

Classifiers to Augment the CDC System to Distinguish the Role of Structure in a Frontal Impact Taxonomy

Dale E. Halloway and Frank Pintar
Medical College of Wisconsin

James Saunders
NHTSA

Aida Barsan-Anelli
Information Systems and Services, Inc.

ABSTRACT

The purpose of the study was to distinguish the role of vehicle structure in frontal impacts in published coded National Automotive Sampling System (NASS-CDS) data. The criteria used: Collision Deformation Classification (CDC) coding rules, crush profile locator data and the projected location of longitudinal structural members in models of vehicle class sizes used by NASS-CDS. Two classifiers were developed to augment the CDC system. The Coincidence classifier indicates the relationship between the quadrant of the clock face the crash vector originates in and the aspect of the end plane the center of damage is located. It has three values: Linear (12 o'clock impacts) Consistent and Variant ('oblique' Principal Directions of Force or PDOFs). The second classifier indicates the number of longitudinal members engaged: 0, 1 or 2.

NASS-CDS data for sample years 2005 to 2009 was filtered for occupants involved in impacts with the highest ranked speed change assigned to the front-end plane. The set excluded impacts assigned a PDOF greater ± 50 degrees and small over-lap (SOI) type impacts. A set of 12165 raw records (4,655,471 weighted) for occupants in wide type impacts that extending from the bumper to the belt line or above was collected and subdivided into linear and oblique categories.

1910 raw records involved Consistent impacts; 75 (3.9%) occupants (16,481 weighted or 3.6%) were in impacts involving 0 rails. 164 (8.6%) or 40,189 weighted (8.7%) involved 1 rail and 1671 (87.5%) records or 405,022 weighted (87.7%) involved 2 rails. 160 raw occupant records involved Variant impacts, 2 (1.2%) or 73 occupants weighted ($>1\%$) involved 0 rails. 80 (50%) or 20,175 weighted (43.9%) involved 1 rail and 78 (48.8%) of the raw records (25,682 weighted or 56%) involved 2 rails.

To evaluate the theory of the Coincidence classifier, a matrix of impact configurations were submitted to NHTSA for simulation. Impacts predicting head motion beyond the perimeter of the steering-wheel were deemed oblique. Twenty one simulations with vectors of 10, 20 and 50 degrees resulted in eight predicted occupant kinematics consistent with an 'oblique' impact.

CITATION: Halloway, D., Pintar, F., Saunders, J. and Barsan-Anelli, A., "Classifiers to Augment the CDC System to Distinguish the Role of Structure in a Frontal Impact Taxonomy," *SAE Int. J. Passeng. Cars - Mech. Syst.* 5(2):2012, doi: 10.4271/2012-01-0575.

INTRODUCTION

In 2010 the Wisconsin Crash Injury Research Engineering Network (CIREN) Center developed an operational definition of small-overlap impacts (SOI) to infer damage to vehicle structure from crush profile data in queries of National Automotive Sampling System (NASS-CDS) coded data¹.

The process involved developing a set of generic models of vehicle front-end structures for each NASS-CDS vehicle class size category by extending the technique for locating vehicle structure proposed by Sullivan². Concurrently, a series of small over-lap crash tests with a pole were carried out at the Vehicle Crash Laboratory of the Medical College of Wisconsin, where it was observed that the Principal



Documents

Document Sharing Hub

Direction of Force (PDOF) at the vehicle center of gravity oscillated within approximately +10 to -45 degrees over a minimum of 70ms, and that this 'swing' in PDOF, affected the kinematics of the Anthropomorphic Test Device (ATD) occupant. The principal direction of force as a function of time was calculated as the direction vector angle at each time point between vehicle X- and Y-acceleration components at the vehicle center of gravity. These tests are labeled FLEED 103 and 104 in [Figure 1](#) below.

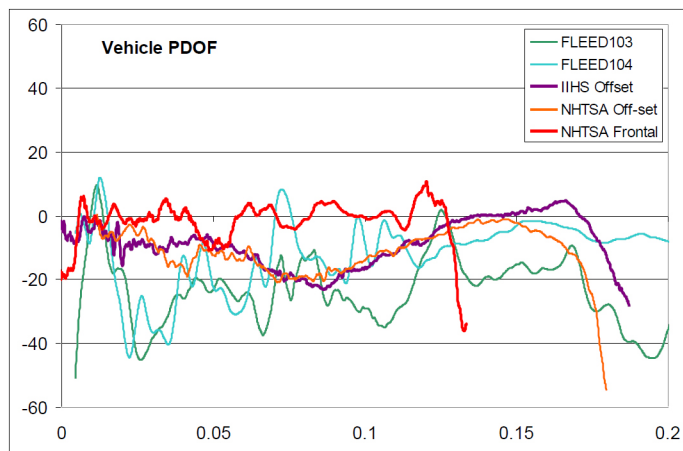


Figure 1. Comparison of PDOF at Vehicle CG in FLEED/ SOL, Offset and Full-frontal Impacts

