HIGH SPEED, REAR END, PARTIAL OVERLAP CRASH TEST OF A LARGE SEDAN AND STATIONARY COMMERCIAL TRAILER

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ABSTRACT

Crash scenarios involving a rear end impact are common place internationally. Some of the most devastating collisions are often where a sedan collides into the rear of a commercial trailer, partial overlap. This type of crash is almost always with serious or fatal consequences. With a high number of these identified in a recent high profile Major Crash Investigation (MCI), a real life high speed test of this scenario was undertaken. Obtaining data from such a crash in a controlled environment for future comparative analysis is rarely presented. This paper presents a brief overview of the setup and results of the high speed rear end, sedan to stationary commercial trailer.

1. INTRODUCTION

Internationally, rear end crash scenarios are well represented in crash statistics (Blower and Campbell, 1999 / Moonesinghe et al., 2003), being also a statistic that is prevalent in South Africa. Such crash scenarios are typically as a direct result of major traffic congestion, vehicles broken down at hazardous locations and/or simply due to driver error in their negligence, either as the vehicle being struck (Target), or the vehicle striking (Bullet). As with opposite direction head-on type impacts, high speed rear end partial overlap impacts present an even greater risk for a number of reasons. This particular crash being remote controlled (Setty et al., 2017) and is available online at: https://www.youtube.com/watch?v=dsT1VCL18Uk.

The nature of a high speed, partial overlap rear end crash is such that massive destruction of the Bullet vehicle is typical. Such disparities are already well identified internationally (Gabler and Hollowell, 1998). If not from the crash itself, the extent of decimation to the Bullet vehicle is typically aggravated by further rescue cutting and recovery processes. These damages all too often contaminate the original damages and on occasion, telemetry that may have been available (Tsoi et al., 2015). On occasion, conflagration results and too, decimates vital evidential factors. There is no doubt that in time, with advancement in technology, detailed telemetry will be and is already to some extent available, be secure and easily downloadable from vehicles post-crash. It may be that such data is streamed live time and stored off-site of the vehicles (Tsoi et al., 2015). Nonetheless, there will almost always be some need to do a physical inspection and consideration of certain parameters of a crash.

The subject matter of rear end impacts is relatively well researched and well documented (Blower and Campbell, 1999). During 2000 they once again accounted for as much as 29.7% of all crash cases (Singh, 2003). In South Africa, it is well documented (DOT RSA 2014) that there is a serious problem in the recording of crash statistics (Roberts, 2014), as such, it is impossible to given any reasonable indication of the level of the problem. Many research papers (Singh, 2003) highlight the majority of rear end crash scenarios being at congested intersections, congested roads, Urban areas and in the vicinity of traffic backup locations such as at off ramps and onramps.

Rather interestingly, it appears that there has been little specific research, nor actual crash testing examples located that deals directly with the issue of rear end, partial overlap, high speed (80 km/h and higher) impacts where sedans or similar passenger vehicles and commercial vehicle are involved (Daily and Strickland, 2005).

The contributions of this paper are:

- Identify the characteristic correlation with the results of the vehicles after a rear-crash of this manner.
- Identify possible weaknesses on the Bullet and the Target that could be improved.
- Identify common evidence after such a crash or accident has occurred.

2. TEST PARAMETERS & METHODOLOGY

The intention of the crash scenario was to document and consider all of the evidential results of a rear end, partial overlap type of crash orientation with a high speed impact. The test parameters involved the positioning of a standard flat deck, double-axle, Swift trailer, 2006 model, as the Target vehicle. The trailer has the basic specifications of 9.0 meters in length, 2.4 meters wide and a mass of 6440 kilograms (Tare).

The rear axles being solid axles, 92 mm square, with a 9000 kg per axle maximum load rating, manufactured by Swift. Tyres fitted at the right rear impact location (left and right sides) were typical commercial Bridgestone, Radial, V-Steel MIX 857 11.00 R20 (Regroovable) 830 kpa, in fair to good condition.

