A REVIEW OF CRASH SEVERITY ASSESSMENT PROGRAMS APPLIED TO RETROSPECTIVE REAL-WORLD ACCIDENT STUDIES.

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ABSTRACT

In-depth, retrospective accident investigation studies provide a means to understand how car occupants are injured in road traffic accidents. In most retrospective studies, crash severity is estimated using the CRASH3 computer program.

This paper gives a brief description of CRASH3, and sets out how it is used by retrospective accident investigation studies. The effects of variations in the data input by accident investigators on results from CRASH3 were investigated. Variations in vehicle damage profile measurements and the application of a single stiffness class to front wheel drive vehicles involved in frontal impacts were looked at specifically. Based on the findings of these investigations, recommendations for the use of CRASH3 in retrospective accident investigation are then given.

INTRODUCTION

Many scientists, engineers and legislators are working towards reducing the frequency and severity of injuries to motor-vehicle occupants involved in road traffic accidents.

In-depth, retrospective accident investigation studies provide a means to understand how car occupants are injured in crashes. In these studies, detailed examinations of the accident damaged vehicles are correlated with occupant injury records. This is done to determine the causes of injury to car occupants.

It is important to gain a measure of crash severity. In most retrospective studies, this is done using a computer program.

Crash Severity Assessment Programs

There are various computer programs available that can be used for the purpose of assessing crash severity, for example, CRASH3, EDCRASH, SLAM for Windows, PC-CRASH and AiDamage. CRASH3, EDCRASH and SLAM for Windows are similar programs, and are discussed in this paper. Although capable of crash severity assessment, PC-CRASH is more focused on accident reconstruction, and is therefore not discussed in this paper. AiDamage is a crash severity assessment tool, and was developed in the UK. This program is not discussed in this paper because it will be reviewed at a later date.

CRASH was developed to assist investigators to assess the severity of motor vehicle crashes. "CRASH" is an acronym for "Calspan Reconstruction of Accident Speeds on the Highway". It was developed throughout the 1970s, on behalf of the United States' Government. By the 1980s, the CRASH program was developed to its third revision - CRASH3 [1].

Data relating to the damage sustained by the vehicle are entered into the program. These data consist of a code describing the damage location and type, and measurements of the damage profile. The program then calculates estimates of crash severity.

CRASH3 has been criticised because the stiffness coefficients and other default data used by the algorithms are considered very much out of date. The program does not have a facility to substitute for the default data. This does not allow proper interpretation of the crash severity estimates to be produced.

EDCRASH is an up-to-date version of the CRASH3 program. This is part of a suite of crash and accident reconstructional aides developed by the Engineering Dynamics Corporation. As computers developed, so too did the CRASH program. The program was no longer tied to a mainframe computer - desktop computers became a viable medium for the program. As a result, graphics and more streamlined calculations were introduced [1], but to calculate estimates of crash severity, the same algorithms as CRASH3 are used.

SLAM for Windows is another version of the CRASH3 program. This was developed by AR Software. SLAM uses a Windows based rather than a DOS based environment. It, too, uses the same algorithms to calculate estimates of crash severity.

The use of the CRASH3 Program in European Accident Investigation Studies

The Co-operative Crash-Injury Study (CCIS) is the UK's largest retrospective accident investigation study. It has been in its current form since 1983. Its sixth phase begins on 1st June, 1998.

The study is funded by the UK's Department of Environment, Transport and the Regions (DETR), and is currently co-sponsored by six motor manufacturers: Ford, Rover, Honda, Toyota, Nissan and Daewoo.

The study is managed by the Transport Research Laboratory, in Berkshire, England. Data are collected, from various locations around England, by five teams from the Vehicle Inspectorate Executive Agency and two University based teams - the Birmingham Accident Research Centre (BARC), Birmingham University, and the Vehicle Safety Research Centre (VSRC) of the Institute of Consumer Ergonomics, Loughborough University.

The study has used CRASH3 as a tool to provide an estimate of impact severity throughout the lifetime of the project.

Recently, work was undertaken to investigate the possibility of harmonising crash investigation within Europe. Those aspects which were common to Europe's three main studies - the Co-operative Crash-Injury Study (UK), BASt (Germany) and INRETS (France) - were sought. CRASH3 and PC CRASH were identified as the crash severity assessment tools used. The results from each program are comparable with the other as each program uses the same algorithms to calculate Delta-V and ETS [4].

