 kph	6.89 mph 11.1 kph	0.57 mph 0.92 kph	-4.74g	0.64g	on	1.2	0.23
16*		6.06 mph 9.75 kph	3.9 mph 6.3 kph	0.27 mph 0.43 kph	-2.41g	0.21g	off	3.5	1.25
17		6.27 mph 10.1 kph	7.3 mph 11.7 kph	0.69 mph 1.11 kph	-3.97g	0.43g	off	6.0	1.09
18		8.71 mph 14.0 kph	10.98 mph 17.67 kph	1.19 mph 1.91 kph	-6.34g	0.90g	off	16.8	1.83

*Test #16 was a partial impact (sideswipe) involving the left front fender of the bullet vehicle and the right end of the rear bumper of the bus. All other tests involved full end engagement.

Both the bus and the bullet vehicles were equipped with MacInnis 5th wheels to measure the velocity and acceleration present during the collisions. The MacInnis 5th wheel consists of a bicycle wheel which drives an optical encoder. The encoder is read by a portable computer through lead cables. Data was gathered at 128 Hz for all of the test impacts.

In order to document the vehicle dynamics and occupant kinematics, video cameras were placed both inside the bus and adjacent the point of impact. In some of the test runs, kinematics of the driver of the striking vehicle were also captured on videotape.

TEST RESULTS

Vehicles

A series of eight impacts using the Chevrolet S-10 Blazer as the striking vehicle were performed. Impact speeds for this vehicle ranged from 1.47 to 7.46 mph. The resulting velocity changes (delta V's) on the bus ranged from a low of 0.18 mph to a high of 1.16 mph. The bus's peak acceleration ranged from 0.26 G's to 1.25 G's. As expected, the S-10's bumper engaged the rear bumper of the target bus. Damage to the S-10 was confined to the bumper. (See Figure 1.)

A series of five impacts using the Dodge Spirit as the striking vehicle were performed. Impact speeds for this vehicle ranged from 5.46 to 9.34 mph. The resulting delta V's on the bus ranged from a low of 0.35 to a high of 0.93 mph. The bus's peak acceleration ranged from 0.22 G's to 0.64 G's. Table One shows the data from these tests. As expected, the Spirit's bumper under-rode the rear bumper of the target bus. The bumper of the Spirit was not damaged. Instead, the grille, hood and headlights were crushed. (See Figures 2 and 3.)

Figure 1 - Cumulative Damage to Chevy S-10 Blazer After Tests 1-5

Figure 2 - Damage to Dodge Spirit After Test 9

Figure 3 - Cumulative Damage to Dodge Spirit After Tests 9 & 10

A series of five impacts using the Plymouth Sundance as the striking vehicle were performed. Impact speeds for this vehicle ranged from 3.9 to 8.71 mph. The resulting delta V's on the bus ranged from a low of 0.27 mph to a high of 1.19 mph. The bus's peak acceleration ranged from 0.21 G's to 0.90 G's. Table One shows the data from these tests. Like the Dodge, the Plymouth's bumper under-rode the rear bumper of the target bus. Damage was confined to the grille, hood and headlights. (See Figure 4.) In one of these five tests (test #16), the Plymouth struck the bus in an offset manner (nearly a sideswipe) at just over 6 mph. This resulted in the lowest accelerations and delta V's in this series of five tests.
Bus post-impact movement was very limited. It ranged from less than an inch to less than 3 inches with the brakes on, and ranged between 6 and 17 inches with the brakes off. Even after all eighteen impacts, there was no measurable damage to the rear bumper of the bus. The only visible damage was small scuffs to the rubber bumper cover. (See Figure 5.)

Figure 4 - Cumulative Damage to Plymouth Sundance After Tests 14 & 15

Figure 5 - Cumulative Damage to Flexible Bus

Table 1 shows the data from the eighteen crash tests. Figure 6 shows the fifth wheel speed data from test #13. Figure 7 shows the fifth wheel acceleration tracing from test #13.