A rear bar / underride was fitted, mounted by means of two flat surfaced brackets welded to the underside of the rear cross member of the upper deck chassis. The underride bolted to this with two bolts per bracket. The Target setup is at a position 50% across the width of a normal freeway lane, to represent a vehicle stationary and protruding partially into a lane. The Target was un-laden and left standing on the trailer landing legs, brakes engaged.

The Bullet vehicle was a good condition, 1996 model, Ford Falcon sedan. The basic specifications of the vehicle was 4.906 meters in length, 1.861 meters in width and a mass of 1457 kg (Tare). The Bullet vehicle was remote control driven and the remote control system designed & fitted in house (Setty et al., 2017).

The target speed of 100 km/h was appointed as the majority of regional routes where such commercial vehicles operate between main freeways and urban areas are sign posted at a maximum of 100 km/h. National routes are at 120 km/h as a maximum. The section where the tests were performed were a 1000 m straight, flat, good condition section. The specific area of positioning of the Target was at a section that has been further widened with an extra two lanes on one side, creating a 200 meter long layby area.

Extensive use of High Definition (HD) high speed cameras was made to allow detailed analysis. The Target vehicle was fitted with a view down the right side, looking towards the rear and therefore directly at the impact (Figure 1). A view from the internal of the Bullet vehicle, from the rear parcel shelf, looking towards the front of the vehicle is shown in Figure 2. A view at right angle to the overall crash, from the left side of the Target and bullet vehicle is described in the test section of the paper (Figure 4).

Figure 1: External view of the Target - impact overlap

Axis orientation for the vehicles was based on the SAE (SAE, 2011) right hand coordinate system, X, fore aft through the longitudinal, Y, left through right and Z vertical through. The Target vehicle was fitted with basic speed and force reading telemetry, being a Geotab GO6 product. The device secured to the target at the chassis members ahead of the axles (Figure 3) and self-powered. The bullet was vehicle fitted with a Geotab GO6 product, providing both force readings and GPS position speed readings. The device internal at the rear foot-well area behind the driver`s seat, secured to the steel floor structure and self-powered. The Bullet vehicle was followed by a chase vehicle, which allowed the bullet vehicle to be remote controlled through acceleration and steering. Impact was targeted at around a 50% overlap and target speed 100 km/h.

3. TESTS AND CREATED SCENARIO

Although the target of 100 km/h was not attained, the speed reached 87 km/h (GPS speed), was high enough to be considered as a high speed, resulting in a very serious crash scenario that would likely see a fatality and if not, serious injuries and damages. An impact overlap of approximate 70% front end width of the Bullet vehicle (Figure 1 and Figure 2) was achieved, with the front end, left side of the bullet vehicle colliding into the rear end right side of the target vehicle. A side view of the crash scenario was recorded with a high speed camera, and the frames of motion can be seen in Figure 4.

Figure 2: Internal view of the Bullet - impact overlap

Figure 3: Telemetry mounted to the Target vehicle

The vehicle's positions were recorded with total station equipment. The Target vehicle was propelled forward a distance of 2.5 meters along the direct centre of mass movement, with a forward movement of 2.1 m. A lateral displacement towards the left side was 0.6 meters. Some clockwise rotation of approximately 3.9 degrees also occurred, as shown in Figure 5.

The Bullet vehicle moved forward a distance of 4.0 meters along the direct centre of mass movement. A lateral displacement towards the right was 2.5 meters. A forward movement of 2.9 meters was observed. Some clockwise rotation of 19.6 degrees occurred, as seen in Figure 6. The rear wheels of the Bullet elevated to a height of 0.52 meters, determined through scaling from the right angle video footage (Figure 7). The visible forward movement of the Target vehicle over the 2.5 meters occurred over a video footage time frame of 1.02 seconds, determined through time frames of the high speed video footage.

4. TEST RESULTS AND DISCUSSION

The results will be discussed such as the vehicle positions, damage, liquid spill, debris, scratches, scrapes and tyre marks.

4.1 Post impact positions

All positions, pre and post vehicle (Figure 8) and other evidential factors were recorded with the use of a Nikon NPR352. The post impact positions are somewhat expected, where, although there is an approximate 4.4:1 mass ratio difference (against the Bullet), some forward displacement, rotation and or lateral displacement of the vehicles would be expected, where the mass of the Bullet at 1457 kg at 87 km/h (24.16 m/s) indicates a kinetic energy of 425 kJ.

