**DEVELOPMENT OF A GENERIC LOW SPEED REAR IMPACT PULSE FOR ASSESSING SOFT TISSUE NECK INJURY RISK**

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ABSTRACT

Five car-to-car full-scale vehicle impact tests were conducted in order to aid the development of testing protocols for the certification and rating of vehicles, with respect to their ability to protect occupants from soft tissue neck injures. A wide range of passenger cars (ranging from the Ford Ka to the Volvo S80) were chosen as the target cars. The Ford Focus, representing the mass of a typical average sized European car, was used as the bullet car. All the tests were 100% overlap rear impacts which aimed to achieve a change in velocity (or "ΔV") of 16 km/h for the target vehicles. Due to the different ride heights of the target vehicles, the tests included over- and under-ride impacts as well as bumper-to-bumper impacts. The results showed significant differences with respect to signal shape and peak acceleration levels when compared with existing proposals. In particular, the crash pulses showed a bi-modal nature and had a high initial peak. These characteristics appear to be typical for current production passenger cars. The recorded crash pulses have been numerically combined into a proposed single pulse. Finally, a tolerance corridor for the sled acceleration signal and the sled ΔV has been proposed.

KEYWORDS
- WHIPLASH
- ACCELERATIONS
- CAR TO CAR IMPACT TESTING
- REAR IMPACTS
- REGULATIONS

SOFT TISSUE NECK INJURIES (STNI) are one of the most frequent types of injury seen in motor vehicle crashes. Recent studies have reported that these injuries (Temming et al. 1998, Hell et al. 1999, Krafft et al. 2000, 2001, Linder et al. 2001):

- Occur frequently (but not exclusively) in rear impacts
- Occur at relatively low speeds
- Appear to be reported more frequently than they did 10 or 20 years ago
- Carry a large burden for individuals, society in general and the insurance industry in particular.

There is therefore considerable interest in reducing the likelihood of STNI, particularly from the insurance industry who would like to reduce the level of pay outs for claims of neck injury.

A lot of research effort is currently focussed on the development of suitable test methods for assessing STNI risk (Hell et al 1999, Anselm et al. 2001). At present however, there is not a full understanding of the mechanisms of STNI and there is no universally consensed view about the choice of test dummy, injury criteria, and test mode or test severity. A suitable test for assessing STNI could potentially be used for consumer safety testing (for example, by Euro-NCAP) (Klanner 2001), for determining insurance ratings (Avery 2001) and for setting minimum protection levels in legislation (Langwieder 2000). There are clear benefits if there is a harmonised test procedure which could be used for each of these three different purposes. Apart from the savings in test costs and the ability to share data, it is also easier for manufacturers to produce optimised designs if they have one set of targets rather than numerous, potentially conflicting, requirements. A harmonised test method would need to be realistic, repeatable and reproducible.

The study described in this paper attempts to address the open issues concerning the appropriate test severity for assessing STNI risk in modern passenger cars in rear impacts. Here there is a choice between carrying out complete vehicle impact tests or replicating such impacts using a sled test. In general, sled tests (using a "seating buck" on a sled rather than a complete vehicle or bodyshell) are preferred over complete vehicle tests (Langwieder et al. 2000). They are cheaper and quicker to carry out and it is usually easier to see and analyse what is happening to the dummy's neck. From a legislative perspective, a generic sled test makes it possible to approve a seat design for different models without the need for numerous tests and it is also possible to approve a new seat design without the need for destructive testing of a complete vehicle.

A potential difficulty in performing sled tests however is determining the appropriate crash pulse. In a real vehicle impact, an occupant will experience a unique crash pulse based on the structural characteristics of both his own vehicle and the impacting vehicle, the seat and head restraint characteristics, the vehicle speeds involved, influence of braking and road surface friction, etc. There is therefore no single "right" answer to the question of what crash pulse to use in a sled test. Instead, it is proposed that a generic pulse (based on the response of typical modern vehicles in car-to-car tests) could be the most appropriate approach to follow.

## METHODOLOGY

Five full-scale car-to-car crash tests were conducted at Ford's Crash Laboratory at Köln in Germany. The tests were 180° rear impacts with 100% overlap. The number of tests that can be conducted is always limited by the very high cost for this kind of test. Therefore, not all possible impact scenarios i.e. heavy braking of the bullet vehicle or variations in bullet vehicle size could be investigated. However, the test series was able to investigate the effect of varying weights of the impacted vehicle. The target vehicles ranged from the smallest currently produced Ford car (the Ford Ka) to one of the largest passenger cars produced within the Ford Motor Company brands (the Volvo S80). The matrix of tests is shown in Figure 1.

| Bullet Vehicle | Test-weight (kg) | Target Vehicle | Test-weight (kg) | Bullet impact speed (km/h) | Target delta V (km/h) |
|---|---|---|---|---|---|
| Ford Focus 4dr | 1300 | Ford Ka | 1021 | 26.2 | 16.9 |
| Ford Focus 4dr | 1301 | Ford Fiesta 3dr | 1165 | 26.5 | 16.2 |
| Ford Focus 4dr | 1303 | Ford Focus 5dr | 1384 | 26.5 | 13.7 |
| Ford Focus 4dr | 1299 | Ford Mondeo 5dr | 1675 | 32.7 | 15.7 |
| Ford Focus 4dr | 1301 | Volvo S80 4dr | 1860 | 33.9 | 16.9 |

Figure 1: **Test matrix**

The bullet vehicles were identical Ford Focus 4 door saloons. The test weight of 1300 kg was chosen to represent the typical weight of an averaged sized European car.

