THE VOLVO DIGITAL ACCIDENT RESEARCH RECORDER (DARR) CONVERTING ACCIDENT DARR-PULSES INTO DIFFERENT IMPACT SEVERITY MEASURES

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ABSTRACT

A crash recorder function is included in the airbag sensor in Volvo cars. The recorder's performance is validated in laboratory tests. In accidents with airbag deployment the impact data is stored in a memory. So far, about 250 accident impact pulses have been collected, 32 of these were selected for further study. Analysis of the pulses offers new insights on the collision dynamics. Impact severity indices were studied. Data now permits a comparison between occupant simulation models and several violence descriptors. Even if actual injuries are too limited to permit a deeper analysis now, it is expected that in the future the results will increase the knowledge of the relationship between impact severity and occupant injury.

WHEN ANALYSING ACCIDENT DATA, it is important to be able to define the violence to which the occupant has been exposed in a given situation. This is a highly complex concept and is difficult to describe in a clear-cut manner. A host of different factors affect the injury mechanism to which the occupant is subjected. With a good impact severity descriptor, it would be possible to establish functions which could describe different types of injury risk for different levels of impact severity. This is of great importance in the development work on car safety systems, where methods of correlating accident data with laboratory data are used (Korner, 1989; Norin and Isaksson-Hellman, 1992).

In early 1994 Volvo began installing the Volvo Digital Accident Research Recorder (DARR) as a standard function in the airbag sensor of Volvo cars. This was undertaken to make possible an increased quality in Volvo's continuing safety studies of accidents. The recorded deceleration impact pulse from the DARR is expected to provide better impact severity parameters.

In this report some details on the crash recorder are presented. This is followed by an account of possible severity measures. Severity descriptors are compared with each other and with response data from occupant simulation models. Results from a number of analysed accident cases are presented. Actual injury data for the sample of accidents are too low and too few to permit meaningful comparisons with occupant simulation models.

In agreement with a draft ISO Standard on Terminology for Traffic Accident Analysis (ISO/DIS 12353-1) we shall use the term <u>impact severity</u> instead of the sometimes used term <u>crash severity</u>. A <u>crash</u> is considered by this ISO Standard to include a somewhat longer time span than the actual impact.

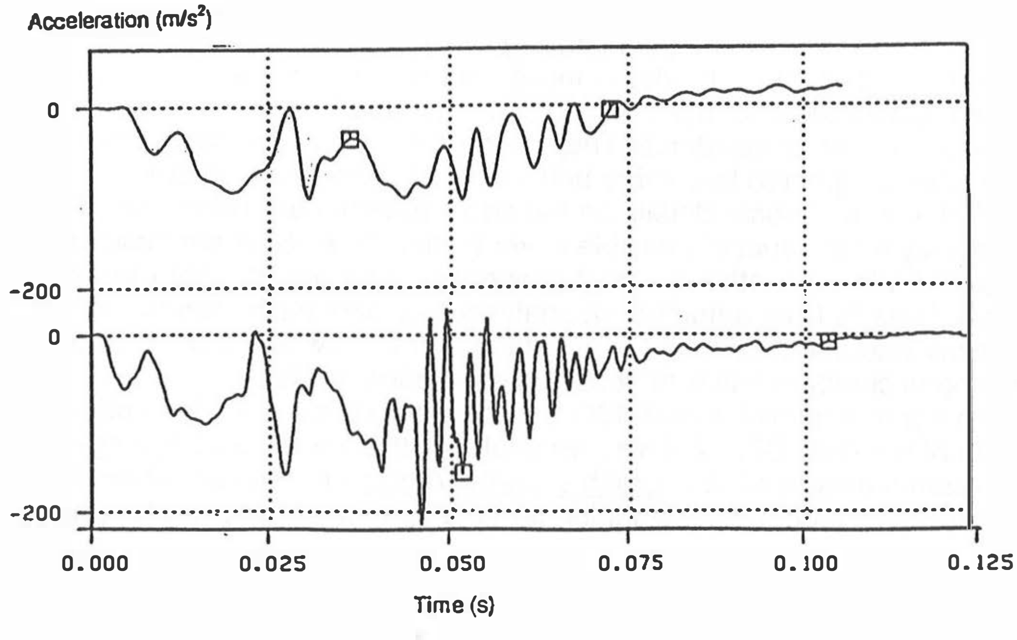
VALIDATION OF MEASUREMENT PERFORMANCE

Detailed information on the DARR device has been previously published (Norin et al., 1994; and slightly revised in Norin, 1995). In the case of a frontal collision where the airbag deploys, the DARR records the longitudinal deceleration pulse. The measurement range is just above ±400m/s^2 and the recording starts at the first instant of the collision. The data comprises 64 digital samples, starting with four pre-trigger samples prior to the actual deceleration pulse. Originally, the recording duration was 107 ms; this has later been expanded to nearly 180 ms (in both cases 64 samples). The design will, no doubt, undergo more modifications in the future.

VALIDATION TESTS - Augmenting the existing airbag sensor with a new software module was an easy way to get a crash recorder function from an already designed reliable electronic unit. However, its circuitry was never intended nor optimised for crash recorder use. Therefore, the new added function required some validation testing. The tests were run by having extra DARR units installed in a number of ordinary car bodies during the normal laboratory programme of impact tests and Hyge sled tests. The DARR pulses from these tests were compared with the more accurate laboratory accelerometer signals. Some findings from the analyses are as follows.

COMPARING DARR SIGNALS WITH REFERENCE SIGNALS - The deceleration signals from the DARR, $a_D(t)$, and from the reference accelerometer, $a_N(t)$, contained vibratory components of dissimilar appearance, see Figure 1. This is due to differences in design and mounting of the transducers and in channel bandwidths. Details about these vibrations are of less interest here.

Figure 1. Signals from the DARR and laboratory accelerometers, recorded during an impact test. The difference in vibration effects from the different accelerometer mountings can be clearly seen. Due to different recording media, the time synchronisation is not perfect between the two signals.



For the comparison we instead use the integral of the acceleration a(t), written $\Delta v(t)$, i.e. the instantaneous velocity change during the collision event.

$$\Delta v(t) = \int_{t=0}^{t=t} a(t)dt$$

Comparing two signals, i.e. $\Delta v_D(t)$ and $\Delta v_N(t)$, results in a difference signal $\Delta v_{diff}(t)$, also comprising 64 samples:

$$\Delta v_{diff}(t) = \Delta v_D(t) - \Delta v_N(t)$$

A correction, i.e. a polarity reversed error signal, can be added to $\Delta v_D(t)$ to reduce the difference. Let the correction be some function, preferably dependent on the recorded velocity, i.e. $\mathbf{h}[\Delta v_D(t)]$.

$$\Delta v_{diff}(t) = \Delta v_D(t) + \mathbf{h}[\Delta v_D(t)] - \Delta v_N(t)$$

The actual function **h** might be a constant, or a time varying signal, or some amplitude non-linearity, or something else. A suitably designed **h** will yield a small difference signal $\Delta v_{diff}(t)$. By fine-tuning **h** the difference could be minimised in some suitable sense. We have chosen to convert $\Delta v_{diff}(t)$ into a convenient single-valued variable $\Delta v_{diffrms}$ representing the difference between the two signals.

$$\Delta v_{diffrms} = \sqrt{\frac{\sum_{i=1}^{64} \Delta v^2_{diff}(t_i)}{64-1}}$$

A profitable strategy for the design of the function **h** would be to select models applicable to some of the known shortcomings of the DARR circuits. Such models have been successfully tried as described below. They have yielded good fits, and the difference between $\Delta v_D(t)$ and $\Delta v_N(t)$ has decreased markedly. The goodness of fit is indicated by the ratio $\Delta v_{diffrms} / \Delta v_{max}$ which on most occasions is found to be less than 0.01.

The piezoelectric decay - A piezoelectric accelerometer has inherently no DC response. This manifests itself as a decaying signal in the case of long duration pulses, Figure 2. The decay comes from a discharge process in the piezoelectric material, its *time constant* is in our case specified at nominally 0.16 seconds. The effect in the case of actual acceleration pulses can be seen in Figure 3. According to electrical circuit theory a compensation can be arranged according to the formula:

$$a_{true}(t) = a_D(t) + \frac{1}{T} \int_{\tau=0}^{\tau=t} a_D(\tau)d\tau$$

where T is the above mentioned time constant. See Warner et al. (1986) for further explanation of the formula and its adaptation to sampled signals. The effect is also described in many measurement textbooks and in product information from transducer manufacturers.

Figure 2. The application of a constant load F to a piezoelectric transducer produces a response u with a decay characterised by a *time constant* T. The e in the decay formula is the base for natural logarithms ≈ 2.718.