4.2 Damage to the Bullet vehicle (evidence from the vehicle)

The damage to the Bullet vehicle was catastrophic and was expected given the parameters (Figure 9). Notably, modern vehicles are designed to absorb impacts and to collapse, however to maintain the general integrity of the occupant compartment, this appears to have occurred.

4.3 Damage to the target vehicle (evidence from the vehicle)

The damage to the Target vehicle is arguably minor to moderate and was expected given the parameters (Figure 10). Notably, the underride bar had totally separated. The two left side mounting bolts between the lower end of the chassis bracket and underride bar sheered. The right side chassis bracket sheared off at the mounting point between the main mounting bracket and chassis itself, at the point of the welded connection. The entire structure of the underride bar separated from the Target vehicle as a complete unit (Figure 9).

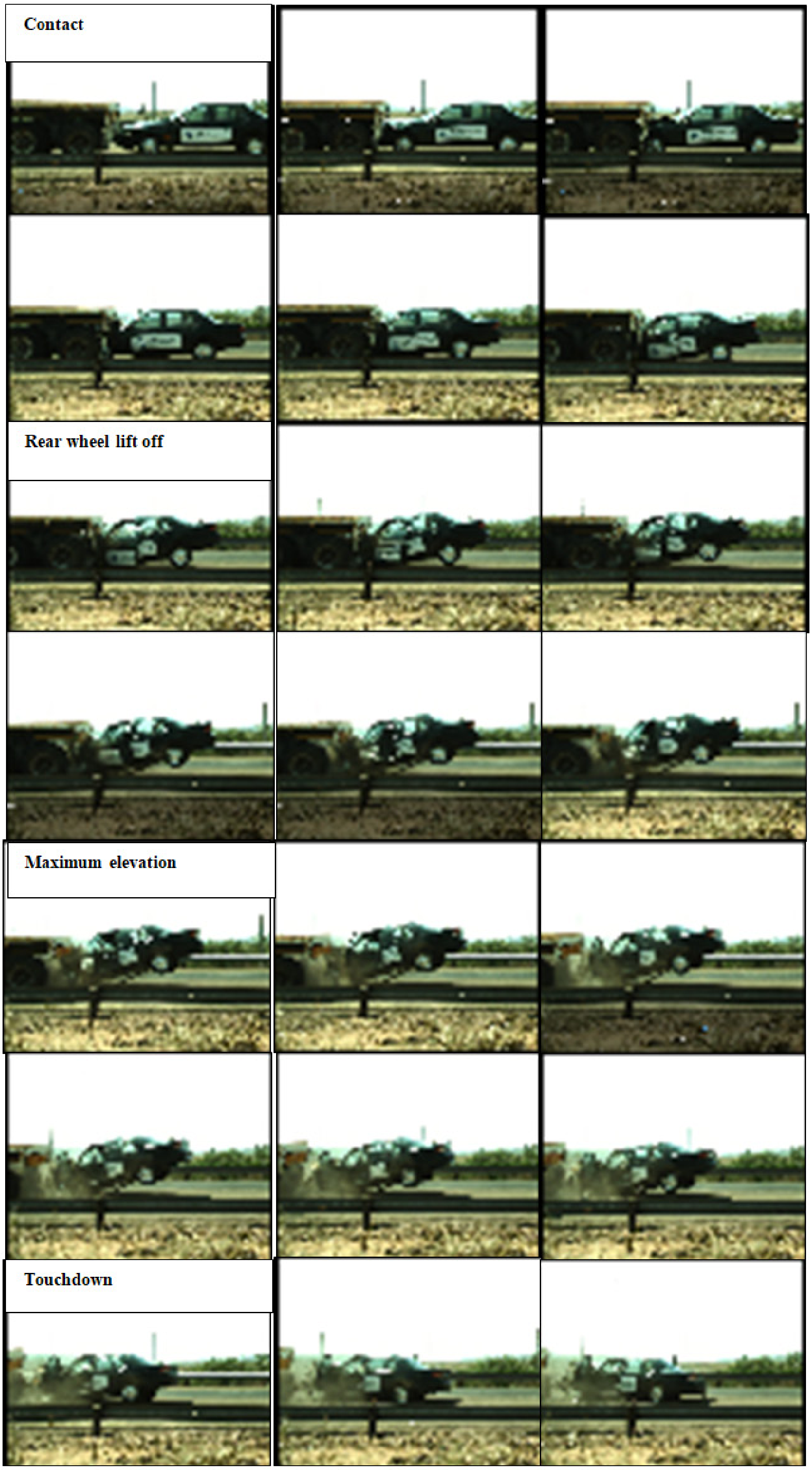

Figure 4: External left side view – crash sequence

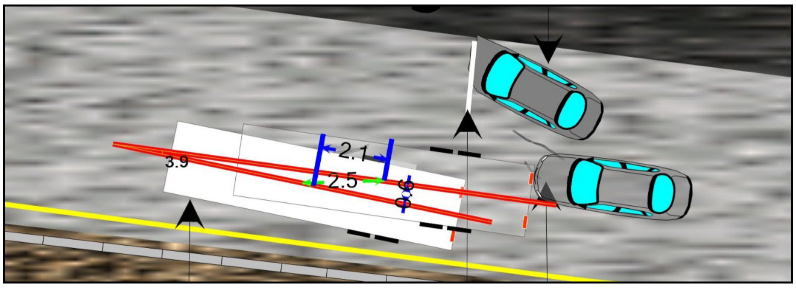

Figure 5: Target - Movement parameters