All bullet and target vehicles were equipped with accelerometers at the B-pillar to doorsill joints. They were loaded with 95% of their fuel tank capacity using a test fuel substitute and had two 50%ile male dummies placed in the front seats to get a realistic on-road weight distribution. In order to achieve the final bullet car test weight of 1300 kg, components were removed or weights rigidly attached as appropriate. The ride-height of the bullet vehicles was left "as found" and not modified in any artificial way.

On the target vehicles, test instrumentation was rigidly attached to the vehicle bonnet. The weight of the instrumentation was partly offset by removal of components in the engine compartment and drainage of liquids from the engine. However, the instrumentation did lead to some forward pitch of the vehicles but this did not significantly affect the actual ride height of the rear bumper system. An example test set-up is shown in Figure 2.


**Figure 2** Test Set-up Example: Focus to Mondeo

The tests were set up with the aim of achieving a $\Delta V$ of 16 km/h for the target vehicle. This choice of severity was based on an analysis of German insurance data which concluded that the speed range between 10 and 20 km/h $\Delta V$ represents the main problem area. However, the lower speed range ($\Delta V<15$ km/h) was associated with a large number (50%) of cases which had insufficient or implausible medical documentation (Langwieder et al. 2001). It has also been proposed by ISO (ISO 1998) and the International Insurance Whiplash Prevention Group (IIWPG) (Avery 2001) to use a $\Delta V$ of 16 km/h in their test method development. The impact speed of the bullet vehicles in this study was therefore adjusted to give a $\Delta V$ of 16 km/h for the target vehicle depending on the relative weight of the target and bullet vehicles. Some degree of iteration of the impact speed was necessary in order to achieve the desired $\Delta V$ of 16 km/h. For example, the first test conducted (Focus to Focus) actually resulted in a $\Delta V$ of only 13.7 km/h. All following tests did fall into the tolerance band of $\pm 1$ km/h to the $\Delta V$ of 16 km/h

In order to allow a detailed analysis of the structural bumper interaction on high-speed film, the plastic bumper skin was removed from those vehicles where the plastic skin was in direct contact with the underlying steel bumper. It was assumed that in these cases the cosmetic components have no significant effect on the interaction between the vehicles.

## RESULTS

Impact Mode - Example shots from the high-speed film of some impacts are shown in the Appendix. Close examination of the film allowed the mode of vehicle interaction to be determined. In particular, it was possible to evaluate if the impact was an over ride, bumper-to-bumper impact or an under ride. These results are shown in Figure 3 (see also Figure 8 to Figure 9 in the Appendix).

| Test | Impact class |
|---|---|
| Focus to Ka | Under ride |
| Focus to Fiesta | Over ride |
| Focus to Focus | Under ride |
| Focus to Mondeo | Bumper to Bumper |
| Focus to S80 | Bumper to Bumper |

**Figure 3** Impact classes

Crash Pulses – The crash pulses from the individual tests are given in Figure 10 to Figure 14 in the Appendix. All the LHS/RHS average acceleration traces (filtered at CFC60 according to SAEJ211) reached their peak in the first 25 msec of the impact. At this time in the crash, the structures of the vehicle were in full engagement and the energy-absorbing crush of the bumper was complete. Comparing acceleration levels after 10 msec for the bumper-to-bumper interactions (eg Mondeo 6g) and with the over-rides (eg Fiesta 4g) or the under-rides (eg. Ka 2g) it was found that the initial acceleration is higher for direct bumper interactions. There is a period of low acceleration of the target when the bullet under rides. This effect led to a significant shift in time (Approx. 10 ms). However, eventually the structures were fully engaged with each other leading to similarly high peaks as in bumper to bumper impacts. The level of the peak acceleration seemed to be relatively independent of under/override or direct bumper-to-bumper engagement. There was no apparent correlation between vehicle weight/class and the levels of peak or mean acceleration in this test series (See Figure 4).

| Impact | Test weight | Acceleration peak CFC60 (LHS/RHS Average) | Time of peak | Mean acceleration |
|---|---|---|---|---|
| Focus – Ka | 1021 | 17 | 25 | 4.3 |
| Focus – Fiesta | 1165 | 14 | 28 | 4.2 |
| Focus – Focus | 1384 | 10 | 17 | 5.0 |
| Focus – Mondeo | 1675 | 15 | 16 | 4.7 |
| Focus – S80 | 1860 | 9 | 20 | 4.6 |

**Figure 4** Peak and Mean Acceleration Levels (The mean is calculated between t = 0 msec and the point at which the trace falls below 1g at the end of the impact event).

Generic Pulse - Due to the time shift in over/under rides, simple overlaying and averaging of the recorded CFC60 pulses give a misleading picture as the peaks of the under-ride pulses correspond to valleys in the bumper to bumper pulses (see Figure 15). In order to generate a generic pulse corridor signals where shifted in time so that all the signals had their onset of crash significant acceleration at t=0 msec (see Figure 5). Displaying the signals in this manner shows a clear quantitative and qualitative correlation. There is a significant initial rise in acceleration, peaking at a time when the bumper crush is complete. This is followed by a characteristic “bi-modal wave” in the acceleration traces.