The altered occupant motion can be explained as due to the deformation of body, suspension and drive-train components outboard of the longitudinal members which produce acceleration on the Y-axis and a translation of the vehicle within the first 100 ms of the crash event. Relative to the vehicle interior this motion can be seen as a resultant vector equivalent to an 'oblique' crash vector inducing occupant motion forward and outboard relative to the vehicle interior ([Figure 2](#)). This implies that whether none, one or two longitudinal members are engaged and how they are engaged may affect occupant kinematics.

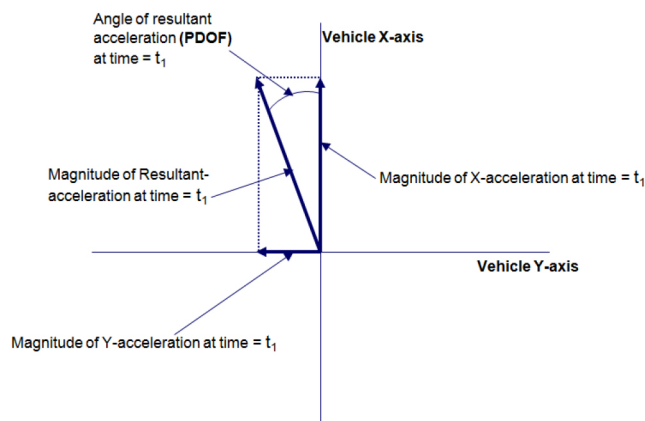


Figure 2. Explanation of acceleration on the Y-axis in a 0° Small-overlap impact

The Wisconsin CIREN Center revisited the concept of a Frontal Impact Taxonomy (FIT) in the context of published coded NASS-CDS data, with the objective of operationally defining 'oblique' frontal impacts. In addition to the generic models, two sets of criteria were used to specify the FIT: Collision Deformation Classification (CDC) coding rules and crush profile data. A theory of an effective center of gravity (ECG) was postulated to explain the observed ATD 'oblique frontal-impact' kinematics occurring in zero degree PDOF small-overlap impacts. This motion is ascribed to the moment arm perpendicular to the crash vector direction between the vehicle center of gravity and the center of damage.

OVERVIEW

The taxonomy described below retains all the CDC classifiers and adds additional prefix and suffix classifiers. The classifiers taken from the CDC system designate the same concepts and follow the coding rules described in J224 MAR 80³. The hierarchical classification scheme is ordered as below:

- Coincidence = DOF (Clock direction) Quadrant consistent with 'Crush profile D' (SAS code DVD) sign: Coincident (C), Variant (V) or Linear (L)
- Direction = DOF or a PDOF of the resultant crash vector
- Phylum = General Area of Deformation (SAS code GAD)
- Class = Damage-distribution location class (SAS code SHL). Un-scaled indicator of the extension of direct-damage on the end plane, a.k.a. overlap.
- Level = Vertical level (SAS code SVL). The extension of direct-damage on the end plane defined by points delimiting areas of structural rigidity.
- Order = Type of Damage distribution (SAS code TDD). Scaled indicator of the extension of direct-damage on the damaged horizontal plane that can be located with reference to structural members.
- Extent = CDC defined extent zone
- Rail Species = Structural members engaged: 0, 1 or 2. Indicator of the number of beams or plates engaged.

FRONTAL-IMPACT TAXONOMY CLASSIFIERS

Coincidence

CDC Direction of Force (DOF) codes are assigned on the basis of the Principal Direction of Force (PDOF) value determined for the impact resultant vector. Conventionally, DOF codes or their component PDOF values have been used to divide frontal impacts into the genera of either collinear or oblique. However, if occupant kinematics are influenced by a relationship between moment arm perpendicular to the crash vector direction and how vehicle structure is deformed, then

to indicating whether and how structural components of vehicle are engaged should be considered.