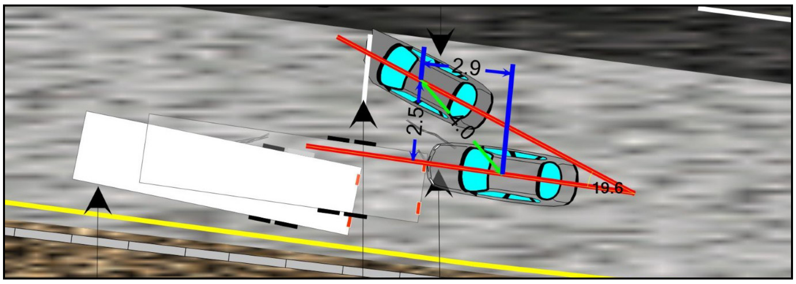

Figure 6: Bullet - Movement parameters

Figure 7: Bullet vehicle rear wheel elevation

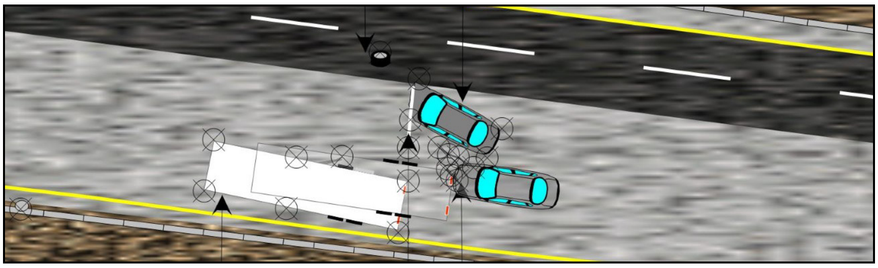

Figure 8: Pre & Post impact positions

Figure 9: Damage to the Bullet vehicle

The rear axle had sheared off at a position on the outer side (right side) of the suspension spring mounting brackets (Figure 10), separating the complete right side dual wheel combination. Minor damage to the rear right taillight housing had occurred. Besides these damages, very little further damage to the trailer appeared evident.

Figure 10: Damage to the Target vehicle

Damages to the respective vehicles allows the primary analysis of the manner in which the two vehicles have collided, is well document and pertains to the issue of the Principal Direction of Force (PDOF) (Tumbas and Smith, 1988). The particular relevance of this analysis was to understand the positioning of the vehicles on the scene relative to one another and likewise allowing considerations of the movement of the vehicles through the phase of the crash and likewise the occupants (Swearingen et al., 1962).