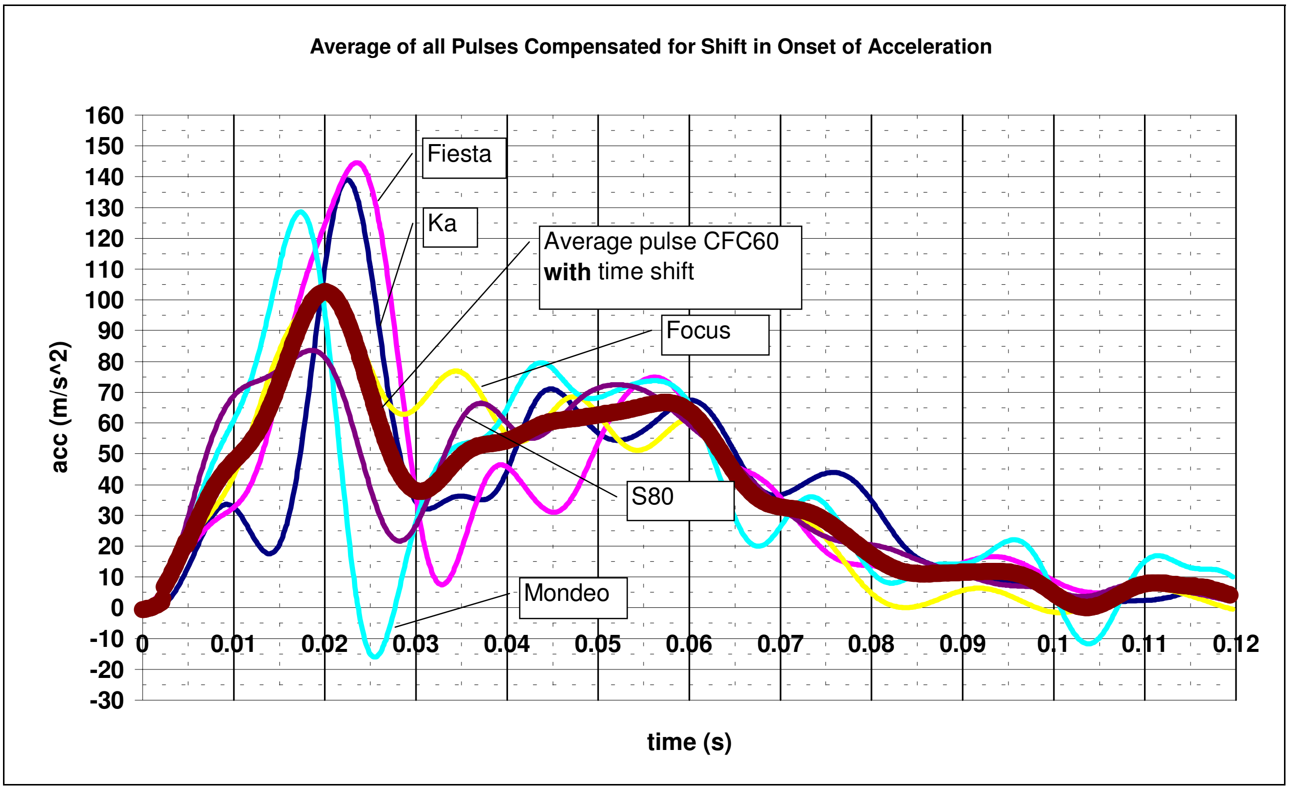


**Figure 5** Acceleration traces from test series filtered with CFC60, shifted to common t=0.

A separate CAE investigation (not reported in detail in this paper) has shown that this characteristic shape of the acceleration traces is caused by the back-swing of the free engine mass (causing a trough in the acceleration trace) followed by a new onset of acceleration as structural deformation resumes. All current mass-produced passenger vehicles share the same basic design features (eg reinforced rear structures and front mounted free-swinging engines). It is therefore reasonable to assume that for this test set-up the general features of the bi-modal pulse would also be exhibited by vehicles not included in this study.

In order to define a generic pulse corridor, an average of all the filtered and time-shifted signals was calculated. For simplification the very low signal levels after 90 msec were ignored. A acceleration corridor in which the sled pulse should fall were generated based on averaged pulse. In addition to these corridors, it is also proposed that a tolerance of ±1km/h should be applied to the proposed $\Delta V$ of 16km/h. The proposed generic pulse and its associated corridors are shown in Figure 6. The same figure also shows some of the other existing or proposed pulses.

