Project F.9

ANALYSIS OF CRASH RECONSTRUCTION PROGRAM RESULTS

FINAL REPORT

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16. Abstract

Several different computer programs are used by crash investigators to estimate the severity of impact to motor vehicles involved in different types of crashes. Crash severity is most often expressed as the change in velocity, or Delta V, experienced by the case vehicle during the impact event, or by an equivalent barrier impact speed. However, the accuracy of these programs is uncertain and has been particularly questioned for some crash conditions such as offset-frontal impacts and pole impacts. Crash tests provide a unique opportunity to examine the accuracy of the different computer programs and their various program options and input parameters because the actual crash severity is measured and therefore known. In this study, residual crush measurements were taken on seven vehicles used in crash tests conducted by General Motors in GM/DOT Project B.3 "Fire Initiation and Propagation Tests." The tests include three offset-frontal pole impacts, three offset-frontal impacts, and one offset-rear impact. These crush measurements were used as input to three different crash-reconstruction programs that are in common use today. The resulting change in velocity estimates are compared to the change in velocity measured in the crash test. Different program subroutines and options were selected, and different values and sources of input parameters were used, to determine their effects on the accuracy of the reconstruction results.

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1.0 INTRODUCTION AND OBJECTIVES

Today, there are several federally and privately funded programs that conduct in-depth crash investigations with the goals of understanding patterns of injuries in different types of crashes, evaluating the performance of new restraint and safety technologies, and detecting emerging patterns in occupant injuries.

As a result of these different crash-investigation programs, there are now numerous databases available that include thousands of variables related to the crash conditions, the vehicles and objects involved, the exterior and interior vehicle damage, and the occupants and their injuries. One of the most important of these variables is the measure of the crash severity. Most databases provide a measure of impact severity in terms of Delta V and/or Equivalent Barrier Speed (EBS) that is associated with each significant impact. Delta V is a the change in velocity at the CG (center of gravity) of a case vehicle that takes place during the primary impact with another vehicle or an object. The EBS is the speed that the vehicle would need to produce the same amount of damage from impact with a rigid barrier.

To assist with the determination or reconstruction of crash severity in motor-vehicle crashes, several different computer programs have been developed. These programs use the basic principles of physics and dynamics to estimate the severity of impact to a “case” vehicle based on measurement of exterior vehicle damage (i.e., crush profile), vehicle mass and stiffness, the principal direction of force (PDOF), and other factors. Crash severity estimates from these programs have been shown to correlate with the frequency and severity of occupant injuries. There has, however, been a great deal of controversy with regard to the accuracy of estimates of crash severity obtained from these programs’ algorithms and their various options or usage modes.

One such computer program was developed by the National Highway Traffic Safety Administration (NHTSA). This computer program has also evolved and since the early 1980s at least three versions have been used to calculate the vast majority of impact severities found in the larger crash databases in the United States (e.g. CDS-NASS, SCI, CIREN, and UMTRI). In order of chronological development, these programs are: CRASH PC, WinSmash version 1.2.1, and WinSmash version 2.06. The NHTSA’s field investigation projects (NASS, SCI, and CIREN) currently use WinSmash (version 1.2.1) to calculate these estimates, while some CIREN centers and the UMTRI team are field testing WinSmash 2.06.

As previously noted, the overall accuracy of these programs has been a matter of debate and concern, particularly for offset-frontal crashes and pole-type impacts. An offset-frontal impact is a frontal impact in which the direct damage includes one of the two bumper corners, but not both. The damage resulting from an offset-frontal impact is commonly described in terms of percent overlap, or percent of the front of the vehicle that is engaged with the striking or struck vehicle or object. As the program evolved from CRASH PC to WinSmash 2.06, a variety of options and/or subroutines were added to the input parameters that allow the user to provide better descriptors of the impact damage (e.g. offset-frontal, endshift, pole impacts, etc.). However, the conditions under which these different options should be used have not been well documented, and the benefits of using these options in terms of improved accuracy of crash reconstructions have not been demonstrated.

One way to study the accuracy of these programs and the benefits of using their different program options is to use the standard field measurement procedures for crash severity reconstructions on vehicles that have been impacted in crash tests where the actual crash severity is measured and known. Hundreds of crash tests are conducted annually by federal, industry, and insurance organizations, but the results of these tests have rarely been used to validate the computer programs used to estimate severities of real-world crashes.

The purpose of this study was to utilize results and vehicles from crashes conducted by General Motors under the GM/DOT settlement agreement to examine the accuracy of some of the most commonly used crash reconstruction programs. It was also desired to document the effects of their various program options for different types of crash modes.

The basic approach of this study is relatively simple. Field investigation techniques were used to measure the crush profiles of seven vehicles used in different types of crash tests. These crush profiles were then used as input to three different computer programs that are currently and commonly used by leading crash-investigation teams. The programs were run initially in baseline modes, and subsequently with various available options that are pertinent the different types of crashes. The program outputs for crash severity or Delta V were then compared to the measured Delta Vs in the tests.