If the resultant vector is considered as acting on the vehicle at the location of the center of damage, then the relationship between the 'clock' quadrant a DOF originates in and the location of center of damage on the front-end plane may serve as an indicator of the length of the moment arm. In NASS-CDS data, the location of center of damage is indicated by either a '+' or a '-' sign appearing before the 'Crush profile D' (DVD) value. The signed DVD value indicates the distance on the y axis the center of damage is from the center-line of the vehicle on the front-end plane.

Figure three illustrates the three Coincidence codes: Linear, Consistent and Variant. Any DOF of 12 is considered Linear (L), regardless of the center of direct-damage (DVD) value. When any other DOF is centered on the vehicle mid line (DVD = 0) it is considered Consistent. A DOF with PDOF of 270 to 340 occurring with a center of direct damage value with a '-' sign is Consistent (C). The same DOF occurring with a center of direct damage value with a '+' sign is Variant (V). An inverse relationship exists for PDOFs originating out of the 1 to 3 o'clock sectors and the right side of the vehicle.

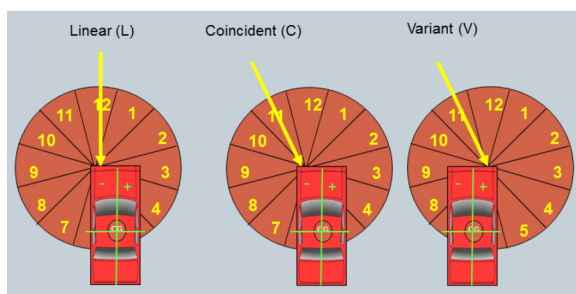


Figure 3. Coincidence Classifier Codes

Phylum

The CDC General Area of Deformation (GAD) classifier designates the phylum of the plane of impact. In FIT the only phylum is the front-end plane (F), but with modifications the scheme can be applied to other planes. The two dimensional front-end plane is divided into horizontal sectors and vertical levels. There are three primary horizontal sectors that in three combinations describe three larger horizontal sectors and three vertical levels that can be combined to describe six vertical sectors.

Class

The class designates the damage-distribution along the lateral axis of the front-end plane. It corresponds to the Specific Longitudinal/Lateral Location (SHL) codes 'D', 'Y', 'Z', 'L', 'C' and 'R' in the CDC system. A damage-distribution location class describes the lateral extension of direct damage on the end plane. The extension of direct damage to sheet metal is not scaled, but established in

relation to mathematically determined points determined by vehicle specifications.

Levels

The levels correspond to CDC Specific Vertical/Lateral Location codes (SVL): 'L', 'M', 'E', 'G', 'H' and 'A' and describe the vertical extension of direct damage on the end plane. The extension of damage is not scaled, but established in relation to specific points on the vehicle body. There are three principal vehicle structure/body level codes: 'L' indicating the frame, 'M' indicating the space from the top of the frame to the beltline and 'G' indicating the beltline and above. All other codes are a combination of these. Level 'A' indicating all levels from the frame up were engaged.

In the following discussion it is assumed that: The 'E' level damage is vertically contiguous and uniform within a horizontal sector; all other level designations are indicative of an impact that does not significantly engage front-end structure; the loading of structure along the vehicle X-axis is not negligible and the damage-distribution does not invoke the field protocol for documenting crush profiles at both the 'L' and 'M' levels.

Order

Scale is incorporated into the FIT by the type of damage-distribution order the direct-impact damage conforms to. The type of damage distribution orders correspond to CDC Type of Damage Distribution codes (TDD): 'W', 'N', 'S', 'O', 'A', 'E', 'K' and 'U'. TDD codes 'S' and 'E' describe direct-impact damage conforming to the criteria for the small overlap (SOI) class designation described in the previously reported SOI methodology.

TDD code 'O' is assigned to rollover crash damage. The 'A' code describes an impact with an 'inverted step' structure which involves direct-damage to above and below the beltline. TDD code 'K' describes an impact that had direct-impact damage that conforms at one point to one distribution type and then converts to conforming to another distribution type. Following Sullivan et al, these are considered as belonging to the 'Other' class. TDD code 'U' describes an impact that left no residual deformation and is not considered. Valid Order codes then are: 'W' = wide, 'N' = Narrow, S = Small overlap, 'O' = other and 'U' = unknown.

The concept of scale inherent in the order codes 'W' and 'N' determines the damage-distribution location class an impact is classified as belonging to. In FIT it is assumed that at a minimum, direct-impact damage must extend across the boundary between an outboard horizontal-sector into the center horizontal-sector by an amount equal to 1/3 the width of the un-deformed end-plane plus 10 percent, before qualifying for membership in the damage-distribution location class 'Y' or 'Z' and direct-impact damage must extend across the center and into both outboard horizontal-sectors by 10 percent, before qualifying for membership in the damage-distribution location class 'D'.

