ACCURACY OF FOLKSAM ELECTRONIC CRASH RECORDER (ECR) IN FRONTAL AND SIDE IMPACT CRASHES

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ABSTRACT

Estimation of crash severity from crash recorders is important in the evaluations of vehicle crashworthiness. The number of cars fitted with on-board crash recorders is increasing. The majority of these recorders are integrated with airbag sensors that usually have limitations regarding e.g. recording time and sampling rate. The aim with this study was to evaluate the accuracy of an Electronic Crash Recorder (ECR) compared to laboratory accelerometers.

The ECR records car body acceleration during a crash event. The ECR is part of a large accident data collection system where 10,000 units per year are installed in various car models in Sweden. The ECR has the possibility to record acceleration in longitudinal and lateral impacts and also in multiple events. The ECR also meet requirements like recording data 30 ms prior to pulse start (t_0) and recording time up to 500 ms with 1 kHz sampling rate.

The focus was to evaluate the accuracy in a wide range of impact speeds and with different pulse shapes. A series of 12 sled tests were conducted with delta-V between 12.3 and 73.5 km/h. In each test the sled was fitted with 10 ECRs as well as a laboratory accelerometer. Five ECRs were fitted in the longitudinal direction and five in the lateral. In total 120 ECR recordings were evaluated.

Acceleration data were filtered according to CFC60 as defined in SAE J211. Change of velocity, mean and peak accelerations were derived from the filtered acceleration.

No systematic error was found regarding delta-V. The systematic error of mean acceleration in the longitudinal direction was 0.4 g (3.5%).

For all tests the standard deviation for delta-V in the longitudinal direction was 0.8 km/h (1.9%). The corresponding value for the lateral direction was 1.4 km/h (3.9%). The standard deviation for mean acceleration was 0.2 g (1.7%) in the longitudinal direction and 0.4 g (3.0%) in the lateral direction. In general no major differences in standard deviation between low and high speed crash tests were found.

Overall the evaluation of the ECR showed that a low cost accelerometer device gives accuracy close to a laboratory accelerometer.

INTRODUCTION

Knowledge of crash severity is important in crash injury analyses. The link between injury outcome and crash severity is essential for both car manufacturers and road designers. Traditionally crash severity, often change of velocity, is calculated with energy based reconstruction software based on measurements of structural deformation of the car. Historically the most frequently used ones are CRASH3, SMASH and WinSmash, where WinSmash is the most recent one. The error of such reconstruction software has been shown to be large, with underestimations of delta-V up to 33% (Smith and Noga 1982; O'Neill et al. 1996; Lenard et al. 1998; Gabler et al. 2004; Niehoff and Gabler 2006) .

Using crash recorders may have a profound impact on vehicle crashworthiness by providing delta-V, mean and peak acceleration to be used in crash reconstruction and analyses. This helps car manufacturers to improve automotive safety more effectively, but also to evaluate benefits of new safety technology. The most used severity parameter in crashworthiness analysis is delta-V. Mean acceleration is also used and shown to have a good correlation to injury risk (Ydenius 2009). Peak acceleration is not commonly used in crash analysis partly caused by the absence of detailed acceleration data in most EDRs.

Folksam introduced a crash recorder in 1992 with a mechanical Crash Pulse Recorder (CPR) (Aldman et al. 1991). The CPR has been installed in Toyota, Saab, Opel, and Honda cars in Sweden. In total approximately 260,000 cars have been fitted with a CPR. The CPR has been replaced by a new electronic crash recorder (ECR) that the present study aims to evaluate. The installation of the successor ECR began in mid 2008 with an installation rate of 8,000-10,000 units per year. The installation of the ECR is continuously implemented in Toyota cars.

The ECR is an electronic accelerometer measuring acceleration in the longitudinal and lateral directions. It is not capable of measuring the variety of parameters such as seat belt use, applied brakes or driving speed, that many other accident data recorders are capable of, e.g. Event Data Recorders (EDRs) used in the USA. The National Highway Traffic Safety Administration (NHTSA) refers to them generically as Event Data Recorders. In this paper the term “crash recorder” is generally used to describe an on-board accelerometer device.

One important use of crash recorder data has been to evaluate the car occupant injury risk and injury tolerance levels. The quality of real world crash data has often been a limiting factor in establishing injury tolerance (Kullgren and Lie 1998; Funk et al. 2008). During the last 15 years, studies aimed at evaluating injury tolerance based on real world crashes with recorded crash severity have been presented (Kullgren et al. 2000; Krafft et al. 2002; Gabauer and Gabler 2008; Kullgren and Krafft 2008; Ydenius 2010). In these studies, injury risks for different injury types versus recorded impact severity have been established.

An additional advantage with crash recorder data is the ability to evaluate effectiveness of various safety technologies. One of the latest introduced safety system is autonomous emergency braking (AEB). Based on analysis of data from crash recorders, injury risk reduction for AEB can be estimated (Kullgren 2008). As more advanced safety technologies are introduced in cars, it is important to continuously evaluate effectiveness for these systems, preferably with help from crash recorder data.

The importance of using crash recorder data in car accident research has led to an increasing number of car fleets with crash recorders as standard equipment. Cars are often equipped with crash recorders making it possible to measure change of velocity time history or acceleration time history during the crash phase. In large car fleets, such as Toyota, GM (General Motors) and Ford in the U.S., EDRs with lower sampling frequency and limited recording time are used.