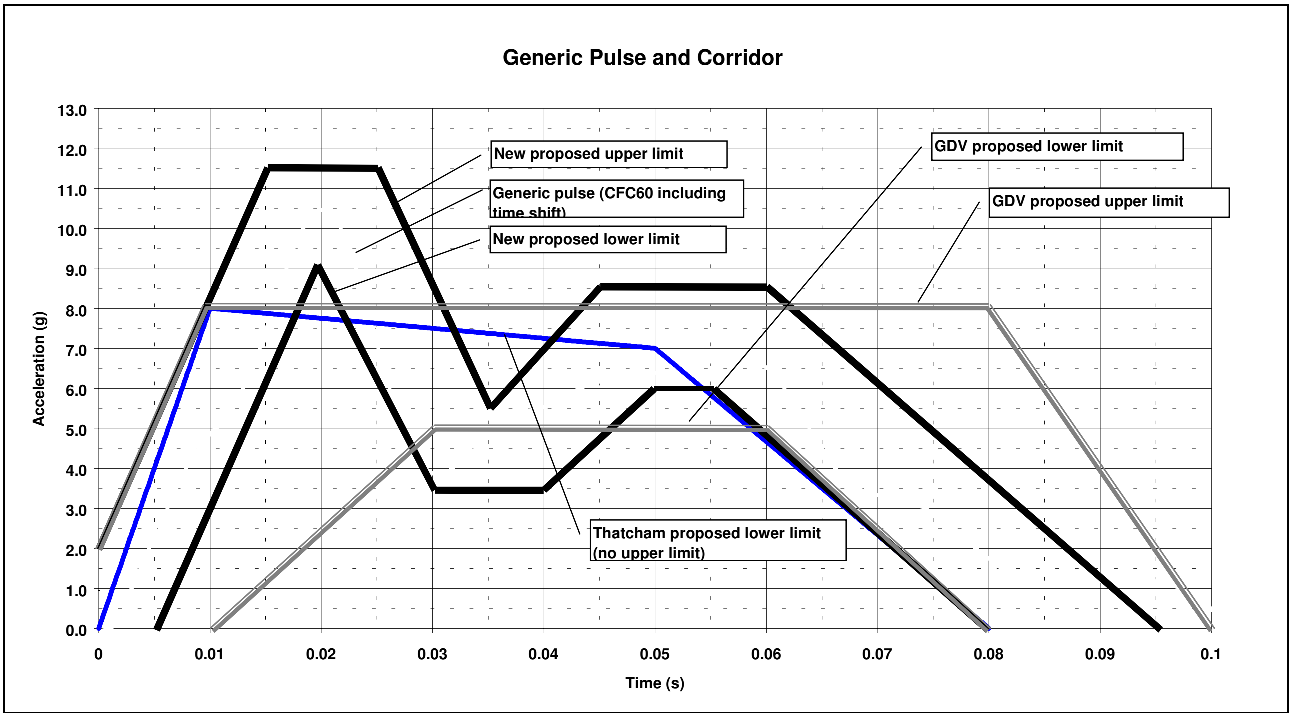


**Figure 6:** Comparison of currently proposed sled pulses

DISCUSSION

The results from the tests reported in this study have been used to propose a generic pulse for dynamic rear impact sled testing. The proposed pulse is characterised by a fairly high initial peak acceleration and a bi-modal wave form in the acceleration trace. It is believed that this pulse is appropriate to most modern car designs. Although the data sample for this study is comparatively small, the results are in line with data published for vehicles from other manufactures (Avery 2001). A simulation of a HyGe sled test has been undertaken to determine if the proposed pulse can actually be reproduced on a commercial HyGe sled. The simulation clearly showed that the proposed pulse corridor is feasible for HyGe sled testing (see Figure 7).

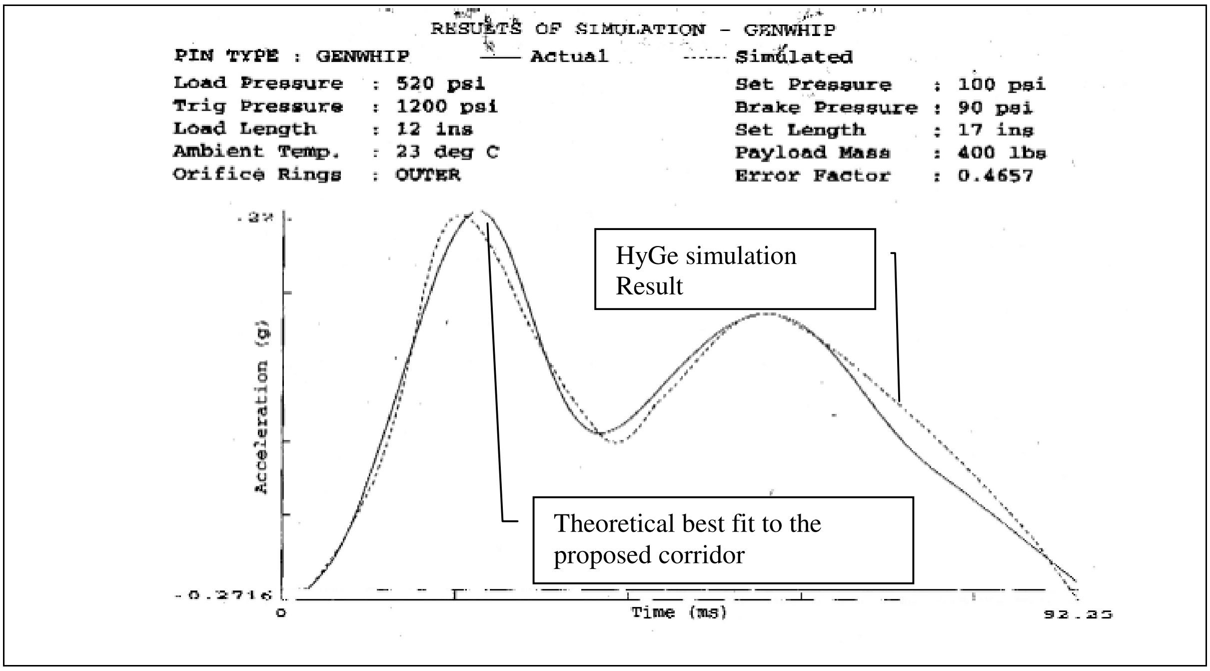


**Figure 7:** HyGe simulation of the generic pulse

Other generic pulses have been proposed by GdV and Thatcham. A comparison of these pulses with the new proposed generic pulse is shown in Figure 6.