The consideration of the damages to the vehicles in respect of measuring the damages, could provide further insight into the speed of the vehicle. The Bullet vehicle damages measured right to left at 0.55 m from ground level, at bumper leading edge height, with measurements of; 1 – 0.53 m; 2 – 0.56 m; 3 – 0.60 m; 4 – 0.64 m; 5 – 0.69 m; 6 – 0.74 m, 7 - 0.35 m and a total crush width of 1.02 m (Figure 11). Cursory application of the measured damage (crush) sees a speed suggestion of 62.8 km/h (Vomhof, 1988) and as low as 46.3 km/h for a typical six point crush analysis.

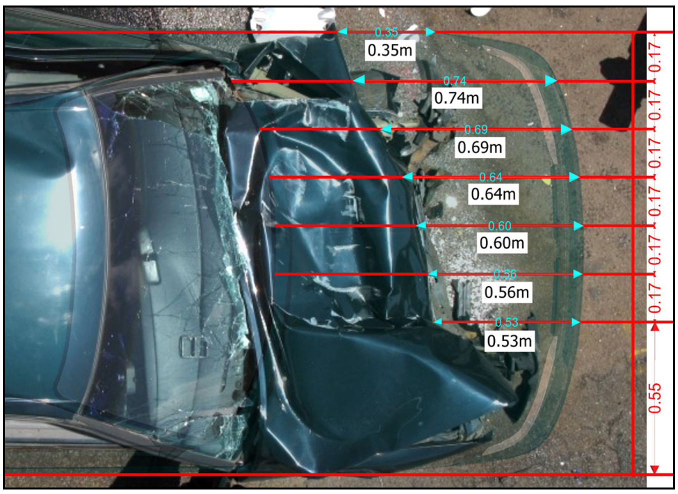

Figure 11: Bullet vehicle damage measurement

4.4 Liquid spill – spatter & soak

Liquid spill, typically as a result of vessel damage, such as the radiator, sump, water bottle and gearbox or even CV joints, almost always results from the Bullet vehicle. The initial impact of the sump, with the road surface causing rupture of the vessel and therefore the initial liquid (oil) spill at the immediate area of the sump and road surface contact. The movement of the Bullet from impact to rest resulted the continued deposit of the liquid debris along this path.

The resting position allowing the further draining and development of the liquid soak patch at that point. All factors located and evident to a large extent as seen in Figure 12.

Figure 12: Liquid spill from rupture sump and other vessels

4.5 General debris

Some shards of glass, paint and small Bullet vehicle component pieces were noted as strewn around the general area, as seen in Figure 13. Although these may not be specifically recorded in each of their positions or specification, their presence were notable as this forms part of determining the general area of a crash. In certain cases these could serve to assist in determining what vehicles were involved, if for example there was a colour matching or glass fragment matching undertaken.

4.6 Specific debris

It is noted that there is a total separation of the entire right side, dual rear wheels, to a position ahead of the bullet vehicle and to the right of both the target and bullet vehicle. The wheels have separated as a result of the snapping of the axle, at a position on the outer side (right side) of the suspension spring mounting brackets. Noting the orientation of the Bullet vehicle laterally (partial overlap) at impact and to the rear of the target, indicates that the approximate centre line of the bullet vehicle and therefore the engine, would have been in the general centre line of the two rear right side wheels at impact.

The wheel combination has separated and essentially become a large section of vehicle's debris from the target vehicle. Even though the wheel combination has largely remained unscathed, there were evident impact markings on the tyre and tyres remained inflated (Figure 14).

4.7 Scratches and scrapes

Minor (yet typical) scratch and scrape marks were noted and recorded at the area of the front left suspension area of the bullet vehicle, directly to the left of the position of the sump contact position (Figure 12 – Total station Staff position indicates). The lower suspension components bottomed out against the surface. In this particular scenario, the trailer landing legs left very distinct marks highlighting their point of origin and the movement as the target was propelled and subsequently their position of rest (Figure 15).