To ensure quality of crash recorder data in the U.S., the road safety authority (*NHTSA 49 CFR Part 563 Event Data Recorders*) has decided a standardization rule for collecting EDR data. The final rule requires an accuracy of delta-V and acceleration of ±10%. Transport Canada and GM found the delta-V error of the GM EDRs to be within ±10% (Comeau et al. (2004). Niehoff et al.(2005) evaluated the performance of EDRs from GM, Ford and Toyota in crash tests. They found that the average error in frontal crashes was just below six percent. One observation done by several authors is that crash recorders generally underestimate delta-V in relation to laboratory accelerometers (Chidester et al. 1999; Lawrence et al. 2003; Comeau et al. 2004; Niehoff 2005).

Smaller car fleets give more freedom to use high performance crash recorders with larger capacity, such as AXA Winterthur (2011) and Folksam (Kullgren and Krafft 2008). The crash recorder used by AXA Winterthur has similar specifications as the one used by Folksam. The AXA crash recorder has an accuracy of ±10% on acceleration measurement. The previous crash recorder CPR from Folksam had a systematic error of 8.8% on delta-V measurement (Kullgren et al. 1995).

The aim with this study was to evaluate the accuracy of the Folksam Electronic Crash Recorder (ECR) compared to a laboratory accelerometer.

METHODS

ECR description

The ECR has a 2-axial accelerometer (see Figure 1). The evaluation of the ECR was done in longitudinal (x) and lateral (y) direction separately. The ECR had an external 12 V power supply. The recording time is 500 ms per event and up to four subsequent events can be recorded. The sampling frequency is 1 kHz. The trigger level of the accelerometer is 1.5 g over a 5 ms time period. Data 32 ms prior to trigger level is recorded. The longitudinal range is ± 72 g and the lateral ± 36 g.

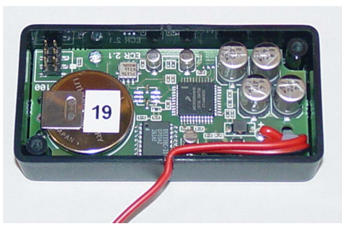

Figure 1. Electronic Crash Recorder (ECR)

Crash tests

Twelve sled tests were performed to evaluate the accuracy of the ECR. In each test 10 ECRs were attached to the sled, five with longitudinal orientation and five with lateral (see Figure 2). As reference accelerometer a laboratory accelerometer (Endevco 7267A) was used with a sampling frequency of 20 kHz. In total 12 crash tests were conducted with impact speed between 10-67 km/h (see Table 1). The test pulses were based on three predefined pulses, Euro NCAP at 64 km/h, US-NCAP at 56 km/h and a "non fire" airbag pulse at 15 km/h. In order to get a variation in crash severity and pulse shape, the impact speed varied and ride down acceleration were adjusted by varying the brake force of the sled.

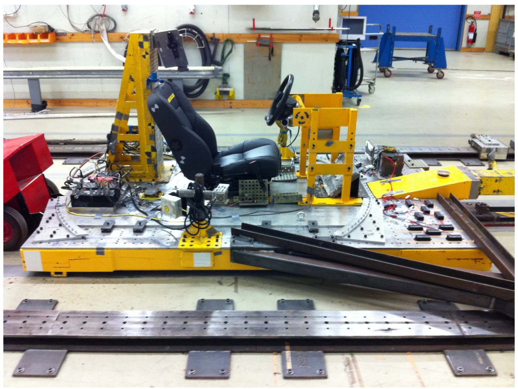

Figure 2. Sled test set up with the ECRs on the sled to the right.

Table 1. Crash test severity level

Test	Delta-V km/h (lab)	Impact speed (km/h)	Severity level
T-0711	12.2	10	Low
T-0712	17.7	15 "Non fire" airb	Low
T-0713	22.6	20	Low
T-0714	28.1	25	Medium
T-0707	28.2	25	Medium
T-0703	28.2	25	Medium
T-0708	32.8	30	Medium
T-0704	33.3	30	Medium
T-0705	62.8	56 US-NCAP	High
T-0709	69.9	64 EuroNCAP	High
T-0706	70.3	63	High
T-0710	73.5	67	High

Computations

Delta-V was derived from the acceleration pulse between t_0 and t_{end} and mean acceleration was calculated. To determine t_0 and t_{end} one of the methods, *Method C*, described in ISO 12353-3 (SIS 2013) was used for both the laboratory and the ECR recordings. The ECR and laboratory recordings were filtered according to CFC60 as defined by SAE J211.

Evaluation of the random and systematic error of the ECR was done in longitudinal and lateral direction separately. The evaluation was done for delta-V, mean and peak acceleration.

The crash tests were divided in three severity levels. Low severity had delta-V below 25km/h. Medium severity were between 25 km/h to 50 km/h and high severity were tests with delta-V above 50 km/h.