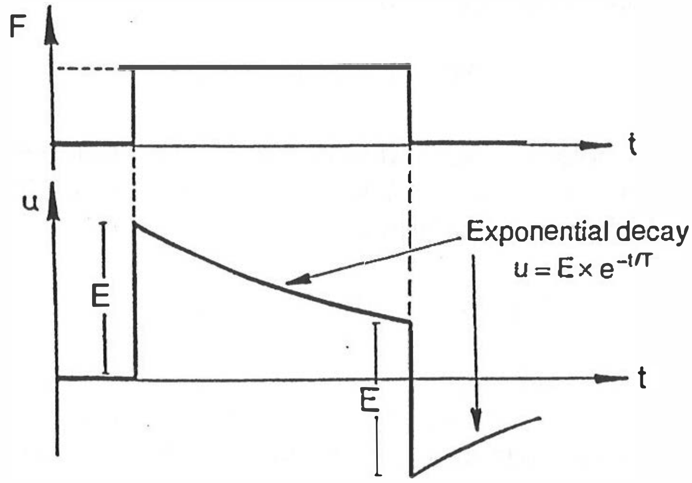
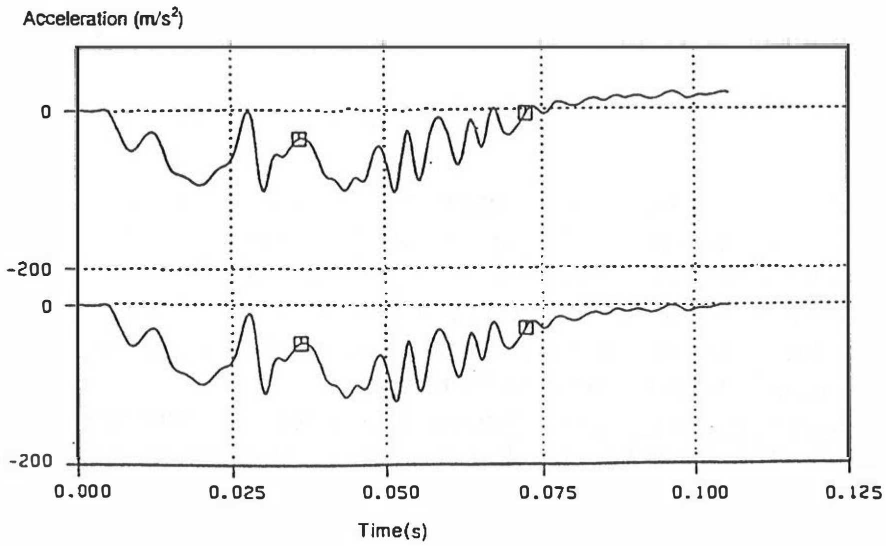


Figure 3. Signals from the DARR accelerometer, before and after correction for the piezoelectric decay.



The integral has been successfully employed as the corrective function **h**. For proper values of T, a good agreement has been found between the reference and the DARR accelerometer signals. The T values are fairly consistent over the range of tested DARR units; T = 0.13 s. The scatter among the tested units, expressed as two standard deviations, was ± 0.02 s.

Calibration uncertainty - The following formula contains a factor, ε, which accounts for the calibration uncertainty of individual units of the accelerometer and associated circuits.

$$a_{true}(t) = a_D(t) \times (1 + \varepsilon)$$

The manufacturer specified the gain uncertainty as $\varepsilon = \pm 0.12$. Data from a number of tested DARR units indicate a gain error ε of +0.03, and its uncertainty as $\pm$ 0.03 (two standard deviations).

Other signal anomalies have also been investigated, but are found to be of a non significant magnitude. Among these are a possible *non-linear amplitude response* (Bouche, 1979) in the DARR accelerometer, and *quantisation noise* in the analogue-digital conversion in the DARR.

CORRECTION OF FIELD DATA - The above-mentioned studies have provided corrections factors which are applied to all collected DARR data, giving the recorded impact pulse and velocity change a "best value". When receiving field data from DARR units we do not usually have access to individual values for T and ε. In these cases a "cover-all" combined value for T and ε is used.

LIMITED ACCURACY - The accelerometer is only sensitive to truly longitudinal accelerations. Therefore information from oblique collisions is less reliable. The laboratory crashes have shown that impact velocity and offset and oblique impacts affect the accuracy of the measured pulses. There is a continuous programme going on to increase our know-how on the involved factors.

IMPACT SEVERITY

EARLY IMPACT SEVERITY MEASURES - Over the years many methods for defining impact severity have been presented. The severity descriptors have undergone a development from simple to complex (and more accurate) measures. In the early days, the severity report was just a notation about a probable speed. Later, the vehicle damages could, via some more or less elaborate energy absorption models, be converted to an equivalent velocity. For more details see Norin (1995).

The severity descriptors, often single-valued numbers, do seldom address the temporal aspect of the impact event. These severity measures apply mainly to the "first collision" , i.e. when the car hits an obstacle. They are not accurate descriptors for the "second collision", i.e. the event when the occupants are exposed to forces arising from their sudden interaction with the interior structures (including restraint systems) of the car. It is the second collision which inflicts injuries to the occupants. The uncertain correlation between the impact severity measure and the injuries yield inaccurate or uncertain occupant injury risk functions. The lack of injury risk functions makes the development of better protection systems difficult. (Korner, 1989)

IMPROVED SEVERITY MEASURES - It is possible to study the temporal aspects of the impact if there is some kind of crash recorder in the vehicle, registering the acceleration/deceleration pulse during the impact. Given the impact pulse, the characteristics of the car body, and some simulation software, we will be in the position to get much more know-how about the violence to the occupant. And, in the end, also provide improved injury risk functions.

DATA FOR TWO INTERESTS - The collection of accident data serves at least two interests. Firstly, the frequency of different accidents influences the setting of priorities for injury reduction programmes. Secondly, each accident is unique, and each new accident might have a new lesson to teach about safety. Mainly for the first application, but also for the second one, the accident data has to be stored in data bases after some quality checks and normalisation. The impact severity measure is concealed in the DARR impact pulse, therefore, some data reduction is necessary in order to make a classification possible.

CLASSIFYING DATA

When classifying impact severity two descriptors are generally used: 1) some measure of violence, and 2) particulars about the event, such as: impact direction, impact point, and collision object. Classification of those data usually follows already established practices. But the time history of the impact pulse must find some suitable practice, not yet standardised.

The visual shape of the pulse could suggest some ad-hoc classifications: flat, peaked, symmetric, skewed, smooth, jagged, interrupted, etc. But the availability of numerical information from the pulse data deserves something more quantitative and objective.

Some suitable guide-lines are presented in a report by Huang et al. (1977): "- - the general requirement was that of characterizing the vehicle deceleration time history with the smallest number of parameters necessary to adequately evaluate occupant response." Additionally, the characterising parameters should be defined by familiar physical quantities.

At the present stage in our programme, we are not able to establish *The Best Impact Severity Descriptor* for an impact pulse. Instead we have decided to use, tentatively, a small assortment of pulse descriptors. Time will reveal which descriptors are the most useful.

A minimised number of parameters shall tell something about the acceleration (indirectly the energy) and its temporal history. This speaks for a substantial reduction of the data in the impact pulse. Some examples, without and with time history, follow. Most of the examples we mention will be used in our subsequent analysis.

SINGLE-VALUED SEVERITY MEASURES, WITHOUT TIME HISTORY- Lundell (1984) considered the integral of the impact pulse, i.e. the velocity change, $\Delta v(t)$, to be a more accurate description than the acceleration pulse. Since many years, the maximum velocity change, Δv_{max}, is an established impact severity descriptor.

The velocity change divided by the pulse length is the mean acceleration, mγ (mean gamma), which is another descriptor advocated by Thomas (1984). The time duration is involved in this case, but the time history of the violence does not affect this severity descriptor.

For comparison purposes we shall also use another single-valued measure, although it is not derived from the impact pulse. Instead it is an energy absorption impact severity descriptor, the EBS (Equivalent Barrier Speed). The vehicle deformation is determined from photographs, and energy absorption characteristics have been determined by laboratory tests. This data makes possible the determination of an approximate Δv_{EBS}. (Magnusson and Jörgensson, 1987)

A quite new, single-valued, violence indicator is the time it takes for the airbag sensor to decide that an increasing deceleration pulse is severe enough to warrant a deployment. The shorter the time is, the more severe is the initial part of the crash pulse. This time is called trigger time (here denoted TT) and is stored in the sensor as a record from the deployment algorithm. This variable is completely insensitive to the remainder of the crash pulse. Since the deployment is decided by a vehicle tailored decision algorithm, this variable can never be used as a global violence measure. However, when comparing crash data from vehicles of the same type this parameter might be of some value.

MULTIPLE-VALUED SEVERITY MEASURES, BASED ON TIME HISTORY - The Δv_{max} and mγ are still single-valued numbers, although now possible to determine with better precision than previously. Some more elaborate models are as follows.

Huang et al. (1977) propose two possibilities. One is to replace the deceleration pulse with a few straight lines, a "Tipped Equivalent Square Wave". Another is to represent the impact pulse with a few superimposed harmonic sine pulses taken from a Fourier series approximation of the deceleration pulse.