J224MAR80 stipulates that the direct-impact damage can be no more than 41-cm, no higher than 15-cm or having a perimeter greater than 162.6 cm² to qualify for TDD code 'N'. Because impacts falling on level 'E' are considered vertically contiguous within a horizontal sector, the stipulations regarding the height and perimeter of direct damage are ignored. In the following discussion only impacts with direct-impact damage conforming to the order 'W' are considered.

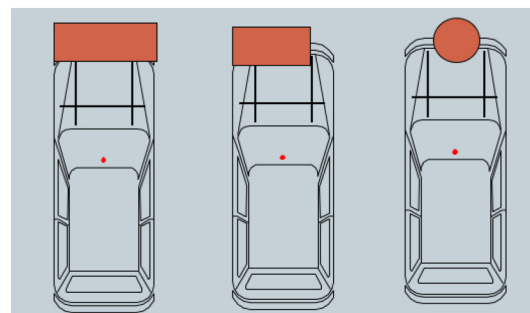
Extent

As described below, FIT assumes the 'E' level damage is vertically contiguous and uniform within a horizontal sector, that the crush was deep enough to engage front structural members and that no 'crash averaging' is reflected in the C-measurements. However, without requesting a supplemental set of crush profile data it is not possible to ensure published, coded NASS-CDS data is entirely congruent all the assumptions of taxonomy. Impacts that qualify for a CDC extent zone 'one' classification may not have residual crush or the crush may not involve vehicle structure. FIT accounts for this by assigning the Perfunctory (P) extent code to any CDC extent zone 'one' classification.

Impacts that are not vertically contiguous and uniform, like an impact with a large animal may result in a CDC extent zone greater than 'one', but not result in crush extensive enough to engage front structural members. When this is the case, a CDC with an extent zone greater than one associated with a crush profile where none of the C-measurements (SAS code DVC₁₋₆) exceed a threshold value determined for each generic model can also be assigned extent code 'P'. In front-plane impacts, the type of damage-distribution order codes 'S' and 'E' by definition, which do not describe impact damage involving structure and these impacts can also be assigned extent code 'P'. In the results that follow only impacts with an extent zone of 2 or greater are considered.

Rail Species

The longitudinal structural member (rail) location is calculated using the front track-width (FTW) and the distance between the longitudinal structural members (D-rail) for each of the generic models. Engagement of the rails is determined by dividing the direct-damage width by two and locating the beginning of the damage on the left side of the front end and calculating whether the damage overlaps the rail positions. This allows frontal impacts in the distributed class (SHL = D) to be distinguished by the number of rails engaged. Simply coding on the basis of the extent of sheet metal deformation, results in homonyms. The CDC 12-FDEW-3 is obscure as to the number of longitudinal members engaged; it could be 0, 1 or 2. See Figure 4.



12-FDEW-3-2

12-FDEW-3-1

12-FDEW-3-0

Figure 4. CDC 'Hollow Box' Model Homonyms Resolved

EFFECTIVE CENTER OF GRAVITY

A theoretical Effective Center of Gravity (ECG) was postulated to aid the evaluation of exterior damage to gain insight into whether the moment arm influences occupant kinematics. The ECG is the area of a circle with a radius equal to the length of the moment arm perpendicular to the crash vector direction between the vehicle center of gravity and the center of damage produced by front plane impacts, centered on the X axis of vehicle with PDOFs ± 10 degrees, the arc of the 12 o'clock direction of force. The CG location is calculated using the weight distribution as percentage of the curb weight at the front axle, the front-overhang and wheelbase length reported in Canadian Specifications⁴. The weight on the front axle expressed as a decimal, is subtracted from 1 and the remainder multiplied by the wheelbase. Then the front-overhang distance is added to the product: $CG = [(1 - \% \text{ front}) * WB] + FOH$. The radius of the ECG = CG location * $\tan 10^\circ$ (See Figure 5).

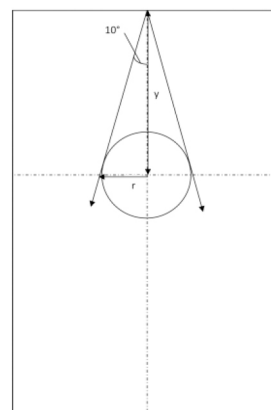


Figure 5. Illustration of the Definition of the ECG