Purpose of this paper

Since it forms the basis of most crash severity assessment programs, this paper gives a brief description of CRASH3, and sets out how it is used by retrospective accident investigation studies. The data input to CRASH3 by accident investigators will have an effect on the results it produces. Two sources of data input are investigated: variations in damage profile measurement and the application of a single stiffness class applied to front wheel drive vehicles involved in frontal impacts. Recommendations for the use of CRASH3 by retrospective accident investigation studies, particularly those in Europe, are then given.

A DESCRIPTION OF CRASH3

The basic function for which the CRASH3 program is used in retrospective accident investigation studies is to calculate the linear impulse that each *vehicle involved* in a crash experiences. This is calculated by assuming the conservation of linear momentum. In addition, the amount of energy used in damaging the vehicle(s) is calculated using a relationship between the stiffness of the vehicle, the amount of deflection and the area over which the damage is sustained. A complete explanation of the exact calculations used are given in the CRASH3 user guide and technical manual [5].

Data Application

The following are the assumptions made by the CRASH3 program. These must be understood if the program is to be used effectively [3]:

1. The effects of road incline and camber and are ignored by the program.
2. Transfers of load distribution within the vehicle and suspension effects during acceleration are ignored
3. the driver is assumed not to control the vehicle (steering and braking).
4. The force - deflection characteristic of the vehicle is assumed to be linear.
5. The crush profile measurement points are taken at single heights; this means that the program does not account for vertical variations in crush profile.
6. The vehicles are assumed to reach a common velocity during the impact; this means that the program is not appropriate for sideswipe impacts.
7. There is negligible ground friction force, between tyre and ground, or vehicle structure and ground, during impact.
8. Vehicle data for a particular size of vehicle is based on the averages of crash test results from a range of vehicles of that size classification.
9. There is negligible elastic recovery of the vehicle structure.

Data Input

Scene data, e.g. impact and rest positions of vehicles, cannot be collected for use within retrospective investigation studies. This means that for use within such studies, the CRASH program has only vehicle damage data available to use in its calculations. The program has been designed so that this is possible. The algorithm that makes use of vehicle damage data is called the DAMAGE algorithm.

Data required for the DAMAGE algorithm of the CRASH program are:

- A Collision Deformation Classification (CDC) - a seven character code which describes the principal direction of force applied to the vehicle, the location of the damage, the type of impact, and a zone in which the damage was sustained. SAE J224 Mar 80 describes this coding system in detail.
- Measurements of the vehicle damage profile (six measurements known as C1 to C6) - this profiles the amount of damage sustained by the vehicle.
- The stiffness classification of the vehicle - these are selected according to the vehicle's size, which is based on the vehicle's wheelbase.
- The mass of the vehicle.

Data Output

The outputs from CRASH3 are Delta-V and ETS. A description of each of these follows.

Delta-V has been defined as "the change in velocity of a vehicle's occupant compartment during the collision phase of a motor vehicle crash (i.e. from the moment of initial contact between vehicles until the moment of their separation)" [2]. Delta-V can be calculated by CRASH3 when data for two vehicles that have crashed with each other are available.

ETS has a similar definition to Delta-V. However, it is calculated when data for only one vehicle are available. In this case, the results given by CRASH3 are intended to be those equivalent to the vehicle being crashed into a rigid barrier. These results have various references: ETS - Equivalent Test Speed; EBS - Equivalent Barrier Speed; EES - Equivalent Energy Speed. They all refer to the same output produced by CRASH3. For the remainder of this paper, this particular output will be referred to as ETS.

Interpretation of Delta-V and ETS

It is desirable to calculate an ETS even when a Delta-V is calculated. Hence, the ETS provides retrospective accident investigation studies with a consistent estimate of crash severity, regardless of whether all collision partners were seen.

Users of data which contain reference to crash severity estimated by the CRASH3 program should be aware that the outputs, Delta-V and ETS, are indeed only estimates. The principles used by the program when calculating Delta-V and ETS are correct, but have limitations.