Brodén and Olsson (1996) at Volvo experimented with different representations of some DARR pulses. One approach was to approximate the velocity change history with a number of straight line segments, each segment requiring two characteristic parameters (amplitude and time). The original and the approximated pulse shapes were used as inputs to a MADYMO occupant simulation model. The occupant's accelerations and HIC responses were compared for the different cases. Roughly, at least six straight line segments (twelve parameters) were needed before an acceptable comparison was achieved.

Brodén and Olsson also tried a smoother approximation. As an alternative to Huang's suggested Fourier series, simple polynomial approximations of different degrees were tried. In the studied cases a polynomial of already the third degree seemed a sufficiently good approximation of the impact pulse. For engineering purposes we determine the polynomial's maximum deceleration and the time of its occurrence (called MD and TMD), and use them as complementary descriptors to the Δv and mγ.

COMPLEX FILTERING - Another approach is possible for estimating the impact severity. Instead of just smoothing the deceleration pulse one can send the pulse through a lowpass filter with a substantially lower bandwidth than recorded. With the proper filter characteristic this would be an approximation of a physical system comprising: the car body, the interior padding, the seat, the restraint system and the occupant. The output from the filter would be the acceleration experienced by the occupant.

As a first attempt one could use a standardised filter like the J-211 series (SAE, 1995), if the cut-off frequency is set sufficiently low. An engineering and biomechanical interpretation of the output is, however, not easy to establish.

A better approach is to model a simplified physical system. One such one-dimensional model, used at Volvo and called Pulse Index, is as follows. A mass of 75 kg is restrained by a spring element with a stiffness corresponding to the average force vs. displacement characteristic of (for instance) a belt system. A slack in the system permits the mass to move, say, 10 cm before the spring is engaged. The input to this model is the impact pulse of a vehicle. The output is a delayed, smoothed and attenuated deceleration pulse for the mass. Its peak value is used as a severity indicator.

A more advanced model is to use a MADYMO occupant simulation model (see for instance Prasad and Chou, 1993) of an occupant together with a suitable restraint system and a suitable vehicle body. The output is, again, delayed and attenuated deceleration pulses experienced by the dummy parts. In the present work we have used a MADYMO model comprising a two-dimensional model of a 50th percentile Hybrid-III crash test dummy. The dummy is positioned in the driver's seat of a Volvo 850 car, with seat belt pretensioner and airbag. The output is in our case an assortment of established injury criteria for the dummy.

The two latter models are, however, more representative for the "second collision". It could be argued whether the occupant responses could be regarded as measures describing the severity of an impact.

COLLECTION OF CRASH RECORDER DATA

To acquire knowledge about the correlation between violence and injuries, as well as the effectiveness of different occupant protection systems, Volvo has been collecting crash data from accidents involving Volvo cars since 1970 (Norin and Korner, 1985).

Volvo's ongoing accident data collection now also includes collection of DARR pulses (Norin et al., 1994). Until now, 250 DARR pulses have been collected. Since 1996 Volvo's running DARR pulse collection activity has been enlarged with co-operation with Volvia's insurance inspectors in the west of Sweden. This will soon be expanded to cover all Sweden. The insurance inspectors collect and regularly transfer the DARR pulses via diskettes to the Volvo Safety Centre. The pulse data can later on be stored in Volvo's accident data base and linked to other information about the accident, received through Volvo's existing accident data collection scheme.

Through the co-operation with Volvia and because of an increasing number of Volvo cars containing DARR, we expect an inflow of some 700 crash recordings per year when the programme has reached its full size.

CONTROL OF RECEIVED DATA

All incoming pulses must undergo a control process where the pulse is classified according to impact type and quality of the pulse. Two controls are performed to qualify the pulses for further use in research analyses.

IMPACT TYPE - As described earlier, the accelerometer is only sensitive in longitudinal acceleration. Therefore all DARR pulses must be identified with regard to the type of impact that has generated the pulse, i.e. to decide the influence of crosswise acceleration, oblique impact, deformation of compartment structure. All to ensure that the impact severity measures are used in the correct way when they are linked to occupants' injuries.

RECORD DURATION - Pulses are characterised by the recorded duration of the pulse. The record duration has recently been extended to nearly 180 ms, but most collected pulses still have a duration of 107 ms (first DARR version). Some pulses are even shorter in those cases where a loss of electrical power occurred during the impact.

When the pulses have been controlled, different impact severity measures can be calculated and the pulse data stored in a data base.

SELECTION OF CASES FOR ANALYSES

PURPOSE OF THE ANALYSIS - The present stage of the DARR programme mainly establishes procedures for the handling of incoming data. Several studies and analyses are performed to ensure suitable and efficient routines. The purpose of the present study was primarily to compare different impact severity measures with simulated dummy response. Secondly the purpose was to gain a better understanding for the time history of the deceleration of the pulse shape.

Today our accident material still comprises too few traffic accidents containing a DARR pulse, especially at higher violence levels. Therefore it is yet hardly possible to establish a useful relationship between real-life injuries and various impact severity measures from the DARR pulse.

However, given the crash pulse from a particular crash, there is the possibility to expose a crash test dummy to the same deceleration pulse as in the accident. This simulation can be done in a computer program. The dummy response gives an indication of the risk of injury for specific parts of the body, and the magnitude of these dummy parameters can then be linked to different impact severity measures from the pulse. When the number of accidents increases in the future, there will also be better opportunities to analyse possible correlations between dummy response and the real-life occupant injuries.

SELECTION OF CASES - All together there were 250 DARR pulses available.

<u>Selection due to impact conditions</u> - The control process reduced the number of pulses. When identifying impact type, only pulses from accidents with frontal impact were selected, where the main deceleration was in the longitudinal direction. All pulses selected for this analysis had a record duration of 107 ms. Pulses, where the records have been interrupted by loss of electrical power, were not used.

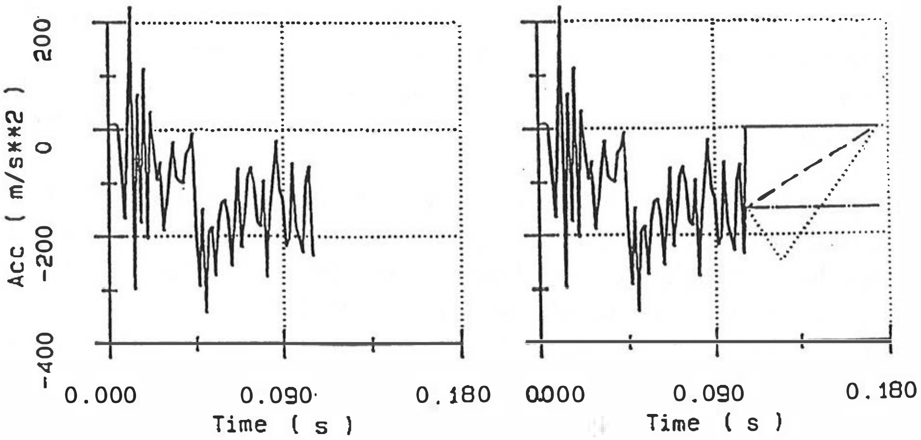
<u>Low speed limit</u> - The purpose of the DARR project is to find relations between impact severity and occupant injuries. One intended tool here is the use of a MADYMO simulated occupant. The available MADYMO model is validated only for velocity changes of 10 mph or above. Consequently, only DARR pulses for Δv_{max} at 4.4 m/s or more were selected. After the selection for this study, 32 pulses remained for analysis and simulation.

Short duration - Among the selected 32 cases, there are 22 pulses with substantial acceleration still after 107 ms. For such cases, we can only make a qualified guess, as to what the tails of these pulses might have looked. For some analyses, where the peak value of acceleration is of interest, we can usually disregard the values in the missing tail.

For analyses, where the total shape or the energy content of the pulse is of interest, we have to discard the interrupted pulses also. In these cases the remaining selection comprises 10 pulses.

The interrupted pulses - An evaluation was made on how different conceivable pulse tails (i.e. extensions to the interrupted pulses) would influence the simulated dummy responses. A number of interrupted pulses were studied. The original 107 ms pulses, were extended with four different theoretical tails each. (Figure 4).

Figure 4. The left diagram shows an impact deceleration pulse. Due to DARR limitations, the recorded pulse is interrupted at 107 ms. The right diagram shows the same pulse, extended with different theoretical tails.



The interrupted and the extended pulses were used as input data to the MADYMO occupant model. The selected output data from the model were:

- Cr - peak Chest resultant acceleration
- Hr - peak Head resultant acceleration
- HIC - Head Injury Criterion (36 ms time limitation)

These three parameters were chosen partly because they are easy to read out from the current MADYMO model and also because they are well established in the literature and in testing during vehicle development work.

The airbag triggering time, recorded with the DARR pulse, was used as trigger time for the protection systems in the MADYMO model.