Systematic error

Systematic errors were calculated according to Equation (1), showing the average difference between the ECR and the laboratory accelerometer.

$$Systematic\ error = \frac{\sum_{i=1}^{n}(x_i - x_{lab})}{n} \qquad (1)$$

Random error

Standard deviation was calculated according to Equation (2). Standard deviation was calculated for each test and for each orientation of the ECRs. The standard deviation for all 12 tests was computed as the mean value of the standard deviation for all 12 tests as well as for the three severity levels.

$$Std\ Dev = \sqrt{Var\ x} = \sqrt{\sum_{i=1}^{5}\frac{(x_i - \bar{x})^2}{(n-1)}} \qquad (2)$$

RESULTS

Pulses from laboratory accelerometers in the 12 crash tests are presented in Appendix A.

Systematic error

No evidence of systematic error for delta-V (ΔV) either in the longitudinal or in the lateral direction was found (see Table 2). In lateral direction there was an underestimation of delta-V less than one km/h for low/medium severity. In high severity tests there was an overestimation of 1.8 km/h (2.8%).

The systematic errors for both longitudinal and lateral mean acceleration (ā) were found to be 0.5 g or less (3.5% and 3.9 % respectively). Longitudinal mean acceleration showed a decreasing error between low severity tests and medium/high severity, from 5.5% to 3.4%.

In both directions there was a larger systematic error for peak acceleration (â) than for the other parameters. The error for peak acceleration was an underestimation of 8.7% and 5.1% in longitudinal and lateral directions respectively.

Table 2. Systematic error of longitudinal and lateral delta-V, mean and peak acceleration - divided in severity levels

		Error		%
Total	ΔV_x	0.2	km/h	0.4
0-75 km/h	ΔV_y	0.0	km/h	0.0
n_x=60	$\bar{a}_x$	0.4	g	3.5
n_y=53	$\bar{a}_y$	0.5	g	3.9
	$\hat{a}_x$	-1.8	g	-8.7
	$\hat{a}_y$	-1.0	g	-5.1
Low ΔV	ΔV_x	0.0	km/h	0.3
0-25 km/h	ΔV_y	-0.5	km/h	-3.0
n_x=15	$\bar{a}_x$	0.3	g	5.5
n_y=14	$\bar{a}_y$	0.2	g	3.0
	$\hat{a}_x$	-0.5	g	-5.2
	$\hat{a}_y$	-0.9	g	-8.4
Medium ΔV	ΔV_x	-0.2	km/h	-0.5
25-50 km/h	ΔV_y	-0.8	km/h	-2.6
n_x=25	$\bar{a}_x$	0.3	g	3.4
n_y=24	$\bar{a}_y$	0.2	g	2.2
	$\hat{a}_x$	-2.3	g	-12.6
	$\hat{a}_y$	-1.3	g	-7.5
High ΔV	ΔV_x	0.6	km/h	0.9
50-75 km/h	ΔV_y	1.8	km/h	2.8
n_x=20	$\bar{a}_x$	0.7	g	3.4
n_y=15	$\bar{a}_y$	1.3	g	6.3
	$\hat{a}_x$	-2.1	g	-5.7
	$\hat{a}_y$	-0.9	g	-2.5

Random error

In general no major differences in standard deviation between low, medium and high speed crash tests were found (see Table 3). For all tests the standard deviation for delta-V in the longitudinal direction was 0.8 km/h (1.9%). The corresponding value for the lateral direction was 1.4 km/h (3.9%).

The standard deviation for mean acceleration was 0.2 g (1.7 %) in the longitudinal direction and 0.4 g (3.0 %) in the lateral direction. The standard deviation for peak acceleration was larger than for the other parameters (see Table 3).

Table 3. Random error of longitudinal and lateral delta-V, mean and peak acceleration - divided in severity levels

		Error		%
Total	ΔV_x	0.8	km/h	1.9
0-75 km/h	ΔV_y	1.4	km/h	3.9
n_x=60	$\bar{a}_x$	0.2	g	1.7
n_y=53	$\bar{a}_y$	0.4	g	3.0
	$\hat{a}_x$	1.0	g	4.6
	$\hat{a}_y$	0.7	g	3.6
Low ΔV	ΔV_x	0.3	km/h	1.6
0-25 km/h	ΔV_y	0.2	km/h	1.1
n_x=15	$\bar{a}_x$	0.1	g	1.5
n_y=14	$\bar{a}_y$	0.1	g	1.2
	$\hat{a}_x$	0.4	g	3.7
	$\hat{a}_y$	0.6	g	5.8
Medium ΔV	ΔV_x	0.9	km/h	3.0
25-50 km/h	ΔV_y	0.3	km/h	0.8
n_x=25	$\bar{a}_x$	0.3	g	2.6
n_y=24	$\bar{a}_y$	0.1	g	1.1
	$\hat{a}_x$	0.8	g	4.4
	$\hat{a}_y$	0.7	g	3.8
High ΔV	ΔV_x	0.9	km/h	1.3
50-75 km/h	ΔV_y	2.8	km/h	4.2
n_x=20	$\bar{a}_x$	0.2	g	1.1
n_y=15	$\bar{a}_y$	0.7	g	3.3
	$\hat{a}_x$	1.5	g	4.1
	$\hat{a}_y$	0.9	g	2.8

Two outliers were identified among the longitudinally mounted ECRs in the medium severity group; one with a delta-V 2.0 km/h below and another with a delta-V 3.6 km/h above the laboratory value. The standard deviation for delta-V in the group with the two outliers was 3.0% compared to 1.9% for all delta-V_x values.