Figure 13: General debris

Figure 14: Specific debris

Figure 15: Scratches and scrapes

A relatively severe combination of scratch and scrape marks were created by the shape and longitudinal orientation of the sump of the engine (Inline, six cylinder) of the Bullet. The sump engaging with the road surface as the vehicle bottomed out (Figure 12 and Figure 16). Note the slight curvature of the sump scratch marks, consistent with the movement of the vehicle. The associated liquid spill of the engine oil is evident where the sump (vessel) ruptured and the liquids largely following the post impact path of the Bullet. This notable evidential factor allows the extremely accurate positioning of the Bullet vehicle.

Figure 16: Scratches and scrapes

4.8 Tyre marks

As the Target vehicle has moved, so the engagement of the tyres with the road surface from their point of origin to rest have created impact scrub marks (Figure 17). Tyre marks would be more common as landing legs would not normally be employed. The detailing of the tyre marks would also form part of the distances required for possible calculative processes undertaken. No tyre marks were notable from the Bullet vehicle. Given the severity of the impact and the resulting deflated front right tyre (the left side remained inflated), it would reasonable have been assumed that severe impact loading tyre scrub marks would have been evident.

Figure 17: Tyre scrub marks from point of origin to rest

4.9 Specific evidence - Broken rear axle

Although not unseen, it is somewhat unusual to see the Axle having sustained such catastrophic damages (Figure 10 and Figure 17). A more common result being the laceration and deflation of the tyre/s and perhaps even the damaging of the rims and even the damaging of the hub and various wheel mounting components. The Axle determined as a Swift, 92 mm square solid bar axle (9 ton). Axle strength along with tyres are major factors considered during the design of a trailer, the axle and tyre combinations being the major factors in the permissible load mass of the trailer. The particular axle on this trailer being that of a now defunct axle manufacturer, Swift Axles, as such no specific detailing could be obtained for the particular model.

4.10 Specific evidence - Separation of underride bar

The total separation of the underride bar as a complete unit is somewhat unusual. It is perhaps more common that severe bending of these units incurred or part of it is decimated / separated. Closer inspection revealed the primary welding of the two main mounting brackets, connected to the rear main structure cross member of the trailer (Target), was poor. Welding was only along one edge of each bracket interface to the chassis and likewise with poor penetration and overall concentration (ASME, 2010).

The underride separated with the left side bracket remaining secure to the chassis at the primary mounting point (welded). The lower section of this left side bracket separating from the underride, where the two mounting bolts are located, sheered. The right side, main mounting bracket sheering from the main chassis mounting point on the Target trailer chassis (Welded), yet the lower section of this left side bracket remained connected (two bolts) to the underride (Figure 18).

Figure 18: Underride bar & mounting bracket separation

4.11 Telemetry data

The telemetry in the form of standard global positioning system (GPS) based vehicle tracking systems (Geotab GO6), with on board crash sensing, mounted to the Target and the Bullet vehicle was utilized. The detailed accuracy thereof is not interrogated at this stage and accepted as being reasonably accurate in respect of the basic data. The Bullet vehicle telemetry self-orientating, as the vehicle travelled pre-crash, therefore provided accurate and correct axis direction speed readings as the vehicle progressed. (Figure 19)
Unfortunately, impact caused a power loss to the bullet unit and therefore further force readings and specific crash telemetry readings to the unit from impact were not held. The positioning of the telemetry on the Target (Figure 20) did not allow for self-orientating as

the device was not moving pre-crash. As such the telemetry is read in the device standard orientation mode, is effectively in reverse.

10:30:55.063	18
10:30:56.063	24
10:30:57.063	28
10:30:58.063	31
10:30:59.063	33
10:31:00.063	37
10:31:01.063	39
10:31:02.063	41
10:31:03.063	42
10:31:04.125	44
10:31:05.063	46
10:31:06.063	48
10:31:07.063	50
10:31:08.063	52
10:31:09.063	52
10:31:11.063	55
10:31:12.063	57
10:31:13.125	57
10:31:14.063	57
10:31:15.063	59
10:31:16.063	61
10:31:17.063	61
10:31:18.063	63
10:31:19.063	68
10:31:20.063	76
10:31:21.063	81
10:31:22.063	87