Results - For each interrupted DARR pulse five tests were run, the original one plus the original one with four different extensions. The tests showed no serious change of the dummy acceleration responses (Cr and Hr) for the five different pulse endings. If the pulse has reached its maximum peak before 100 ms, it is very likely that the dummy responses also reach their highest values, irrespective of the acceleration magnitude in the pulse tail.

On the other hand, HIC values, calculated for interrupted pulses, show lower and misleading values; and the tests with extended pulses showed somewhat increased HIC values. This is understandable since the HIC algorithm takes regard to a window of acceleration values on both sides of the peak value, and this is sometimes affected by a interrupted tail after 107 ms.

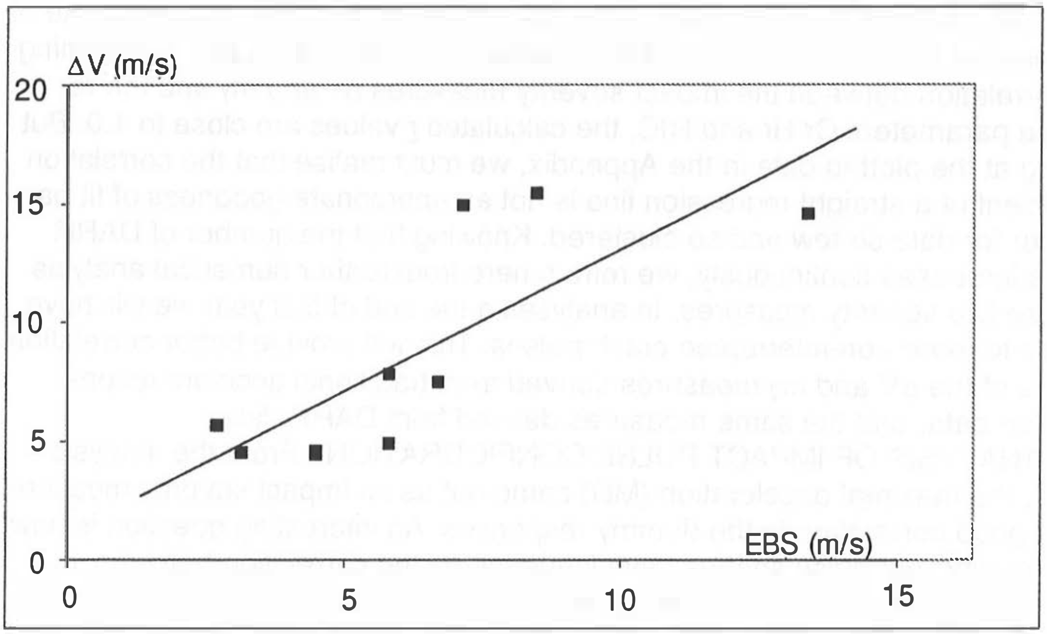
ANALYSIS OF CRASH DATA

To sum up, from the 250 available DARR crash pulses, 32 were selected as usable and relevant for this study. Among these, 10 pulses are faithfully recorded and finished within the available 107 milliseconds. The selected pulses will be studied and analysed in different aspects. The study is mainly done as a regression study. Sets of 32 (or 10) impact severity measures are compared pair-wise in a linear regression model. The correlation coefficient r is used as an indicator of similarity between the data sets.

CORRELATION OF IMPACT SEVERITY PARAMETERS - Four impact severity measures have been calculated from the selected DARR impact pulses. These are the maximal change of velocity (ΔV), the mean acceleration ($m\gamma$), the maximal deceleration (MD), (approximated by a least-square fitted 3rd degree polynomial) and the Pulse Index (see description under Complex filtering above). Furthermore the Equivalent Barrier Speed (EBS) was calculated from vehicle deformation data.

Those severity measures which are related to the total energy content of the pulse (ΔV, $m\gamma$) are of course more dependent on the presence of a proper energy containing tail. For the subset of 10 pulses the correlation between EBS and ΔV and $m\gamma$ is moderate: EBS vs. ΔV (r=0.79) (see Figure 5.) and EBS vs. $m\gamma$ (r=0.77). The 32 pulses yield EBS vs. MD (r=0.61).

Figure 5. Correlation of ΔV and EBS, r = 0.79



The somewhat lower agreement between the EBS measure and the measures derived from the DARR pulses is probably an indication of a real difference in the concept of severity measures. The EBS is a total energy measure, which can not discriminate between a peaked and a more flat pulse. However, the peak value in a pulse is decisive for the peak load exposure to the occupant. Furthermore, neither the pulse duration nor the triggering time has any influence on the EBS measure. Here we shall not analyse this any more, but we will certainly pay attention to these facts in our future work.

CORRELATION OF IMPACT SEVERITY PARAMETERS AND DUMMY RESPONSES - A MADYMO simulation was run for each of the 32 cases, using the recorded deceleration pulses and trigger times as input data. From the simulation data, the correlation between the impact severity parameters (MD, Pulse Index and EBS) and the dummy responses (Cr, Hr and HIC) were calculated, see Table 1. Graphs showing the data are presented in Appendix 1.

Table 1: Correlation $\underline{r}$ between impact severity parameters and dummy responses.

Severity parameter	Responses	Cr	Hr	HIC
MD		0.96	0.96	0.91
Pulse Index		0.96	0.95	0.93
EBS		0.56	0.55	0.46

It is seen that MD and Pulse Index show good correlations to all dummy responses in the analysis. Dummy peak accelerations, Cr and Hr, have higher correlation factors than HIC.

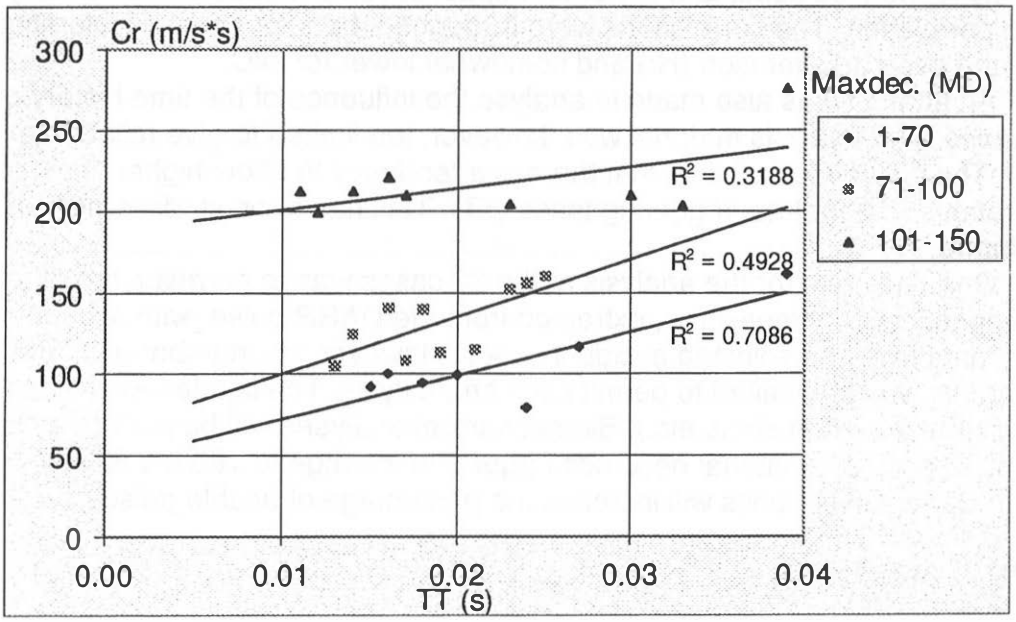
EBS exhibits, as previously, lower correlation factors. The previous note of the need for future studies of the EBS measure stands unchanged. Concerning the correlation between the impact severity measures Δv and $m\gamma$ and the response parameters Cr Hr and HIC, the calculated $\underline{r}$ values are close to 1.0. But looking at the plotted data in the Appendix, we must realise that the correlation coefficient of a straight regression line is not an appropriate goodness of fit parameter for data so few and so clustered. Knowing that the number of DARR pulses increases continuously, we refrain here from further numerical analysis of these two severity measures. In analyses a the end of this year we will have access to more non-interrupted crash pulses. This will provide better correlation studies of the ΔV and $m\gamma$ measures derived from traditional accident reconstruction data, and the same measures derived from DARR data.

ANALYSIS OF IMPACT PULSE CONFIGURATION - From the analysis above, the maximal deceleration (MD) came out as an impact severity measure with a good correlation to the dummy responses. An interesting question is now whether different pulse shapes have influence on the correlation between impact severity measures and dummy responses.

Even if the material for this type of analysis is still limited, an attempt was made to see whether there are any tendencies as to this question. The two parameters chosen for this analysis were the point in time for MD (i.e. TMD), and the airbag triggering point in time (TT).