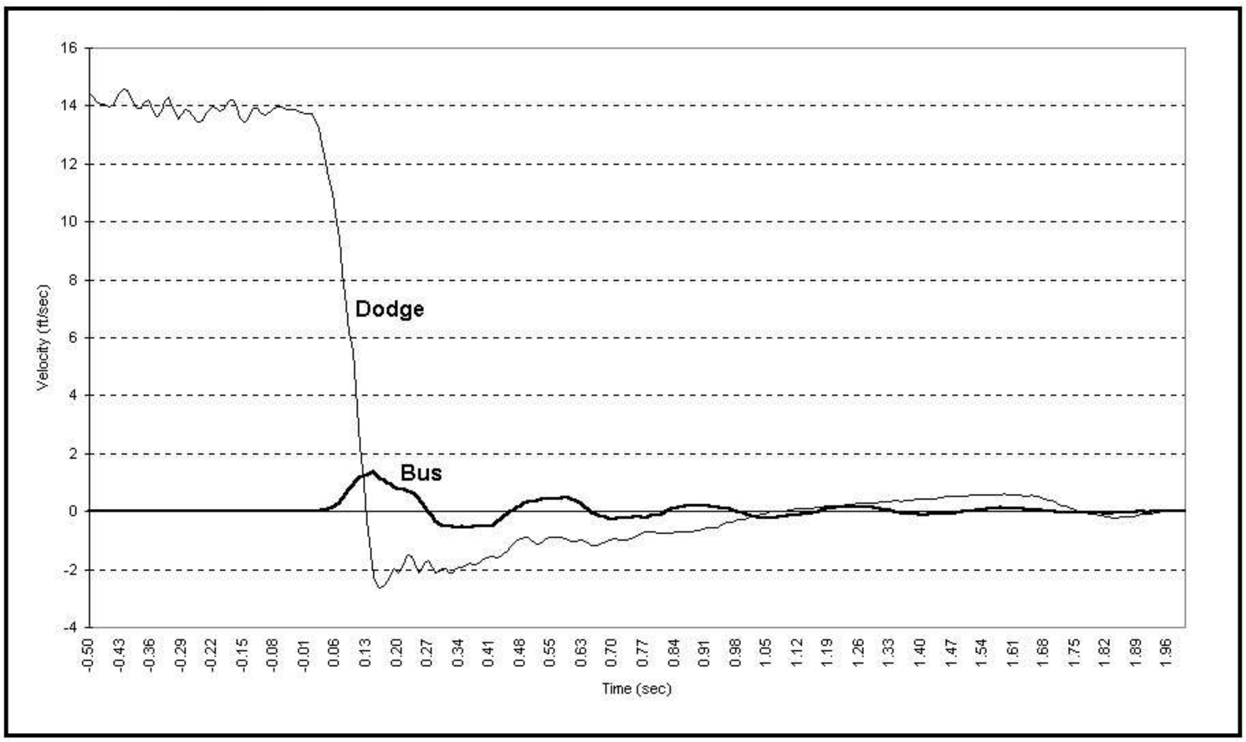

Figure 6 - Velocity Readouts for Flexible Bus and Dodge Spirit, Test 13

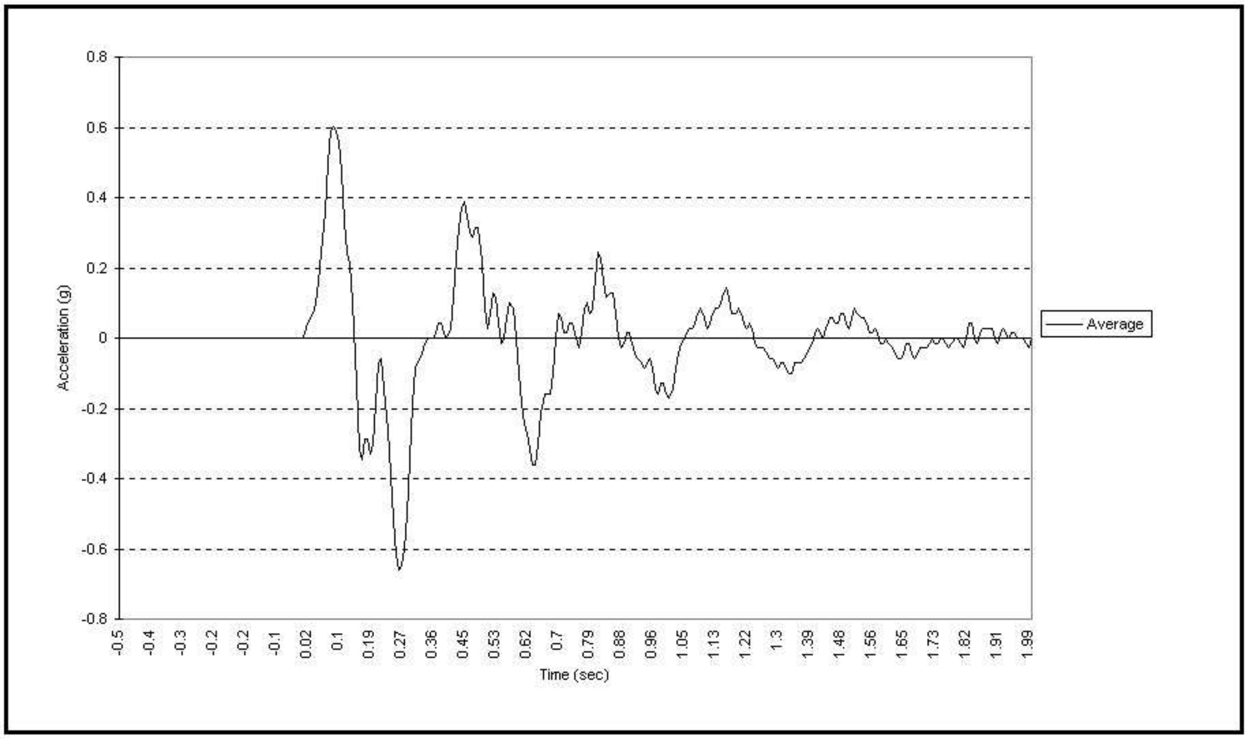

Figure 7 - Acceleration Readout for Flexible Bus, Text 13

Occupant Kinematics

Throughout the series of test impacts, there were a varying number of passengers on the bus, some seated and others standing. The most significant movement encountered by the occupants of the bus was a slight rocking movement of the head and upper torso. This movement was usually less than 4 inches and typically less in seated occupants than those standing. Some of the passengers reported being startled by the noise of the collision. Some passengers expressed the opinion that they experienced more force from routine braking than they experienced from these test impacts.

None of the test subjects reported any pain, even after experiencing multiple impacts.

The same 41-year-old male drove the striking vehicle for all eighteen tests. He was exposed to delta V's ranging from 2.15 to 11.15 mph [3.5 to 18 km/h], and peak accelerations ranging from 1.25 to 8.9 G's. After the tests, this test subject reported both a headache and posterior neck stiffness. Both conditions resolved themselves within 48 hours. The only medical intervention was the use of Advil for the first 24 hours.

DISCUSSION

Acceleration is only one of the variables necessary to evaluate the injury potential from a collision. However, it is the opinion of many researchers that for bumper-to-bumper impacts, the best method for comparative analysis of force on vehicle occupants is to first reconstruct the change in velocity of vehicles. This is then compared to crash test research using crash dummies, and in low speed testing, human volunteers.