In one of the high severity tests there were three outliers among the laterally mounted ECRs. The standard deviation for delta-V_y in that test was 4.2% compared to 3.9% for all delta-V_y values.

All individual data from the 120 ECR recordings as well as the figures of standard deviation are presented in Appendix B.

DISCUSSION

NHTSA has published a standardization rule for EDRs that requires an accuracy of measured delta-V and acceleration within ±10%. The present study shows that the Folksam ECR has no systematic error and a longitudinal random error of 1.9% of measured delta-V. Compared to other crash recorders (AXA Winterthur 2011; Comeau et al. 2004; Niehoff et al. 2005), the Folksam ECR appears to measure more accurately. The Folksam ECR is one of the most highly specified large fleet crash recorders on the market regarding acceleration recordings.

Although crash recorders have been introduced in accident research, crash severity estimations are still performed with computer software that estimates delta-V based on post-crash measurements of car structural deformation. The accuracy analysis of such reconstruction software has been shown to be large, with underestimations of delta-V between 10%-33% and with large random errors (Smith and Noga 1982; O'Neill et al. 1996; Lenard et al. 1998; Gabler et al. 2004; Niehoff and Gabler 2006) . The influence of large measurement errors on injury risk curves will be extensive (Kullgren and Lie 1998; Funk et al. 2008). In order to conduct an appropriate injury tolerance analysis it is essential to have crash severity data with low measurement errors, especially concerning random errors. Using crash recorders gives a possibility to obtain this.

Studies of the accuracy of reconstruction program are in some publications done in comparison with EDR data, not laboratory data (Gabler et al. 2004; Niehoff and Gabler 2006). Although there is a variation in accuracy of different types of crash recorders, the error output from reconstruction programs are greater and in addition more sensitive to crash modes than crash recorders. Furthermore, this comparison favors reconstruction programs since studies show that errors of EDRs usually are underestimations as well as errors from reconstruction programs (Chidester et al. 1999; Lawrence et al. 2003; Comeau et al. 2004; Niehoff 2005).

The accuracy of a crash recorder is not only dependent of the accelerometer specifications but also recording capacity. Problems with truncated pulses are an important source of error. Absence of sufficient recording time may lead to larger systematic errors than minor measurement errors. Although there are methods to make estimations of the missing parts of truncated pulses under certain circumstances (SIS 2013), it results in an underestimation of delta-V when the whole pulse is not captured. In many crashes the crash recorder does not cover the whole event (Gabler et al. 2005; Niehoff 2005; Ydenius 2010). To ensure a 95% coverage of the whole pulse in frontal crashes, at least 250 ms recording duration is needed (Niehoff 2005) and in car to roadside events, at least 300 ms (Gabler et al. 2005; Stigson et al. 2009; Ydenius 2010). To capture the majority of long crash pulses the authors suggest ensuring at least 300 ms recording time.

The systematic error for peak acceleration was larger than for the other parameters. Both the laboratory accelerometer and the ECR recordings were filtered according to CFC60. Despite that an explanation could be the large difference in sampling rate between the ECR and the laboratory accelerometer (1 kHz compared to 20 kHz).

Five outliers were found in two tests influencing the standard deviation. These were included in the evaluations. A possible explanation to these outliers could be the attachments to the sled that may have caused small movements during the deceleration. Two outliers were found among the longitudinally mounted ECRs in test T-0703 and three among the laterally mounted ECRs in test T-0709. The random error in T-0703 was for delta-V_x 3.0% compared to 1.9% for all delta-V_x. Changing the random errors of these outliers to zero would have changed the standard deviation of delta-V_x from 1.9% to 1.4%. And in test T-0709 the random error for delta-V_y was 4.2 % compared to 3.9% for all for delta-V_x. Changing the random errors of the outliers to zero would have changed the standard deviation of delta-V_y from 3.9% to 1.7%.

An accelerometer with laboratory specifications is still an expensive component if no compromises regarding sampling frequency, recording time or ability of multiple event recording are made. It is reasonable to assume that a car manufacturer will use the most cost effective crash recorder solutions in the future. However, the present study shows that the Folksam ECR is almost as accurate as a laboratory accelerometer. It is encouraging to find that it is possible to achieve this for a relatively low cost.

Limitations

It was decided to conduct twelve crash tests at different crash severity levels. From a statistical point of view it would have been more favorable to run a larger number of ECRs in each crash test in order to better evaluate the random error of the ECR. However, since the ECR is used in real-world crashes, the intention was to evaluate if any differences could be found between high and low speed crashes. The number of possible tests to run was limited, so 10 ECRs in each test (5 lateral and 5 longitudinal) was a good compromise.

In each of the 12 crash tests one single laboratory accelerometer was used as a golden standard. Although laboratory accelerometers could be assumed to have high accuracy, these accelerometers are also associated with random errors themselves. Therefore, it would have been better to use for example three laboratory accelerometers and use the average of their measurements in the comparisons with the ECR.

CONCLUSIONS

Regarding systematic and random measurement errors of the Folksam ECR the following were found based on 12 crash tests with 120 ECR recordings in three severity levels:

- No systematic error was found regarding delta-V.
- The systematic error of mean acceleration in the longitudinal direction was 0.4 g (3.5%) and 0.5 g (3.9%) in lateral direction.
- In general no major differences in standard deviation between low and high speed crash tests were found.
- For all tests the standard deviation for delta-V in the longitudinal direction was 0.8 km/h (1.9%). The corresponding value for the lateral direction was 1.4 km/h (3.9%).
- The standard deviation for mean acceleration was 0.2 g (1.7%) in the longitudinal direction and 0.4 g (3.0%) in the lateral direction.