The GdV pulse was based on analysis of data from older vehicle models, designed prior to the mid 1990's (Langwieder et al 2000). This proposal does not show a distinct initial acceleration peak but instead has a slow rise in acceleration up to a plateau level of 6.5g. Most of the crash pulse data used to generate this proposal came from vehicles manufactured in the 1980's and it is felt that vehicle design has changed significantly enough to warrant a re-assessment based on more recent vehicle designs.

The Thatcham proposal (Avery 2001) is based on more modern vehicles and goes some way towards replicating the fall of in acceleration seen after the initial peak. However, due to the prescribed lower limit corridor (an upper limit is not given) that produces an $\Delta V$ of 15.7 km/h, it is practically not possible to have initial peaks of more than 8g if the resulting $\Delta V$ is not to be larger than 16 km/h. However, the results reported in this study show peak accelerations of between 9g and 17g (LHS/RHS average, filtered with CFC60). As a result of this study, it is felt that a generic pulse ought to specify initial acceleration peaks of around 10g, with corridors allowing peaks up to 11.5g.

## CONCLUSIONS

1. Five car-to-car full-scale vehicle impact tests were conducted in order to aid the development of testing protocols for the certification and rating of vehicles, with respect to their ability to protect occupants from soft tissue neck injures.
2. The results show significant differences with respect to signal shape and peak acceleration levels when compared with existing proposals. In particular, the crash pulses showed a bi-modal nature and had a high initial peak. These characteristics appear to be typical for current production passenger cars.
3. The recorded crash pulses have been numerically combined into a proposed single pulse suitable for sled testing and a tolerance corridor for the sled acceleration signal and the sled $\Delta V$ has been proposed.

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APPENDIX – HIGH SPEED CAMERA SHOTS AND ACCELERATION TRACES FROM CAR-TO-CAR TESTS