McConnell, et al., recently conducted such low speed crash test research. They concluded that the injury causation potential in low speed automobile rear-end impacts with a change in velocity of less than 2.5

miles per hour [4 km/h] was "minimal or nonexistent." For volunteers exposed to multiple impacts involving delta V's of 4 to 5 mph, very mild symptoms were experienced by the test subjects. They indicated that the typical human threshold for very mild, single event, musculoskeletal cervical strain injuries was at, or near, the 4 to 5 mph change in velocity level.1 In a second series of tests performed by this same group of researchers, they reaffirmed the 5 mph delta V limit for assessing injury potential.2 Their findings were corroborated by West, et al, who also experimented with human volunteers.3
The test impacts performed resulted in substantially lower delta V's and peak acceleration measurements for the bus compared to the striking vehicles. This is due primarily to the significant difference in weight between the striking vehicles and the bus. This finding is consistent with the laws of physics, even though according to Newton's Third Law the forces acting on two colliding vehicles should be equal and opposite. Newton's Second Law states that acceleration is equal to force divided by mass. The acceleration of each vehicle is inversely proportional to the mass of the vehicle. Thus, in a case where vehicle A has a tenfold weight advantage over vehicle B, the occupants of vehicle B should, theoretically at least, see 10 times the G's as the occupants of vehicle A.

In our tests, the target bus had a 7 to 1 weight advantage over the S-10, and about a 10 to 1 weight advantage over the automobiles. Table One shows the resulting acceleration and delta V measurements for the respective vehicle to be reasonably consistent with inverse of weight ratios.

Weight ratios have a profound effect on relative injury potential of vehicle occupants in automobile/commercial bus accidents. The typical transit bus has an approximate 8 to 1 weight advantage over the typical automobile/light duty truck. This means that no matter what the speed change experienced by the bus, the typical passenger vehicle will experience approximately 8 times the delta V. This indicates that in order for the bus passengers to sustain the 5 mph [8 km/h] delta V associated with the lower threshold of neck sprains, a car's occupants must be subjected to a delta V of approximately 40 mph, a level of impact severity with often fatal consequences.

The authors have performed many car-to-car rear-end impacts which have produced peak levels of vehicle acceleration greater than 4 G's with no reports of injury to the occupants of the test vehicles. The highest peak acceleration measured for the bus in this series of tests was 1.25 G's. This was the result of Test #5, in which the heaviest of the three bullet vehicles, the S-10 Blazer, struck the bus at an approach speed of 7.5 miles per hour [12 km/h]. This same impact resulted in a peak acceleration of 8.9 G's and a change in velocity of 9.5 mph [15 km/h] for the S-10.

In view of the above, it is not surprising that the occupants of the test bus experienced only slight movements as a result of the test collisions. The amount of movement is a small fraction of that typically associated with injury, and none of the bus occupants reported any pain or discomfort in the aftermath of the crash tests. It was only the driver of the two cars and utility vehicle who reported any injury.

To see what effect bumper under-ride had on peak acceleration, the results of the five S-10 tests with impact speeds in the range of 4.9 to 6.5 mph were compared with six auto tests conducted in the same impact speed range. (Offset test 16 was excluded.) The S-10's average impact speed, average peak acceleration, and bus average peak acceleration were 5.59 mph, 5.41 G's and .73 G's respectively. The cars' average impact speed, average peak acceleration, and bus average peak acceleration were 5.94 mph, 3.75 G's and .39 G, respectively. Theoretically, the lighter cars should have registered higher peak acceleration, especially in light of their higher impact speed. Moreover, the S-10 generated peak G's on the bus that averaged nearly twice as high as those generated by the cars. This is higher than can be accounted for by the approximate 4 to 3 truck/car weight ratios.

The results confirm that the peak levels of acceleration are significantly reduced in rear-end impacts where the bumper systems do not interact. The level of peak acceleration is reduced due to contact with "softer" components in the bumper under-ride collision. Both vehicles are allowed to change velocity over a greater distance (i.e. crush depth) than in bumper-to-bumper collisions.

Impact configuration also appears to influence peak deceleration. In test #16, only the left front fender of the Plymouth engaged the back of the bus at 6 mph. For this test the peak G's were 2.41 and 0.21 for the car and the bus respectively. For two other Plymouth tests conducted at approximately 6 mph, the peak G's on both vehicles were twice as great. This suggests that offset impacts usually generate lower G forces on occupants than full engagement impacts, all other things being equal.