The cases were divided into three groups of maximal deceleration (MD); 0-75 m/s², 76-100 m/s², and 101-150 m/s². For each group, Cr was plotted vs. TMD and TT respectively. No clear correlation between Cr and TMD could be found. But for TT there is a tendency to higher chest acceleration (Cr) for later TT, especially for the two lowest MD-levels, see Figure 6.

Figure 6. Chest peak resultant acceleration (Cr) vs. triggering time (TT) for different Maximal deceleration levels (MD).



The tendency for the peak chest acceleration to be dependent on the air-bag trigger time was analysed one step further. A more complex relation was tried:

$$Cr \approx a_0 + a_1 \times MD + a_2 \times TT + a_3 \times MD \times TT$$

This relation can, by regression, assume values for the constants a_0 a_1 a_2 and a_3 such as providing an r-value approaching 0.99. The physical interpretation of such a formula will be difficult, therefore such correlations will not be pursued further here.

SUMMARY

In this report the first experience from the Digital Accident Research Recorder (DARR) is presented. The techniques and characteristics of the DARR as well as the manner in which the data is collected and prepared for analysis is described earlier (Norin et al., 1994). This report describes the validation tests of DARR, and the quality control of incoming accident DARR data.

Different impact severity measures are also analysed in relation to MADYMO dummy responses.

Totally 250 accident cases where the DARR pulse was recorded were reported to Volvo's Accident Team. From these, 32 cases were selected for further analyses.

Different possible impact severity measures, extracted from the DARR pulse, were studied (ΔV, Mean acceleration, Maximal deceleration (MD) (approximated by a least-square determined 3rd degree polynomial). Additionally, EBS, calculated from the vehicle deformations, was included in the comparison.

These impact severity measures were correlated with dummy responses.

The result from this analysis showed that EBS had a low correlation to the dummy responses used, and the other impact severity measures had a fairly good correlation. The correlations were throughout best for chest acceleration (Cr) and head acceleration (Hr) and somewhat lower for HIC.

An attempt was also made to analyse the influence of the time history of the pulse. The analysis material was, however, too limited to give reliable results. The only observation is that there is a tendency to show higher chest accelerations (Cr) for later triggering times (TT). This has to be studied more in the future.

One early aim for the analysis of the 32 cases was to correlate the different impact severity measures, extracted from the DARR pulse, with occupant injury data from the selected accident cases. However, the number of injured occupants was too limited to permit such an analysis. The injuries were mainly minor (bruises, contusions etc.). Biomechanical analyses will be performed when the accident material becomes larger. The change to 180 ms pulse duration in newer DARR units will increase the percentage of usable pulses.

CONCLUSIONS

- The accident material, with relevant DARR data, is still too limited for reliable analysis. However, the analysis done indicate a promising future development of the use of DARR data.
- Further research must be done to develop impact severity measures from the DARR pulse, especially the influence of different pulse shapes on dummy responses and occupant injuries.
- There is a need for further dialogue between researchers about crash recorder data, to harmonise the development of impact severity measures.
- The present DARR configuration has a limited performance. It should be augmented to make possible the study of a wider spectrum of accidents.

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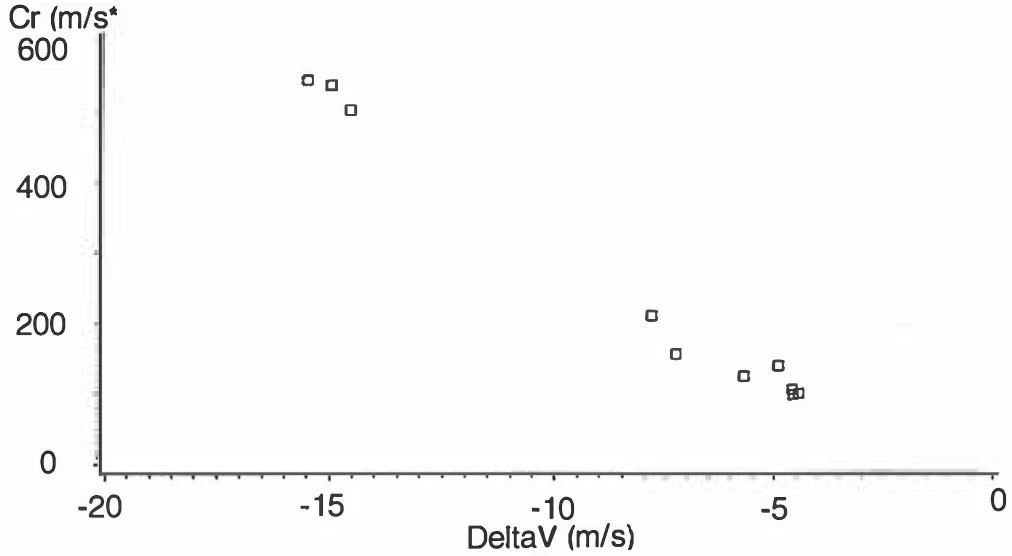
APPENDIX



Cr (m/s*
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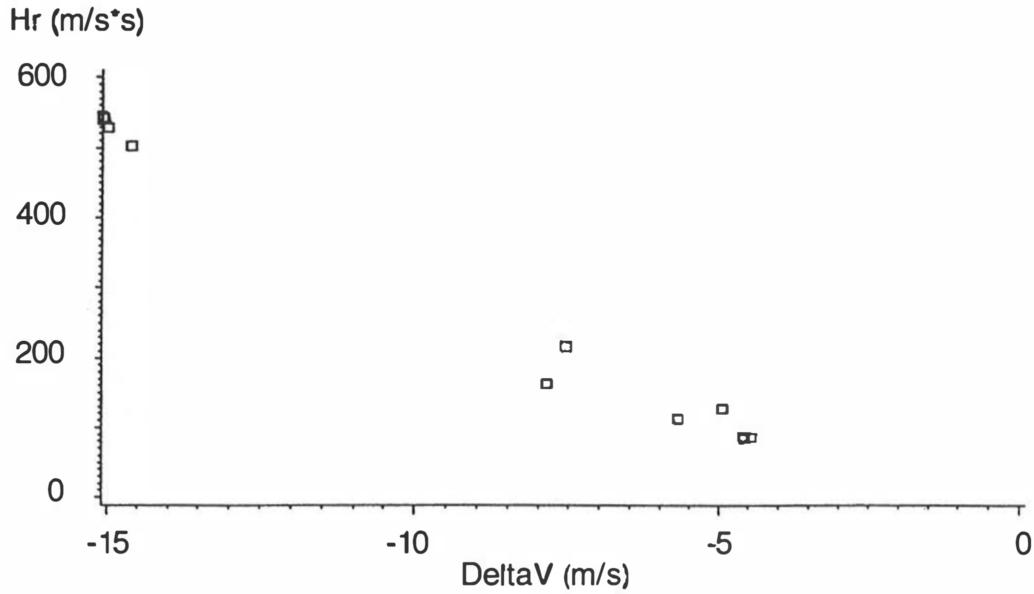
400
200
0
-20
-15
-10
-5
0
DeltaV (m/s)



Hr (m/s*s)
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400
200
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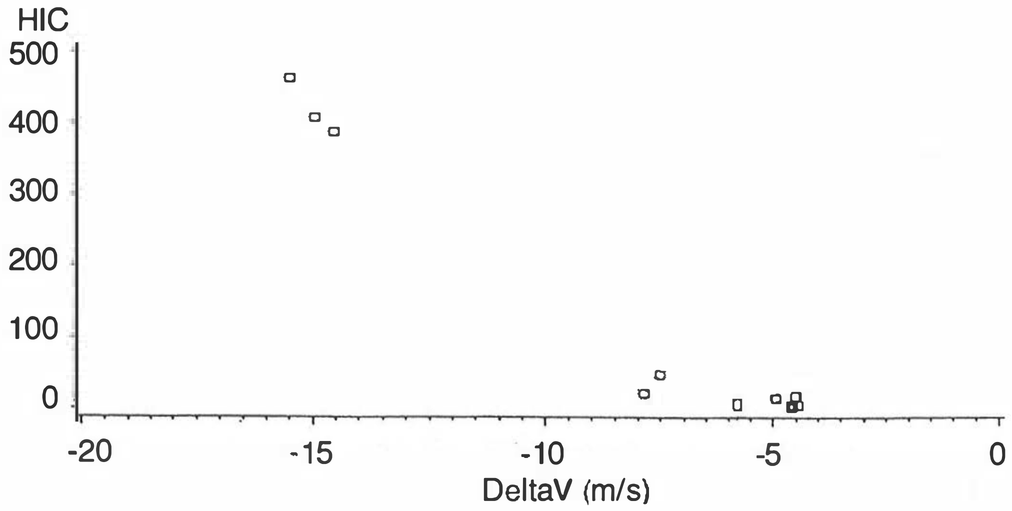
-15
-10
-5
0
DeltaV (m/s)