0 msec 80 msec

**Figure 8** Focus to Ka

0 msec 80 msec

**Figure 9** Focus to S80

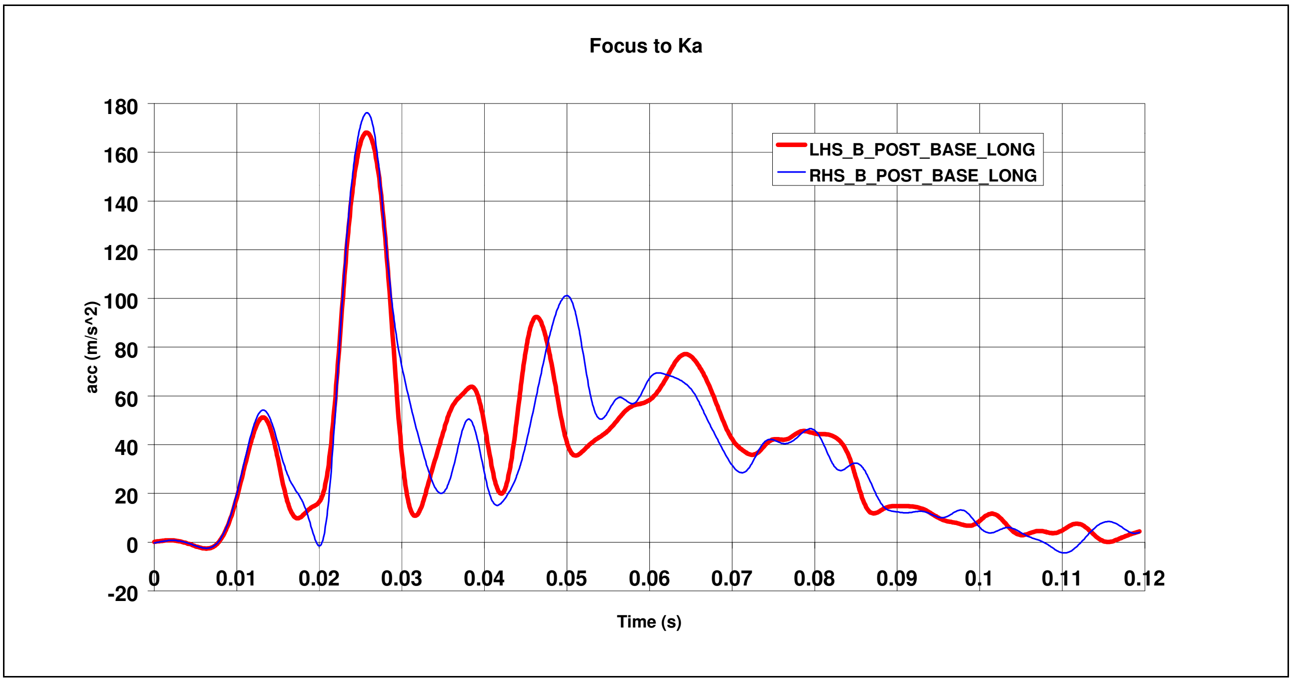


**Figure 10** Pulse diagram Ka

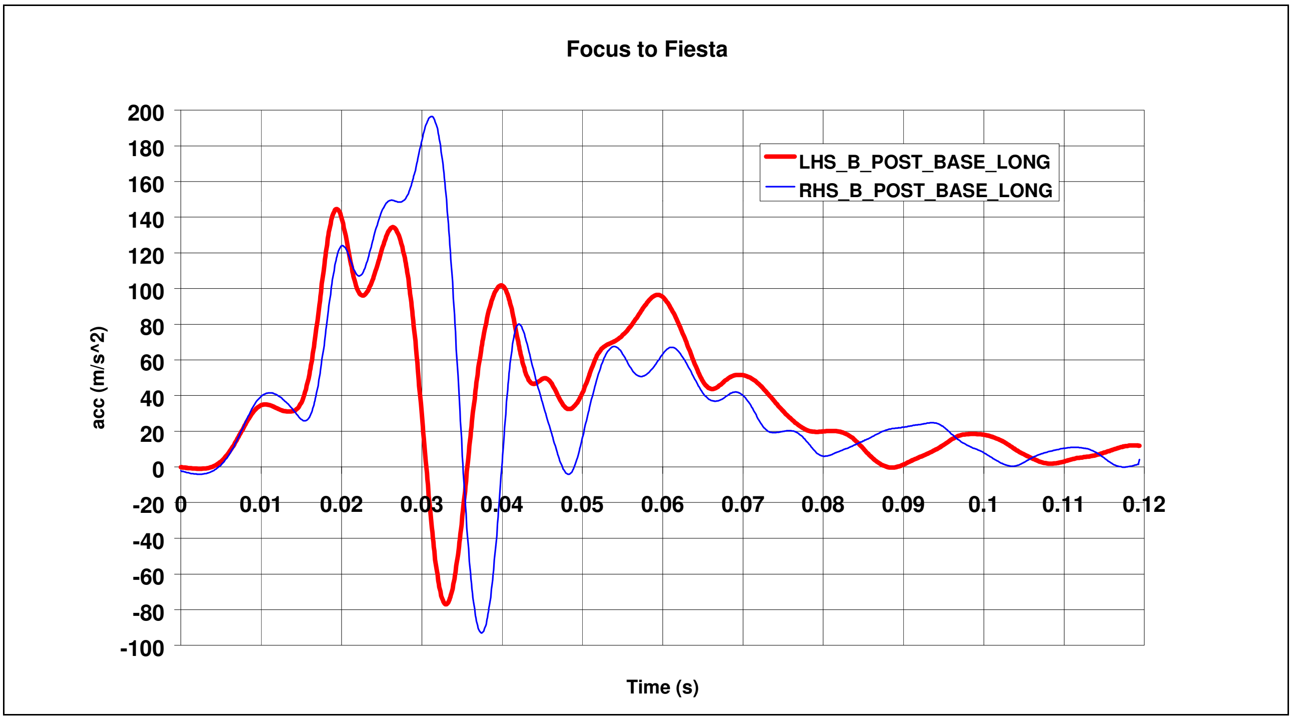