In practical application, every collision has its own unique characteristics. The stiffness characteristics of vehicles in a collision will play a significant role in the resultant damage seen to the vehicle. The first phase of a typical car-to-bus accident reconstruction is the determination of impact speed. In most cases, this can best be accomplished by evaluating deformation to the striking vehicle. The damage to the striking vehicle is used because typically the bus will show little or no deformation as a result of a minor collision. Even if the bus does show damage, there is limited reliable information on the crush stiffness characteristics of buses.

Tumbas and Smith outlined the protocol for measuring vehicle damage to determine damage energy.4 Accident Reconstruction Journal has recently presented under-ride test data and photographs in a variety of impact speed ranges.5,6 In the latter report, Craig proposed a methodology for estimating delta V based on crush damage to bumper under-ride collisions using Campbell equations.6 In cases in which there is no visible damage to the striking vehicle, an upper limit of the vehicle's damage threshold can be used to estimate a maximum speed.

Care must be taken when estimating delta V in low speed impacts. In a low speed collision, external forces such as braking and restitution cannot be ignored. One can easily see in the charts that the delta V of the striking vehicle was always greater than the impact speed, except in the one sideswipe impact performed. The authors have observed an average restitution of approximately 0.29 in the bumper under-ride (car/bus) test impacts they performed. The average coefficient of restitution in the bumper-to-bumper (S-10/bus) test impacts was approximately 0.45. Therefore, restitution must be considered to properly estimate the impact speed in low velocity collisions.

SUMMARY AND CONCLUSIONS

Eighteen test impacts were completed to evaluate the occupant kinematics and the vehicle damage characteristics of low speed car-to-bus collisions. One of the test vehicles, a Chevrolet S-10 Blazer, was used for bumper-to-bumper impacts with the bus. Two vehicles, a Dodge Spirit and a Plymouth Sundance, were used to evaluate bumper under-ride impacts to the rear of the bus. All of the bumper under-ride impacts resulted in moderate damage to the striking vehicles, while the bumper-to-bumper impacts resulted in deformation mostly to the bumper assembly of the Chevrolet.

Even in the absence of tire marks, the accident reconstructionist can evaluate the damage to the striking vehicle to determine the delta V for the striking vehicle. Once the delta V for the striking vehicle has been established, a delta V for the bus can be estimated.

In car-to-bus impacts, there is a significant disparity in weight between the vehicles. Because of the disparity in weight, the car will typically experience a delta V much more significant than that experienced by the bus. For instance, if there is an 8 to 1 weight ratio between the bus and the striking vehicle, when the bus experiences a 3 mph delta V, the striking vehicle will experience a 24 mph delta V. In most modern passenger vehicles, a delta V of 24 mph is more than sufficient to trigger an air bag deployment.

Although the authors used a wide range of human volunteers as occupants of the bus, they made no attempt to determine the potential for injury to the individual. Notable, though, is the minimal kinematic response observed throughout the series of test impacts. Some of the minor impacts resulted in little or no observable movement of the occupants. The higher speed impacts resulted in a slight rocking movement by the seated occupants. Some of the occupants noted the sensation of movement from the test impacts was less significant than one would experience while riding in a moving transit bus. None of the bus occupants had any injuries or complaints of pain or discomfort. The authors see little, or no, injury causation potential for the range of delta V's experienced by the bus occupants during these test impacts.

The only injuries sustained from these test impacts were sustained by the volunteer driving the striking vehicle. This 41-year-old male, who sustained 18 impacts with delta V's averaging approximately 7 mph, reported a headache and minor posterior neck stiffness which lasted for approximately 48 hours.

It would be desirable to test a wider range of striking vehicles in order to compare vehicle damage profiles. It would also be desirable to conduct additional testing at impact speeds greater than 10 mph. However, injury risks to the driver of the smaller impacting vehicle must be taken into consideration. Use of an alternative propulsion method, such as a cable and pulley hook-up, would be prudent.

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