As already stated, the program makes assumptions on which to make its calculations feasible. One of these assumptions states that, for a particular size class, the vehicle data used by the program is based on the averages of crash test results from many vehicles of that size classification - it is applying its calculations to a 'typical' vehicle.

These data, such as vehicle stiffness, are based on 'typical' vehicles in the United States from the 1970s, when the program was developed. These are inevitably different to vehicles in the 1990s. The user must be aware of this when applying the CRASH3 program today, particularly to European vehicles. This topic is not dealt with in this paper, but is dealt with in the paper, "The accuracy of CRASH3 for calculating collision severity in modern European cars" [6].

The output will also be influenced by the data input by investigators - i.e. the CDC, stiffness class, size class, vehicle mass and the damage profile measurements. The data output can only be as good as the data input.

APPLYING CRASH3

The following sections detail how measurement and stiffness class can affect the accuracy of results given by the CRASH3 program.

Effect of variations in measurement on Delta-V and ETS

In order to investigate the influence of measurement on Delta-V and ETS, a frontal, more than two-thirds distribution impact, applied to the stiff structure level of the vehicle, with a moderate amount of deformation was selected. This was represented by a CDC of 12FDEW3. Measurements representing different size classes of vehicle were applied, along with the CDC to the CRASH3 program. The measurements were then adjusted varying up to ±25cm. Table 1 shows the measurements that were used.

Table 1.
Nominal Input Data for Assessing CRASH3 Data Output from Toleranced Measurements

Size class	Damage width (cm)	C1 (cm)	C2 (cm)	C3 (cm)	C4 (cm)	C5 (cm)	C6 (cm)
1	175	0	6	12	18	24	30
2	180	0	8	16	24	32	40
3	185	0	10	20	30	40	50
4	190	0	12	24	36	48	60
5	195	0	14	28	42	56	70
6	200	0	16	32	48	64	80

For a tolerance of -5cm to +10cm on the nominal measurement, the variation in ETS is less than 1km/h per cm variation in measurement. This is illustrated in Figure 1.

Variation in ETS due to stiffness class

Many European vehicles have front wheel drive transmission. For frontal impact configurations, the CRASH3 program assumes a single stiffness category for such vehicles, regardless of their size. This is because the transmission is assumed to become involved in the deformation phase of the impact. The effect that this categorisation makes to ETS was investigated.

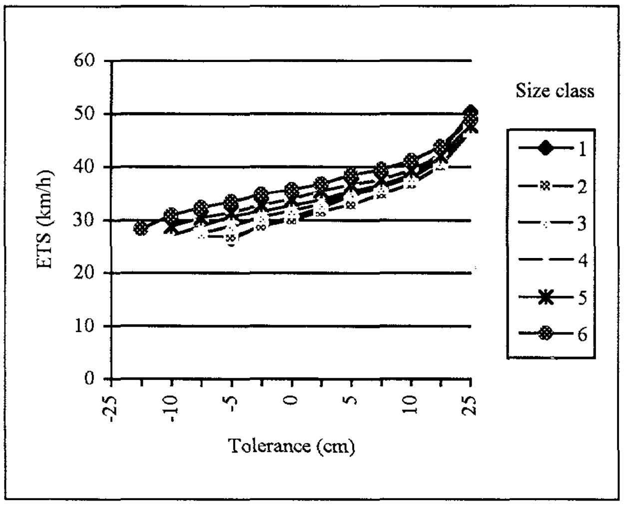

Figure 1. Results from CRASH3 using a range of measurements.

A CDC representing a frontal, more than two-thirds distribution impact, applied to the stiff structure level of the vehicle was selected: 12FDEW_. CRASH3 was run, using the CDC only, for increasing amounts of deformation, represented by each extent code: 1 to 9.

This was repeated for the smallest size vehicles, i.e. size class 1, medium sized vehicles, i.e. size class 3 and large vehicles, i.e. size class 6, using default data from the program. The comparison was made for stiffness class for the size of the vehicle, and for the stiffness class representing a front wheel drive vehicle.

For a large, front wheeled drive vehicle in a frontal impact, the results show a higher ETS from CRASH3 than a rear wheel drive vehicle, of the same size, with the same CDC. This is illustrated in Figure 2.