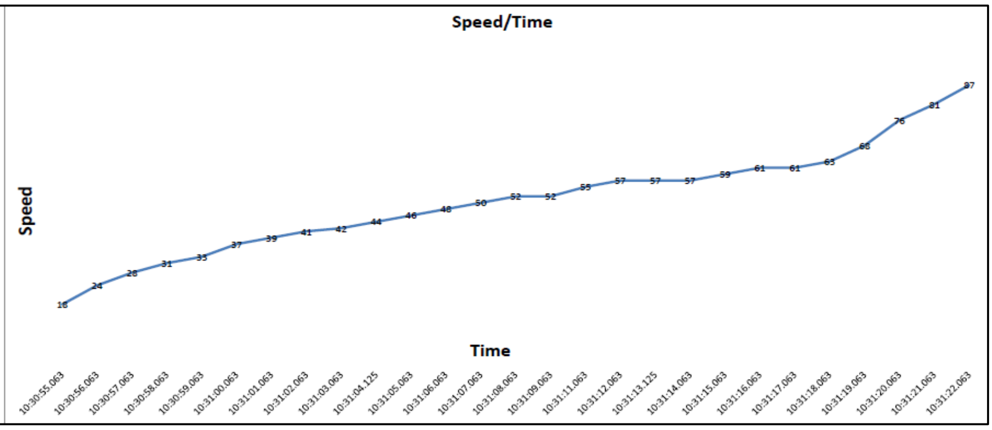

Figure 19: Speed and time of Bullet vehicle

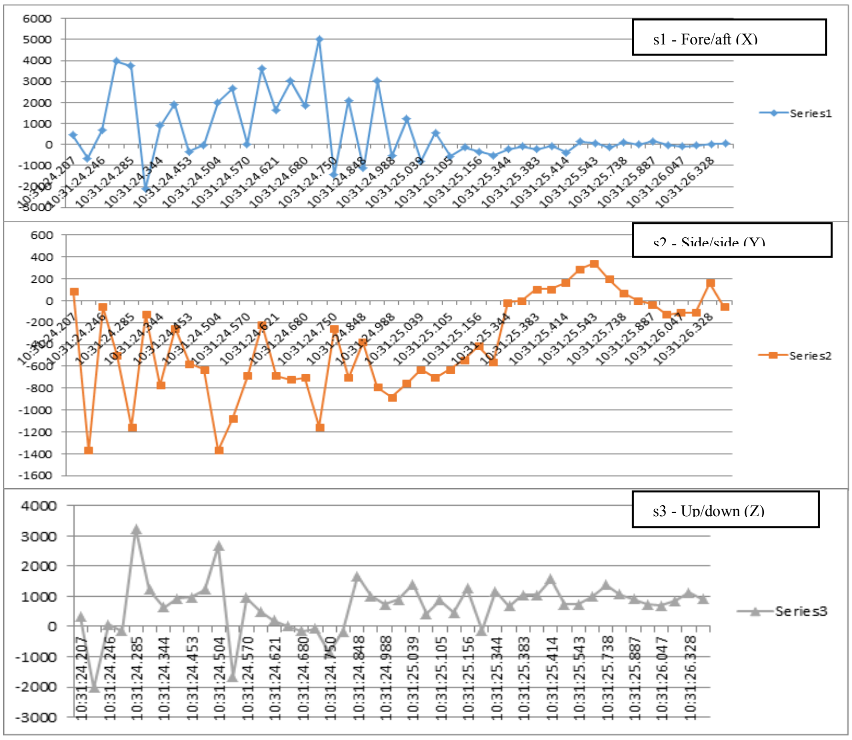

Figure 20: Target vehicle telemetry

Time (Clock) recordings were not identical across the two units. The Bullet unit indicating impact at time frame 10:31:22, while the Target unit indicating impact time at 10:31:24.680.

Nonetheless, the Target vehicle readings (Figure 21) peaked at 5 g (Series s1 - fore and aft (X)). Such high readings are not surprising, given the high speed impact and largely direct inline impact and largely forward displacement of the Target. An approximate 1.4 g lateral reading was recorded (Series s2 - Side/side (Y)). Such readings are not surprising, given that there was rotation and lateral displacement of the Target.