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400
300
200
100
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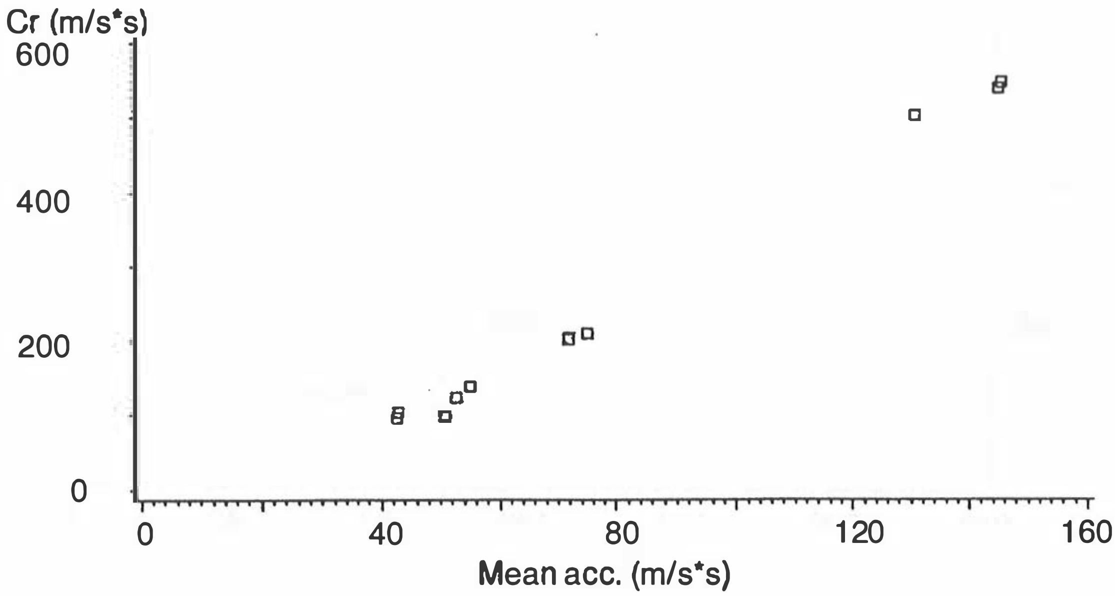
-20
-15
-10
-5
0
DeltaV (m/s)


Cr (m/s*s)
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400
200
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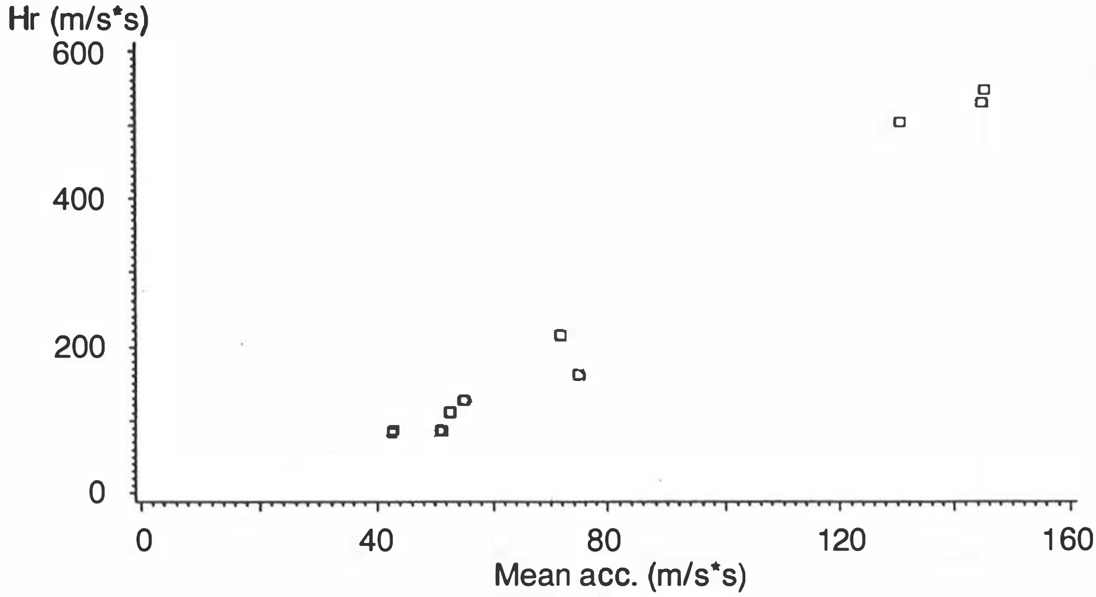
0
40
80
120
160
Mean acc. (m/s*s)