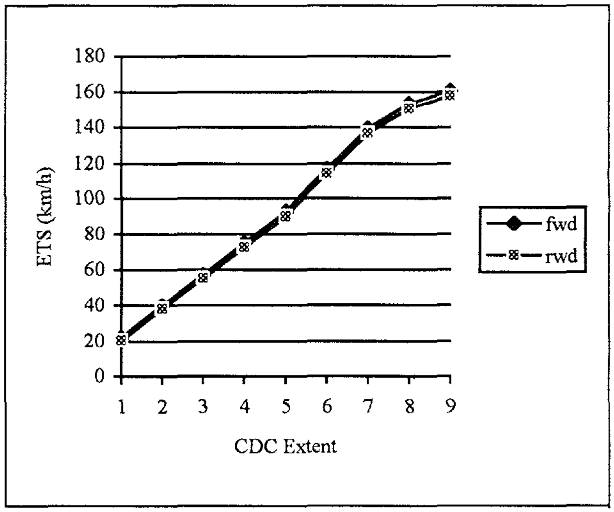

Figure 2. Results from CRASH3 comparing ETS for front wheel versus rear wheel drive vehicles, size class 6, with a CDC of 12FDEW_.

This suggests that a large, front wheel drive vehicle is slightly more stiff than the equivalent rear wheel drive vehicle. The shape of the curves up to extent zone 5, which corresponds on a vehicle to the bulkhead / bottom of the windscreen, show a linear increase in ETS. This illustrates the program's assumption that the force - deflection characteristic of the vehicle is linear. For extent zone 6, which represents the section of the vehicle defined by the windscreen, the gradient of the curves increase. This suggests that the vehicle is assumed to become stiffer beyond the bulkhead. The gradient decreases again for extent zones 7 to 9 (representing from the header rail to beyond the B pillar).

For a medium size vehicle, and a small vehicle, the shape of the curves are identical to that for a large vehicle. However, for a medium size vehicle, the results suggest that the front wheel drive vehicle is slightly more stiff than the equivalent rear wheel drive vehicle for zone 1 - which corresponds to one fifth of the length of the bonnet, at the front of the vehicle - only. Beyond this zone, the equivalent rear wheel drive vehicle is more stiff than the front wheel drive vehicle.

A similar effect is seen for a small vehicle, with the change occurring beyond zone 3. Figures 3 and 4 illustrate these results.

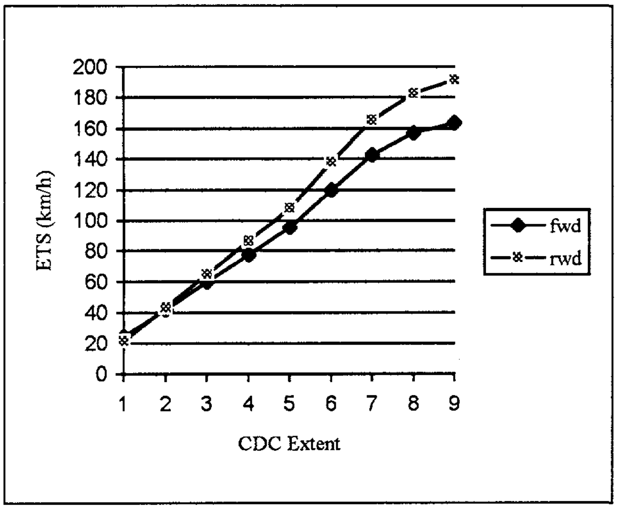

Figure 3. Results from CRASH3 comparing ETS for front wheel versus rear wheel drive vehicles, size class 3, with a CDC of 12FDEW_.

CONCLUSIONS

1. Within the tolerance range of -5cm to +10cm on nominal vehicle measurements, CRASH3 gives less than 1km/h variation in ETS per cm variation in measurement.

2. CRASH3 assumes front engined front wheel drive vehicles involved in frontal impacts have a single stiffness category . If the equivalent rear wheel drive vehicle is compared with a front wheel drive vehicle, following this rule, the following are observed:

- Large vehicle (size class 6) - a front wheel drive vehicle appears to be more stiff than an equivalent rear wheel drive vehicle for any amount of deformation.
- Medium vehicle (size class 3) - a front wheel drive vehicle appears to be more stiff than an equivalent rear wheel drive vehicle for a small amount of deformation, i.e. up to extent zone 1, only. Beyond this, the equivalent rear wheel drive vehicle appears to become considerably stiffer than the front wheel drive vehicle.
- Small vehicle (size class 1) - a front wheel drive vehicle appears to be more stiff than an equivalent rear wheel drive vehicle for a moderate amount of deformation, i.e. up to extent zone 3. Beyond this, the equivalent rear wheel drive vehicle appears to be slightly stiffer than the front wheel drive vehicle.