**Figure 11** Pulse diagram Fiesta

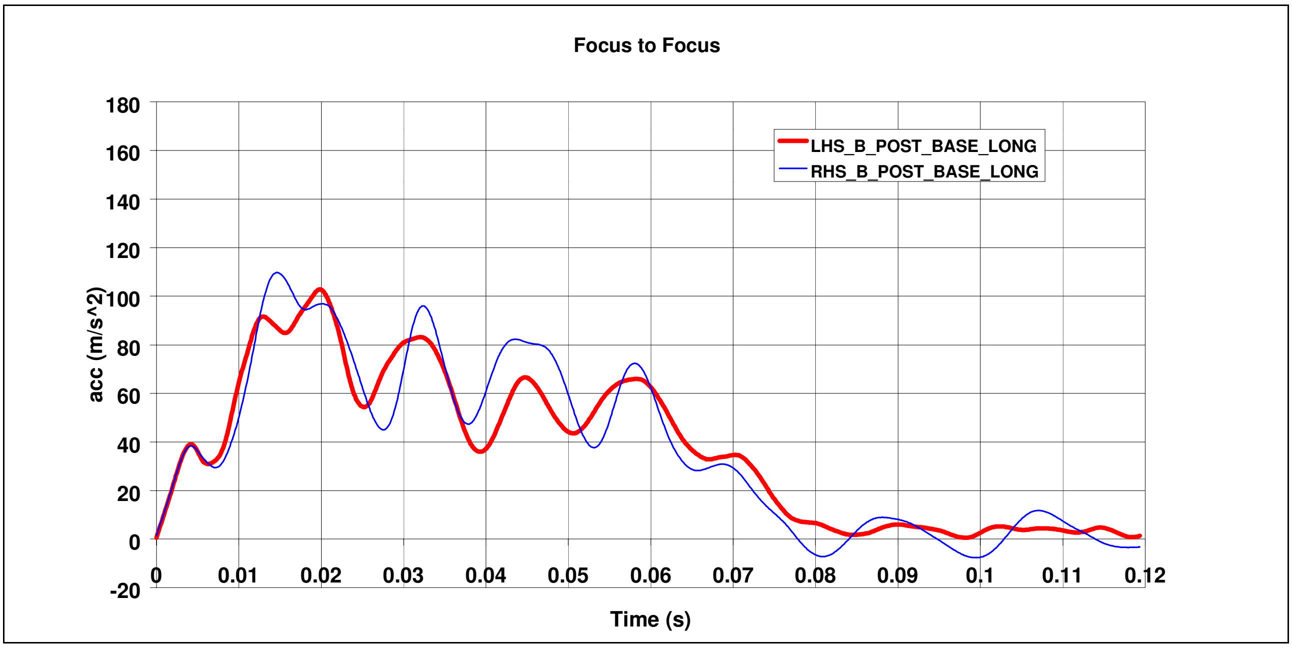


**Figure 12** Pulse diagram Focus

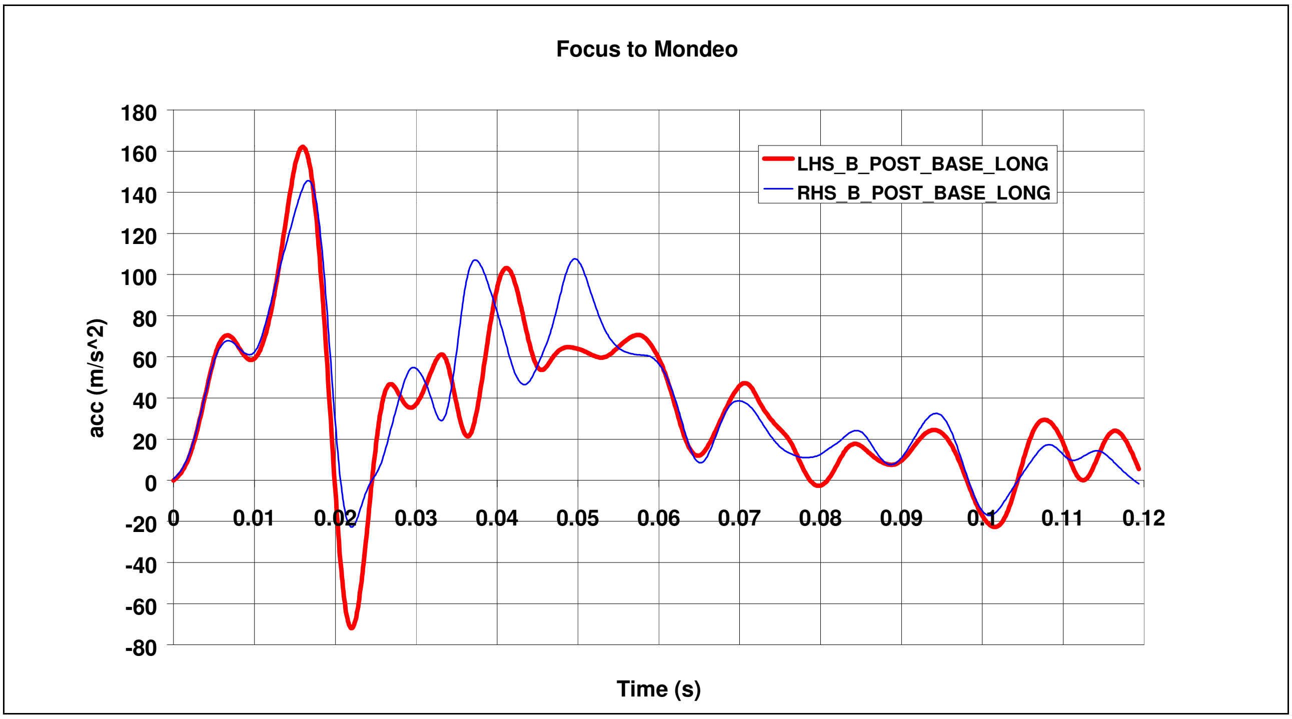


**Figure 13** Pulse diagram Mondeo