Hr (m/s*s)
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400
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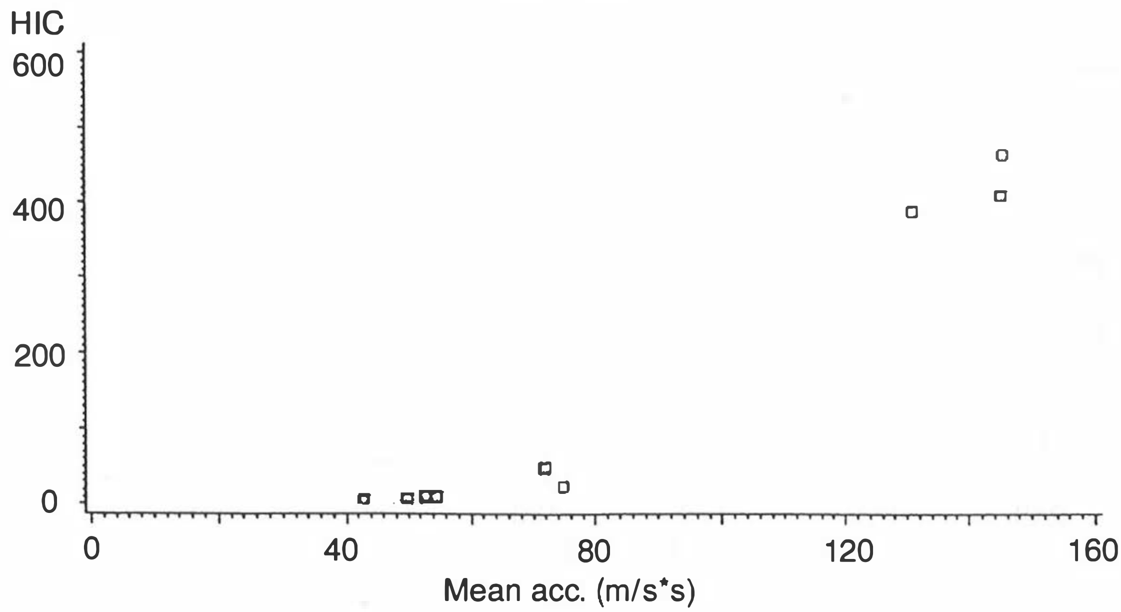
0
40
80
120
160
Mean acc. (m/s*s)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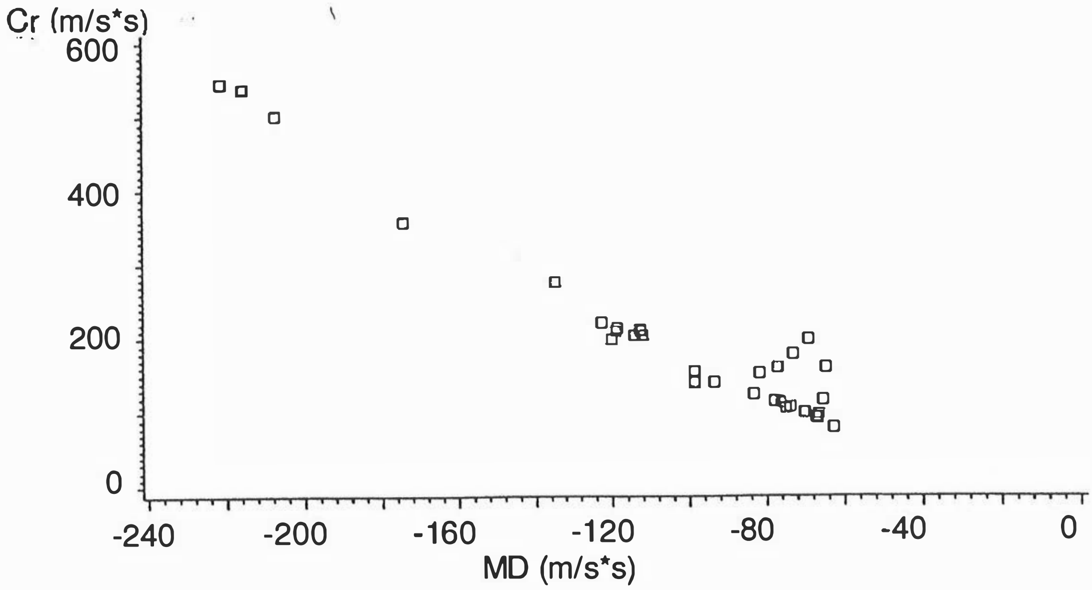
400
200
0
0
40
80
120
160
Mean acc. (m/s*s)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200
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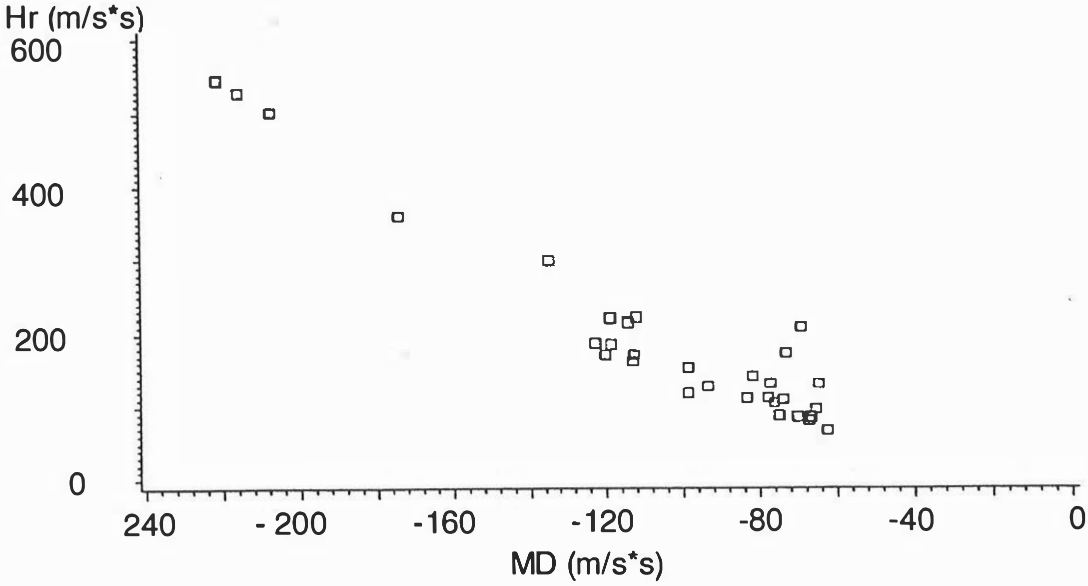
-160
-120
-80
-40
0
MD (m/s*s)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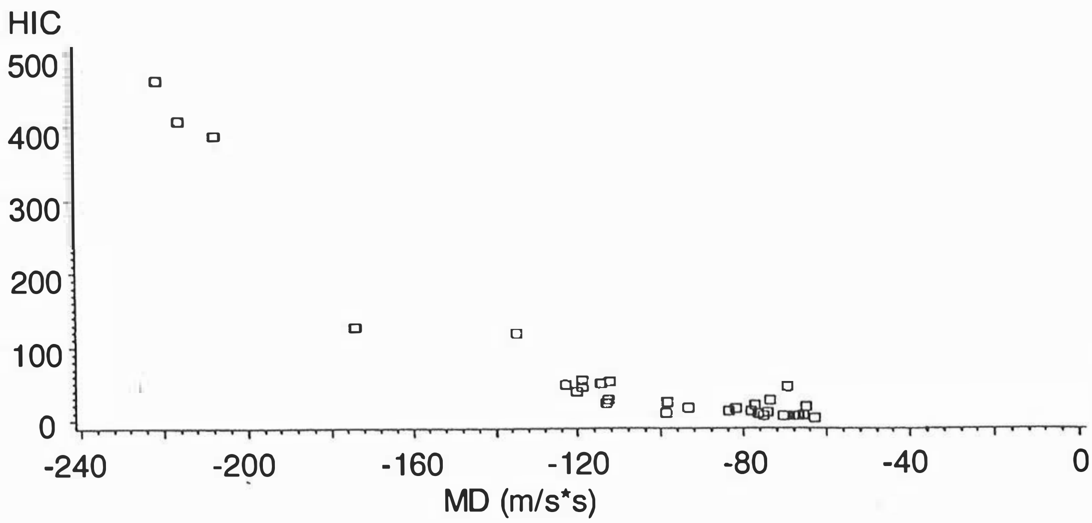
240
- 200
-160
-120
-80
-40
0
MD (m/s*s)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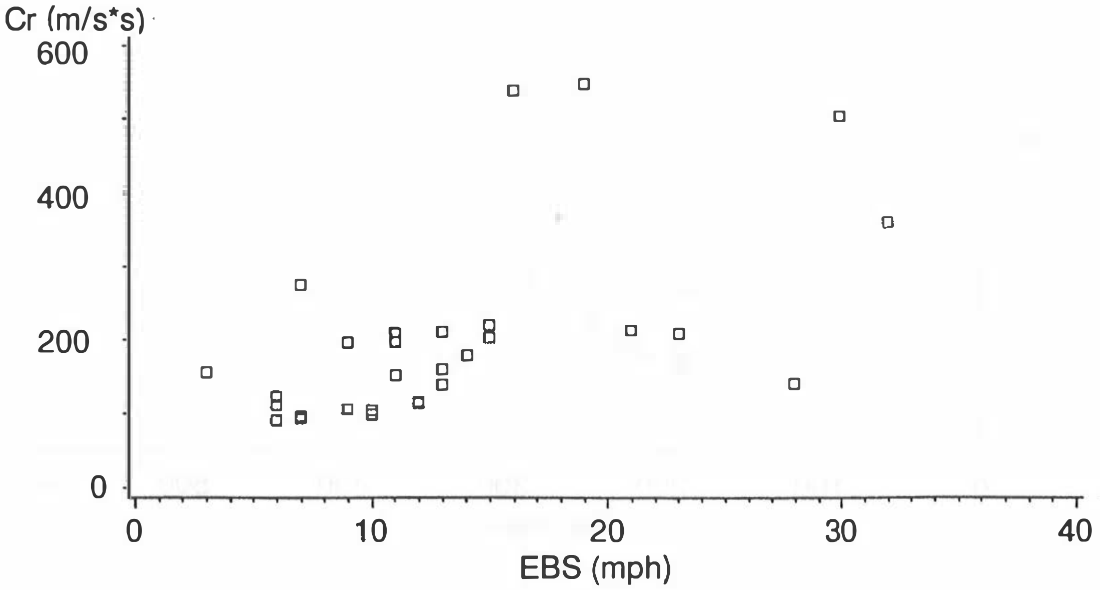
-120
-80
-40
0
MD (m/s*s)