An important note to make here is the significance of entering damage profile measurements into the CRASH3 program. The program will make an estimate of Delta-V and ETS from a CDC alone. In this case, the program will call upon its default data. As the default data has been compiled as data for a 'typical' vehicle, it is advantageous to be able to enter more relative information. Hence, taking and entering damage profile measurements will inevitably improve the accuracy of the estimate from CRASH3.

3. The CRASH program has been used by the CCIS since it began in 1983. To change to a program with different approach to calculation of Delta-V and ETS would make any future data less compatible with data already held.

4. The three main crash investigation studies in Europe all make use of the same algorithms to calculate Delta-V and ETS, and hence estimate crash severity.

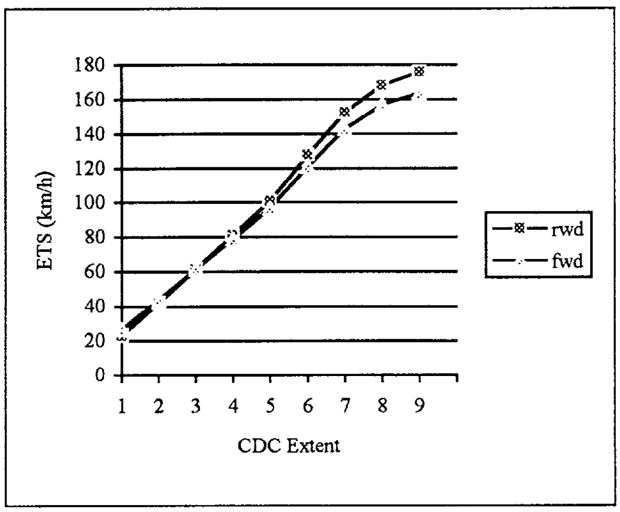

Figure 4. Results from CRASH3 comparing ETS for front wheel versus rear wheel drive vehicles, size class 1, with a CDC of 12FDEW_.

RECOMMENDATIONS FOR THE USE OF CRASH3 BY RETROSPECTIVE ACCIDENT INVESTIGATION STUDIES

1. Keep the DAMAGE algorithm as the crash severity assessment tool for retrospective accident investigation studies. It has been demonstrated that a tolerance for measurement of vehicle damage in the field can be specified. Further work will confirm, or redefine, which specific tolerance will be most appropriate. The CRASH3 program has been used by the CCIS since it began in 1983, and the DAMAGE algorithm is used throughout European accident investigation studies. Changing to a different method of assessing crash severity may produce a step in continuity of data. With regard to assigning a single stiffness class to front wheel drive vehicles, involved in frontal impacts, there does not appear to be a need to change away from this rule. The results have shown that there is no significant difference in results between front and rear wheel drive vehicles, and, to change now would, again, produce a step in the continuity of data held. It would be beneficial to consider the situation for different impact configurations, and for the 3 remaining size classes of vehicle.

2. Alongside CRASH, the CCIS should review EDCRASH and SLAM in terms of (a) consistency with the CRASH DAMAGE algorithm, (b) updated crash test data and (c) application to European vehicles. EDCRASH has been identified as the leading contender for updating the CRASH3 principles. It has a more user-friendly working environment, it can be 'fine tuned' to specific vehicle parameters, and is a modular part of a suite of accident investigation and reconstructional aides. It also provides access to more up-to-date vehicle stiffness data. These should also be assessed as to their appropriateness to European vehicles. It may be the case that EDCRASH contains the same default data as CRASH3. If this is the case, it will be compatible with existing data.

3. Review other crash severity assessment programs available, such as PC-CRASH and AiDamage. This is a basic requirement of accident investigation to ensure that the most appropriate tools are being used to make best use of the data available.

ACKNOWLEDGEMENTS

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