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APPENDIX A

Crash pulses from laboratory accelerometers in the twelve sled tests are presented below.

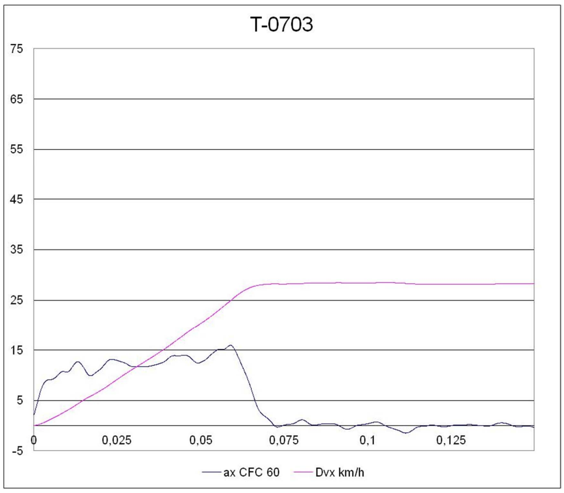

Figure A1. T-0703 (modified US-NCAP)

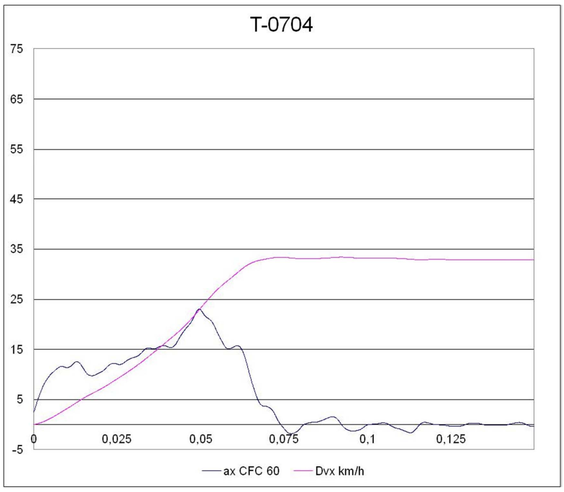

Figure A2. T-0704 (modified US-NCAP)

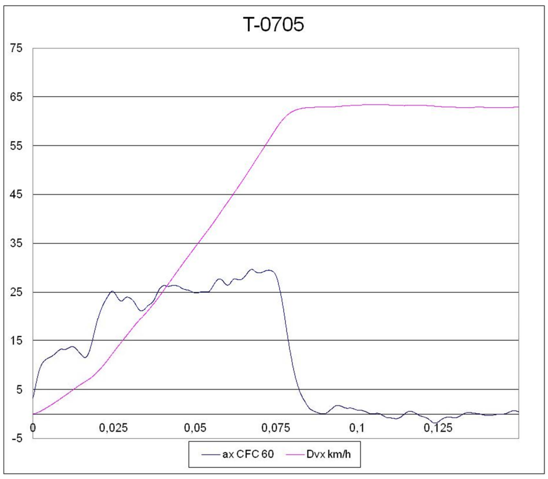

Figure A3. T-0705 US-NCAP (56 km/h)

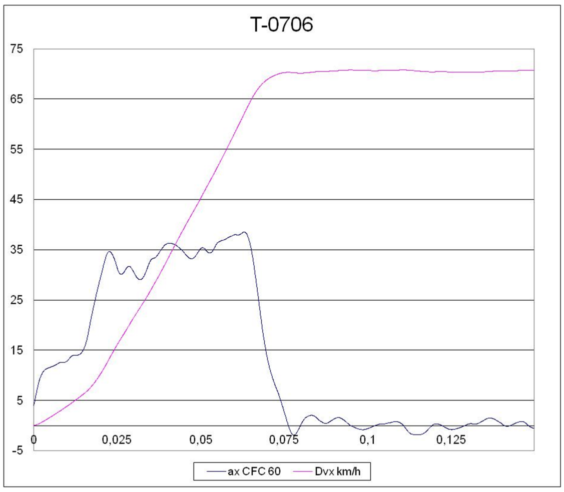

Figure A4. T-0706 (modified US-NCAP)

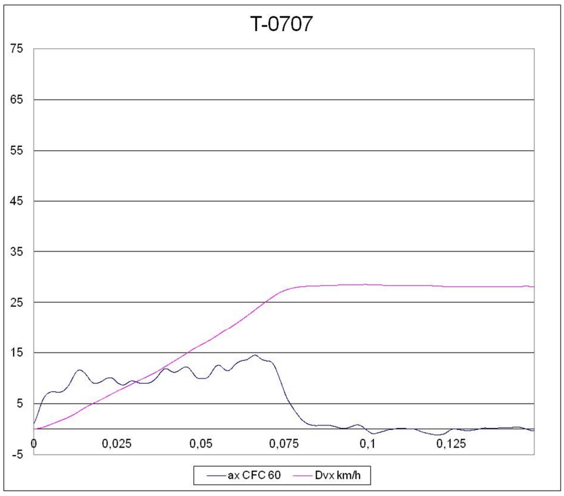

Figure A5. T-0707 (modified EuroNCAP)