An approximate 3.1 g was recorded in an upward direction (Series s3 – Up/Down (Z)). Such readings are not surprising, given that the front end of the Bullet vehicle is relatively low and largely collided at a level just lower than the centre line of the rear tyres diameter of the Target and into the rear underride bar.

5. CONCLUSION

The contributions of this paper are: Identify the *characteristic correlation* with the results of the vehicles after a rear-crash of this manner; Identify *possible weaknesses* on the Bullet and the Target that could be improved; Identify *common evidence* after such a crash or accident has occurred.

In respect of the contributions of the paper and the identified results set out, perhaps the most obvious being that the scenario presented certainly highlights and confirms the opinions already set out in many research papers and general commentary in articles; Incompatibility between vehicles is a major problem. Although the rear under-ride and axle of the Target broke and the right wheel combination separated, in general, the Target suffered repairable damage. Comparatively, the Bullet is decimated. These factors too are consistent with the writer`s findings in similar actual crash cases considered.

The specific *characteristic* of the damages to either vehicle are expected and typical. The careful consideration of these damages allow a very accurate orientation of the vehicles relative to one another at impact, this is a crucial factor in the overall crash position analysis of the vehicles relative to one another and therefore in respect of the specific point of impact on the road.

The complete separation of the rear under-ride and likewise the right side of the rear axle are not unheard of, but are certainly less common. Through inspection, the separation of the rear under-ride is almost certainly as a direct result of the poor attachment. This should be very carefully considered in any case considered as the under-ride is a crucial safety device specifically intended to absorb energies and prevent under-ride. The break of the axle and separation of the right side wheel of the Target, may well not have occurred had the under-ride been sound.

The *possible weakness of the two vehicles considered*, notes that the Target main structural chassis appears to have suffered no damage. As already highlighted, the key weakness being the inappropriate securing of the rear under-ride and therefore not performing to the maximum. The limited deformation space between the rear under-ride and the rear most wheels is also a notable factor. To this end, the South African National Road Traffic Act, Regulation 218 and the South African National Standards Document (SANS 1055:2007) as well as other international specifications, should be kept in mind and referenced when considering a case. It may be a consideration that further specific evaluation against the results could provide some guidance to improvement of safety in respect of minimum mounting specifications and perhaps clearances to allow for suitable deformation.

Although the Bullet vehicle is somewhat older model, the general structure of the driver and passenger cell of the Bullet have remain largely intact, serving their intended purpose. Dislodging of the rear lower bench seat portion of the seats was observed and is a factor that may need to be considered in similar crash cases.

There is a plethora of *common evidence* produce, all of which must certainly be identified and appropriately recorded in cases dealt with and can be referenced against. Perhaps the most notable evident would be the evidence that identifies the positioning of either vehicle on the road surface, at pre-impact position. This position, typically of the Target vehicle, being the typical crucial factor or question that is asked in such real life cases. The majority of this evidence being the evidence that results on the road surface itself, ironically, this too is the evidence that is so often overlooked and not identified and recorded.

The positioning or orientation of the vehicles relative to one another at impact are key and therefore the damages crucial. The evidence on the road surface the same, therefore allowing either or both positing on the road surface at impact. The session supports the scope for further research and improvement in design of compatibilities between vehicles and arguably stronger regulation of designs, to improve compatibility. Improvements in a range of specific safety aspects need to be considered, such as improved structural strength and improved impact absorbing qualities. Similarly, further justification for research and improvements in technology driven safety mitigation products are needed. As highlighted in other research and commentary, this scenario highlights the need for careful consideration of underride devices. The need to ensure that such devices are correctly fitted and are regularly inspected is also highlighted.

Unfortunately, no specific impact telemetry resulted from the bullet vehicle. This serves to highlight that when any such tests are conducted that a secondary recording device should be employed. Nonetheless, the readings of 5g on the Target vehicle, certainly serves as strong indication that readings of the Bullet unit would have resulted and have been substantially higher. The lack of recording of certain telemetry also serves as a stark reminder that in the modern age of Crash Data Retrieval information from the vehicles, that the specific identification of scene evidence as a whole, is critically important and that the reliance on telemetry alone to provide answers, should not be the case, but as a support. The identification and collection of evidence should always serve to bolster or validate telemetry evidence.

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