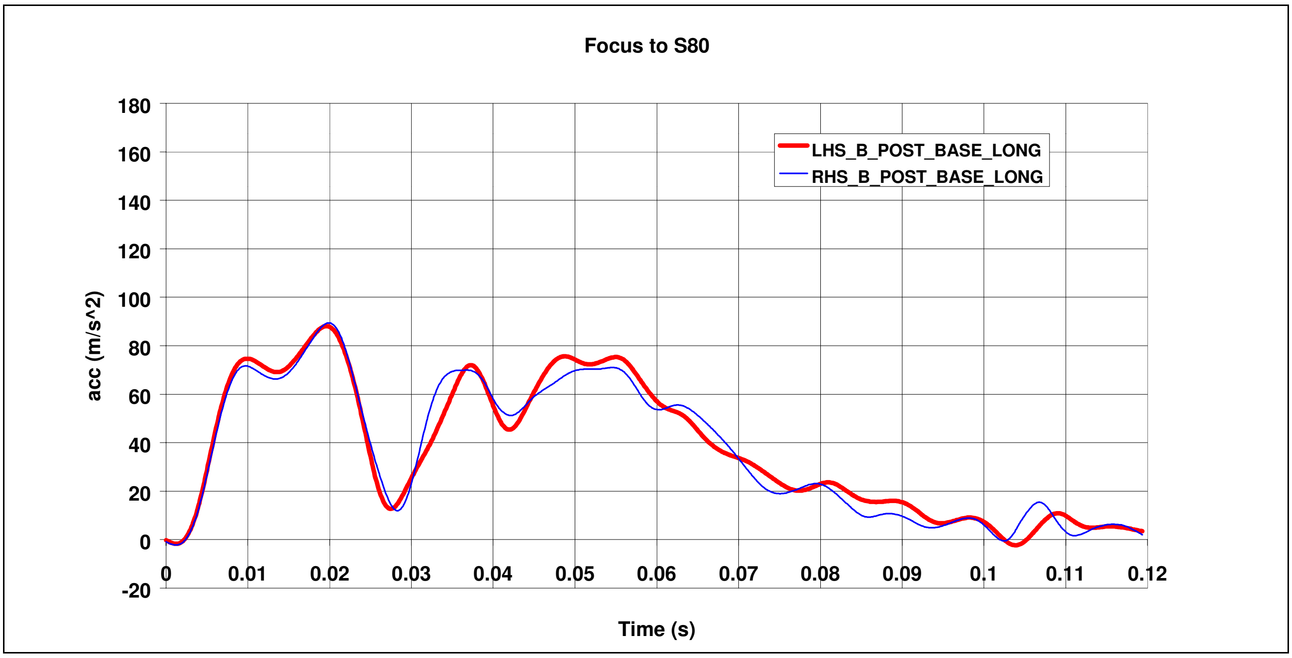


**Figure 14** Pulse diagram S80

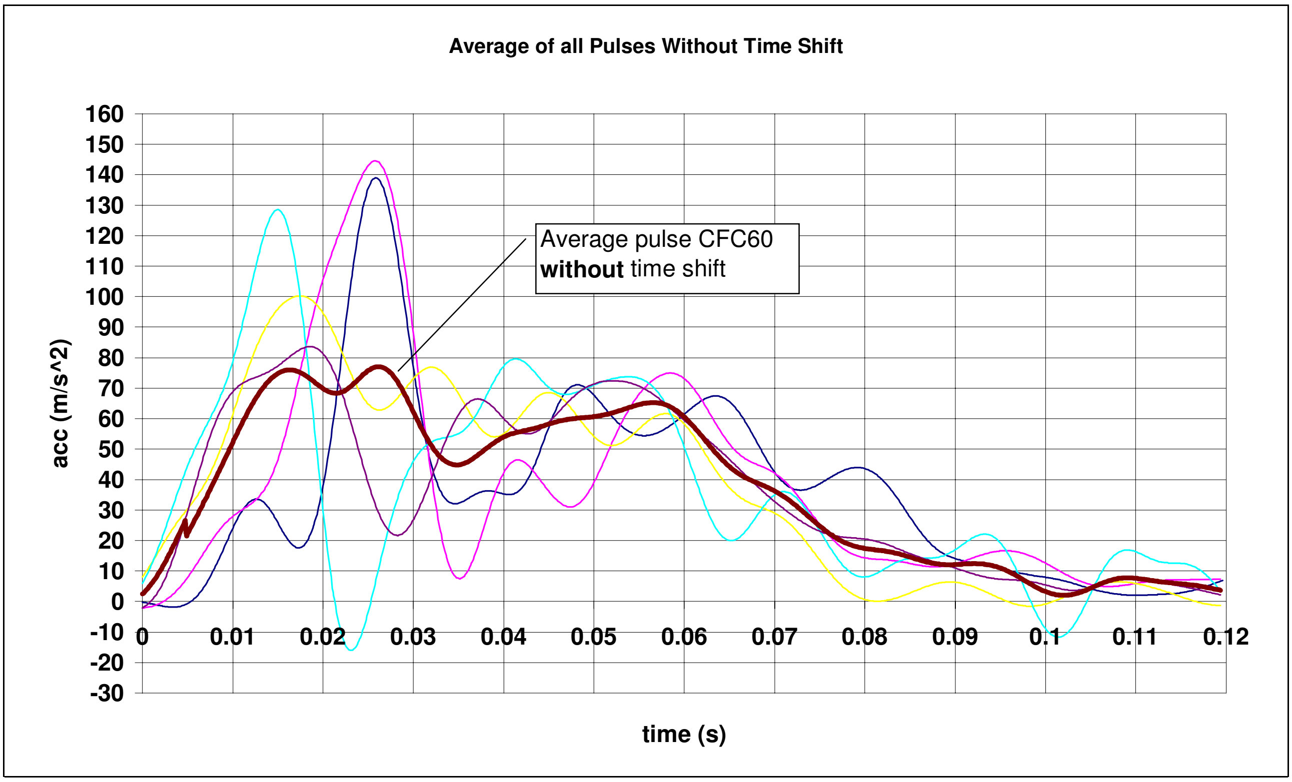


**Figure 15** Average of all pulses without compensation for over-under ride time shift