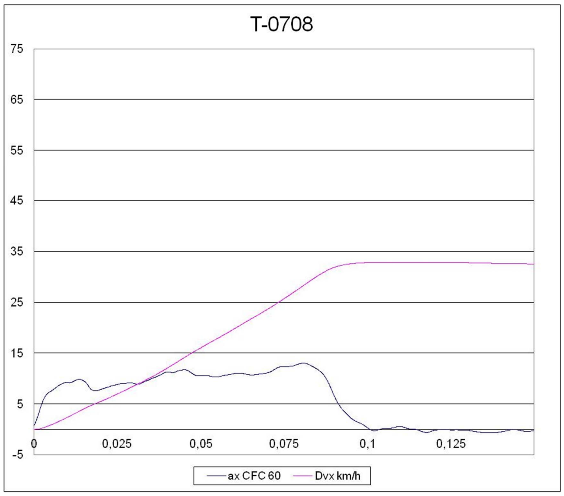

Figure A6. T-0708 (modified EuroNCAP)

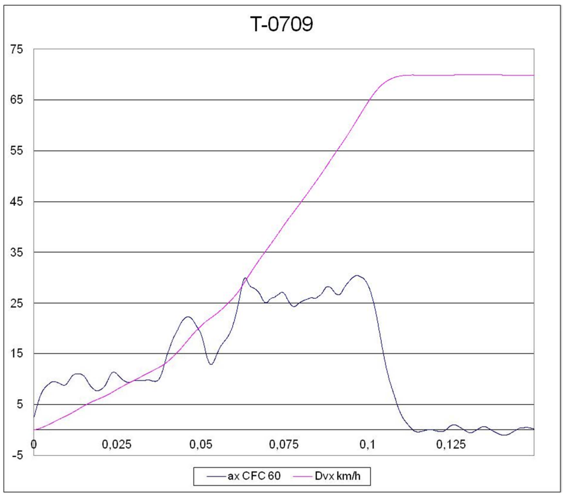

Figure A7. T-0709 EuroNCAP (64km/h)

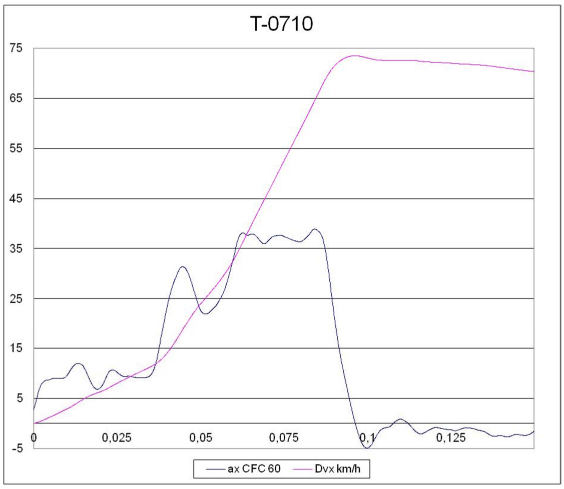

Figure A8. T-0710 (modified EuroNCAP)