Cr (m/s*s)
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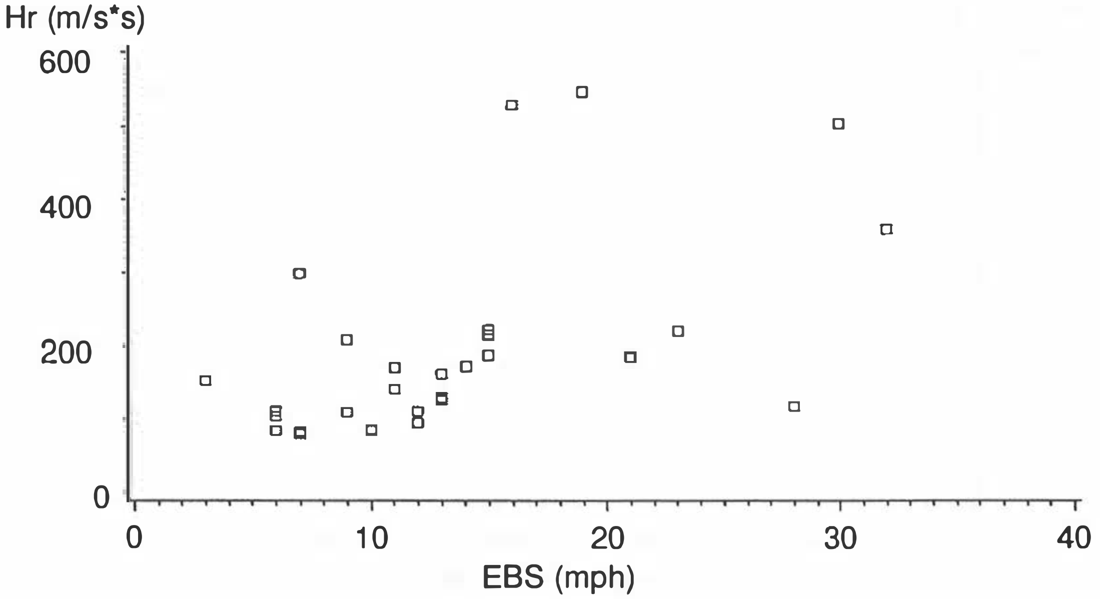
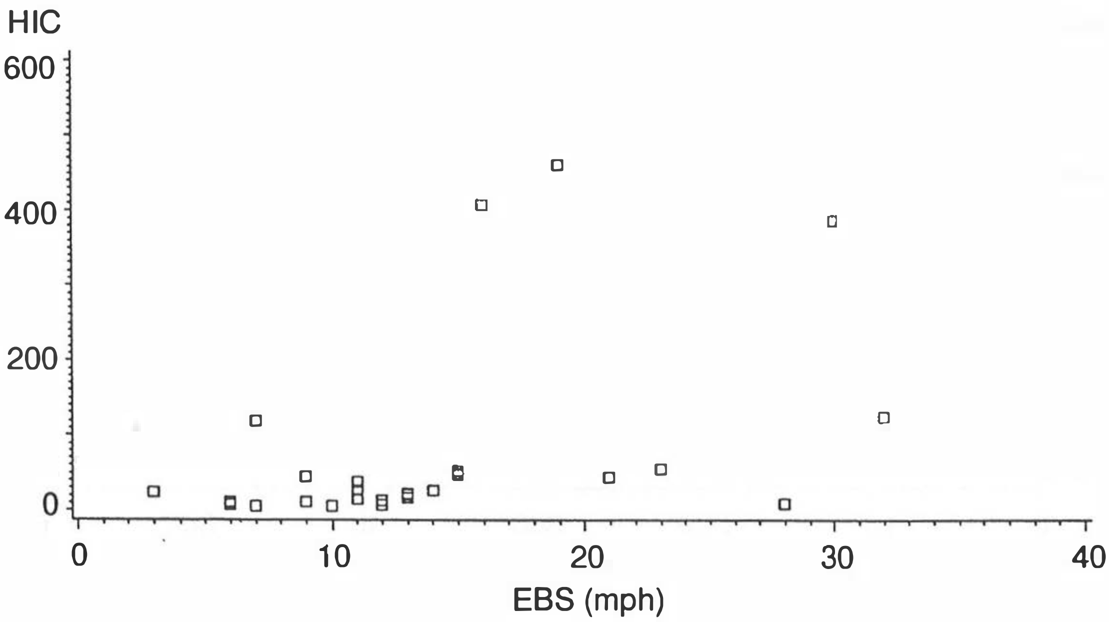
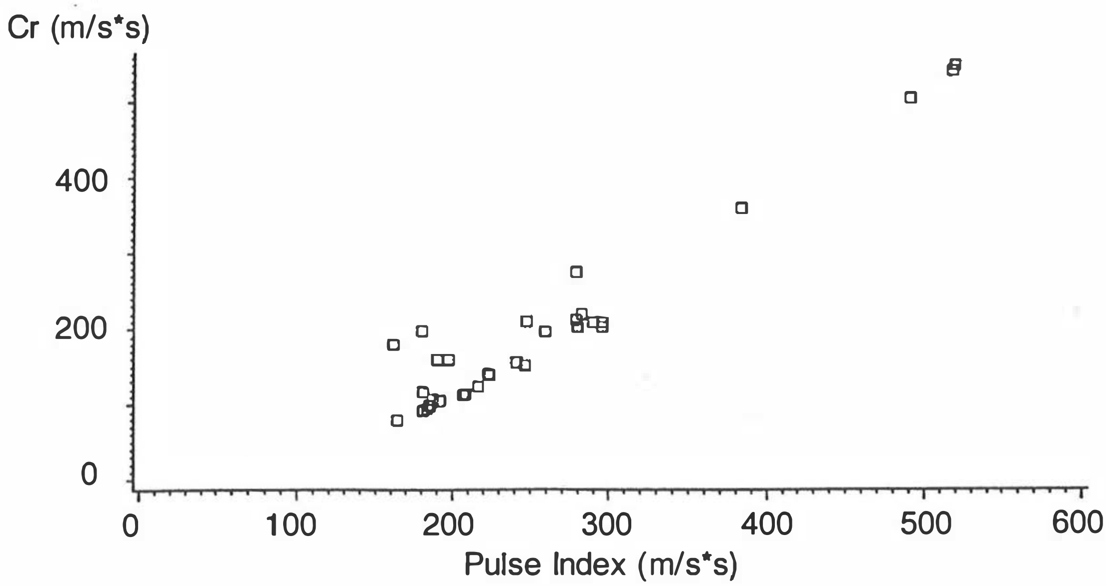
400
200
0
0
10
20
30
40
EBS (mph)


Hr (m/s*s)
600
400
200
0
0
10
20
30
40
EBS (mph)


HIC
600
400
200
0
0
10
20
30
40
EBS (mph)


Cr (m/s*s)
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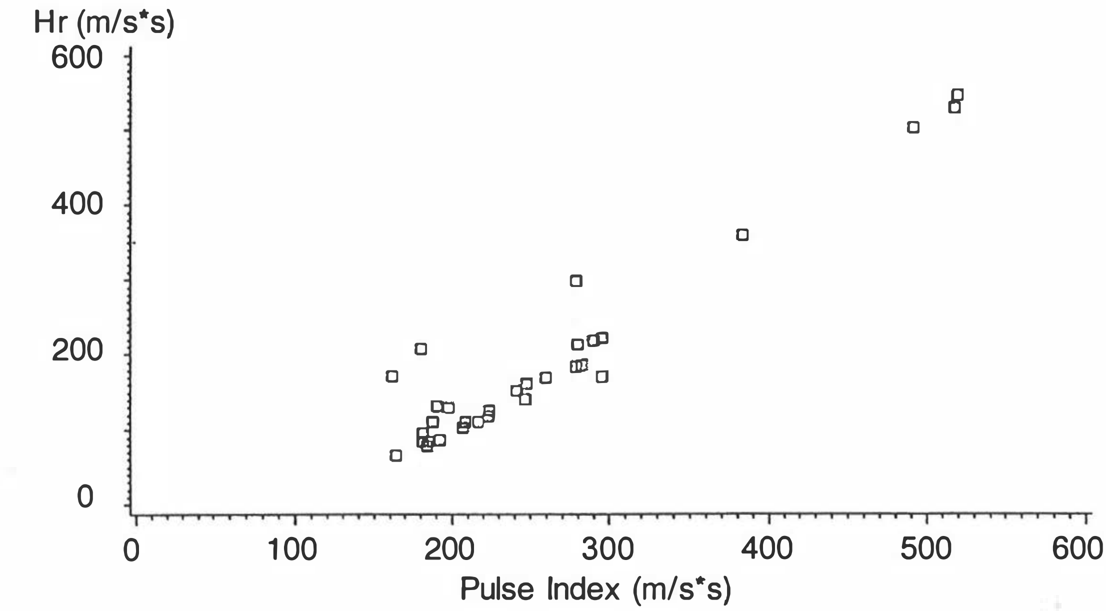
200
0
0
100
200
300
400
500
600
Pulse Index (m/s*s)


Hr (m/s*s)
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400
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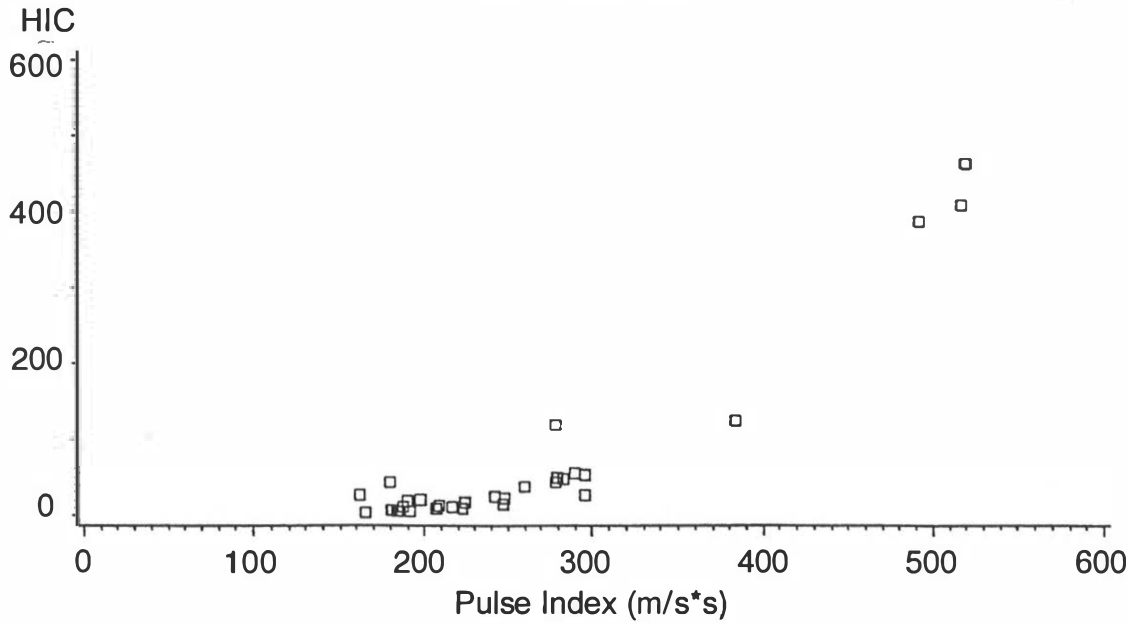
0
0
100
200
300
400
500
600
Pulse Index (m/s*s)


HIC
600
400
200
0
0
100
200
300
400
500
600
Pulse Index (m/s*s)