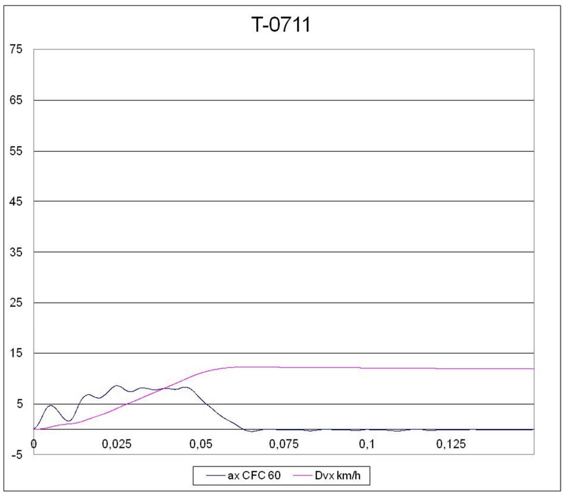

Figure A9. T-0711

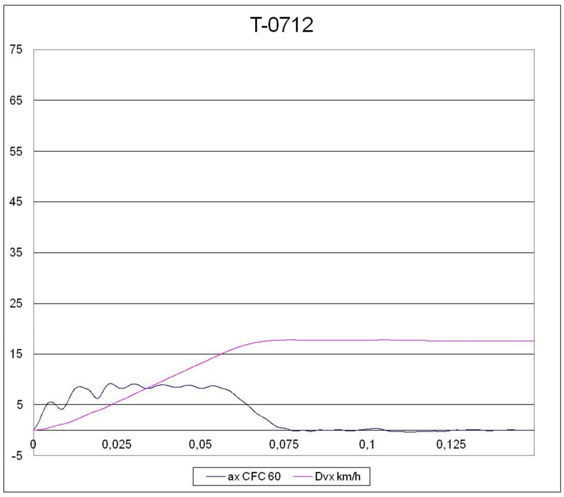

Figure A10. T-0712

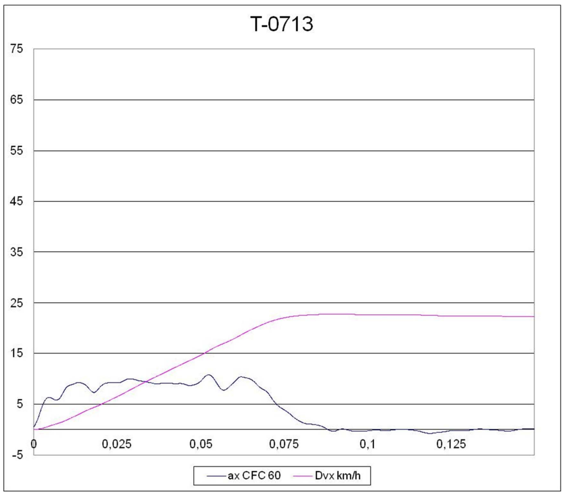

Figure A11. T-0713

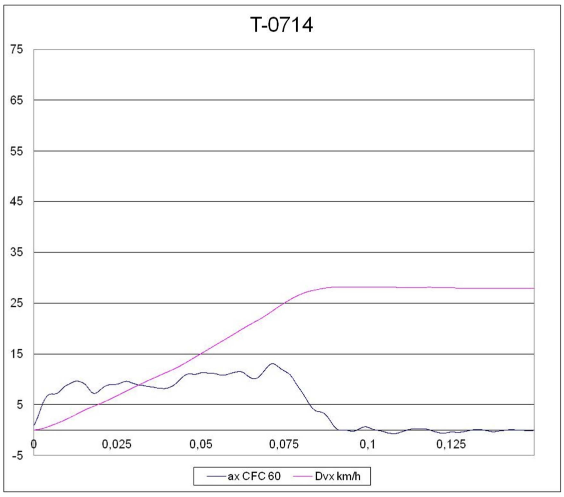

Figure A12. T-0714

APPENDIX B

Random errors for each tested ECR device.

Table B1. Random error delta-V- longitudinal

	T-0703	T-0704	T-0707	T-0708	T-0714	T-0711	T-0712	T-0713	T-0705	T-0706	T-0709	T-0710
Lab	28.2	33.3	28.2	32.8	28.1	12.3	17.7	22.7	62.8	70.3	69.9	73.5
ECR1	28.2	33.4	28.0	33.1	28.6	12.5	17.5	23.3	62.6	70.2	69.3	72.8
ECR2	27.9	33.2	28.3	33.5	27.7	12.1	17.3	22.2	60.7	69.9	67.7	73.9
ECR3	28.3	33.2	28.8	33.3	28.7	12.4	17.3	22.7	61.4	70.6	67.5	72.4
ECR4	28.9	33.9	28.4	32.8	27.5	12.0	17.7	23.0	60.5	70.1	68.6	74.0
ECR5	28.2	34.1	27.1	32.6	28.1	12.2	17.5	22.6	63.8	70.6	69.9	73.5
Mean	28.3	33.5	28.1	33.0	28.1	12.2	17.5	22.7	61.8	70.3	68.6	73.3
Var	0,1	0,2	0,4	0,1	0,3	0,0	0,0	0,2	1,9	0,1	1,0	0,5
Std Dev	0,3	0,4	0,6	0,3	0,5	0,2	0,2	0,4	1,4	0,3	1,0	0,7
Std Dev(%)	1.2	1.3	2.3	1.1	1.8	1.8	0.9	1.9	2.2	0.5	1.5	0.9

Table B2. Random error delta-V - lateral

	T-0703	T-0704	T-0707	T-0708	T-0714	T-0711	T-0712	T-0713	T-0705	T-0706	T-0709	T-0710
Lab	28.2	33.3	28.2	32.8	28.1	12.3	17.7	22.7	62.8	70.3	69.9	73.5
ECR1	29.2	34.3	28.7	34.5	29.0	12.7	17.6	23.2	60.2	71.1	64.3	-
ECR2	28.4	34.5	28.7	33.7	29.1	12.7	18.0	23.6	63.5	70.9	70.0	-
ECR3	29.1	-	28.9	34.0	28.8	13.0	17.7	23.6	64.4	70.8	67.9	-
ECR4	28.5	34.3	28.7	33.4	28.8	12.8	18.2	23.7	61.7	70.0	62.4	-
ECR5	28.7	34.6	28.7	33.7	28.8	12.7	-	23.4	63.5	68.9	57.8	-
Mean	28.8	34.4	28.7	33.8	28.9	12.8	17.9	23.5	62.7	70.4	64.5	
Var	0.1	0.0	0.0	0.2	0.0	0.0	0.1	0.0	2.9	0.8	22.7	
Std Dev	0.4	0.1	0.1	0.4	0.1	0.1	0.2	0.2	1.7	0.9	4.8	
Std Dev(%)	1.3	0.4	0.4	1.2	0.4	1.2	1.3	0.9	2.7	1.3	7.4	

Table B3. Random error mean acceleration - longitudinal

	T-0703	T-0704	T-0707	T-0708	T-0714	T-0711	T-0712	T-0713	T-0705	T-0706	T-0709	T-0710
Lab	11.1	13.1	9.6	9.5	8.8	5.7	6.8	7.7	20.7	26.3	17.7	21.6
ECR1	10.5	12.8	9.6	9.4	8.7	5.5	6.4	7.1	19.9	25.5	17.1	21.2
ECR2	9.8	12.9	9.0	9.4	8.6	5.4	6.5	7.3	19.2	25.4	17.1	21.3
ECR3	10.7	12.9	9.6	9.4	8.7	5.4	6.3	7.4	19.7	25.7	17.0	21.2
ECR4	10.5	13.0	9.0	9.3	8.4	5.3	6.5	7.5	19.2	25.5	17.0	21.6
ECR5	9.9	13.2	8.7	9.1	8.8	5.3	6.4	7.5	20.1	25.3	17.4	21.4
Mean	10.3	13.0	9.2	9.3	8.6	5.4	6.4	7.4	19.6	25.5	17.1	21.3
Var	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Std Dev	0.4	0.2	0.4	0.1	0.1	0.1	0.1	0.1	0.4	0.1	0.2	0.2
Std Dev(%)	4.2	1.3	4.3	1.6	1.6	1.5	1.3	2.0	2.1	0.5	1.0	0.7

Table B4. Random error mean acceleration - lateral

	T-0703	T-0704	T-0707	T-0708	T-0714	T-0711	T-0712	T-0713	T-0705	T-0706	T-0709	T-0710
Lab	11.1	13.1	9.6	9.5	8.8	5.7	6.8	7.7	20.7	26.3	17.7	
ECR1	10.7	13.1	9.2	9.6	8.5	5.5	6.4	7.5	18.7	25.4	15.6	
ECR2	10.6	13.2	9.3	9.3	8.7	5.4	6.4	7.6	19.9	25.7	17.2	
ECR3	10.7	-	9.4	9.5	8.8	5.6	6.4	7.6	20.2	25.7	16.6	
ECR4	10.9	13.0	9.1	9.3	8.7	5.5	6.7	7.6	19.6	25.1	15.4	
ECR5	10.5	13.1	9.2	9.4	8.7	5.4	-	7.6	19.7	25.0	14.5	
Mean	10.7	13.1	9.3	9.4	8.7	5.5	6.5	7.6	19.6	25.4	15.8	
Var	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.1	1.2	
Std Dev	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.6	0.3	1.1	
Std Dev(%)	1.2	0.7	1.2	1.5	1.1	1.3	1.8	0.6	3.0	1.4	6.8	

Table B5. Random error peak acceleration - longitudinal

	T-0703	T-0704	T-0707	T-0708	T-0714	T-0711	T-0712	T-0713	T-0705	T-0706	T-0709	T-0710
Lab	15.9	23.1	14.5	13.0	13.1	8.6	9.1	10.7	29.7	38.5	30.5	38.9
ECR1	19.5	27.1	17.4	15.2	15.0	8.9	9.3	12.7	33.8	41.3	32.3	39.9
ECR2	16.2	27.6	15.8	15.2	14.9	8.4	9.3	11.4	31.3	39.4	33.0	40.4
ECR3	18.2	27.2	18.3	14.7	14.5	8.3	9.0	11.9	30.2	39.4	33.7	39.7
ECR4	17.5	26.8	15.2	15.0	14.6	8.4	9.1	12.7	30.4	40.3	32.8	42.1
ECR5	16.8	27.5	15.1	15.0	15.4	9.1	9.4	12.3	36.9	38.1	33.1	41.0
Mean	17.6	27.3	16.4	15.0	14.8	8.6	9.2	12.2	32.5	39.7	33.0	40.6
Var	1.7	0.1	2.0	0.0	0.1	0.1	0.0	0.3	8.2	1.4	0.3	0.9
Std Dev	1.3	0.3	1.4	0.2	0.3	0.4	0.1	0.6	2.9	1.2	0.5	1.0
Lab	7.3	1.2	8.6	1.5	2.3	4.4	1.5	4.7	8.8	3.0	1.5	2.4

Table B6. Random error peak acceleration - lateral

	T-0703	T-0704	T-0707	T-0708	T-0714	T-0711	T-0712	T-0713	T-0705	T-0706	T-0709	T-0710
Lab	15.9	23.1	14.5	13.0	13.1	8.6	9.1	10.7	29.7	38.5	30.5	
ECR1	17.7	26.5	15.2	14.5	13.5	8.8	9.3	12.2	29.7	38.9	31.2	-
ECR2	16.4	26.4	15.2	14.2	13.9	8.8	9.4	12.3	31.7	39.0	29.7	-
ECR3	17.7	-	15.1	14.4	14.3	9.5	10.6	11.7	31.9	38.9	32.7	-
ECR4	17.3	23.9	14.7	14.4	14.7	8.7	11.4	12.2	29.7	38.8	31.4	-
ECR5	16.4	25.1	16.0	13.6	14.4	8.9	-	11.7	30.3	40.8	31.6	-
Mean	17.1	25.5	15.2	14.2	14.1	8.9	10.2	12.0	30.6	39.3	31.3	
Var	0.4	1.6	0.2	0.1	0.2	0.1	1.0	0.1	1.1	0.7	1.2	
Std Dev	0.6	1.2	0.4	0.3	0.5	0.3	1.0	0.3	1.1	0.8	1.1	
Std Dev(%)	3.8	4.9	2.9	2.4	3.2	3.5	9.8	2.4	3.5	2.2	3.4	