Section 2 of this report provides further details on the different aspects of this process, including information on the different crash-reconstruction programs and their different user options. Section 3 presents the results obtained from the different computer runs and compares these results to the measured crash severities in the different crash tests. Section 4 is a summary and discussion of these results, and Section 5 provides conclusions of the study, and recommendations to crash investigators that will help optimize the accuracy of estimated crash severities when using these computer programs. A glossary of terms used throughout this report is provided immediately following Section 5.

Appendix A provides post-test photos of each of the vehicles used in the crash tests, along with the crush measurements taken using field investigation procedures. Appendices B through D contain the outputs of the three computer runs for the three reconstruction programs used in this study.

2.0 METHODS

2.1 Types of Crash Modes and Test Vehicles

Seven vehicles from seven crash tests conducted by General Motors were selected for this study. These seven tests involved four different crash modes, including one or more of the following:

- in-line offset-frontal impact,
- oblique offset-frontal impact,
- in-line frontal narrow pole impact, and
- offset-rear in-line impact

As shown in Table 1, the seven test vehicles include four 1996 Dodge Caravans and three 1996 Chevrolet Camaros. Post-crash photos of these vehicles are included in Appendix A, along with the measurements of the damage or crush profile. The four Dodge Caravans were all impacted on the frontal plane; two were in-line narrow pole impacts, one was an in-line offset-frontal impact with a non-moving rigid barrier (NMRB), and one was an oblique (25 degrees) offset-frontal impact with a moving deformable barrier (MDB). Two of the three Chevrolet Camaros were impacted on the frontal plane; one was an in-line narrow pole impact and one was an oblique (22 degrees) offset-frontal impact with a moving deformable barrier (MDB). The third Chevrolet Camaro test was an in-line-offset rear impact with a moving deformable barrier. Many of these vehicles were exposed to a fire subsequent to their individual crash test (as part of another test conducted under the GM/DOT settlement project), but prior to their examination for this project.

TABLE 1

Summary of Field Measurements

Vehicle	Impact Type	UEW (cm)	FL (cm)	DL (cm)	Adjusted Profile (cm)	Raw Profile (cm)	DD (cm)	FD (cm)
96 Dodge Caravan	In-line Pole	154	93	40	2, 26, 53, 86, 88, 48	22, 33, 55, 88, 95, 68	+25	0
96 Chevrolet Camaro	In-line Pole	152	52	36	21, 56, 98, 104, 97, 80	39, 64, 102, 108, 105, 98	+38	0
96 Dodge Caravan	In-line Pole	154	81	24	14, 50, 55, 81, 104, 53	34, 57, 57, 83, 111, 73	+27	0
96 Dodge Caravan	Oblique Offset Frontal with MDB	154	119	62	54, 57, 56, 34, 13, 2	74, 64, 58, 36, 20, 22	-46	0
96 Chevrolet Camaro	Oblique Offset Frontal with MDB	152	80	57	67, 73, 67, 46, 28, 5, 0	85, 81, 71, 50, 36, 23	-47	0
96 Dodge Caravan	In-line Offset Frontal with NMRB	154	131	68	61, 57, 51, 31, 10, 0	81, 64, 53, 33, 17, 17	-43	0
96 Chevrolet Camaro	Offset Rear with MDB	154	108	84	95, 102, 106, 100, 74, 23	107, 107, 107, 101, 79, 35	-35	0

MDB = moving deformable barrier; NMRB = non-moving rigid barrier.

2.2 Selected Computer Reconstruction Programs

Three computer reconstruction programs were selected for use in this project; CRASH PC 2.0, WinSmash 1.2.1, and WinSmash 2.06. These programs were selected because they represent the most widely used programs that calculate impact severity within larger crash databases. The majority of the crash severities coded in the CDS-NASS database were generated by one of these programs.

CRASH PC 2.0 is currently the only program that the NHTSA has validated and made available to the general public. It is a much simpler program in that it offers fewer options and subroutines as compared to the two WinSmash programs. This program was used through the 1980's and into the mid-1990's, before being replaced by the Smash/WinSmash programs. WinSmash 1.2.1 was used during the late 1990's and was represented as a "reformulation" of the original CRASH3 algorithm. It was the first program to provide options for compensation in pole and/or offset-frontal impacts. Contractors at the Transportation Research Corporation (TRC) in Ohio developed this program. WinSmash 2.06 was developed by the Volpe Institute in the late 1990's.

2.3 Field Measurements of Selected Test Vehicles

Each crash-tested vehicle was measured according to standard CDS-NASS protocol (SAE J2433). Figure 1 shows how a vehicle damage profile is measured and documented according to this protocol. Baseline measurements included overhangs, wheelbase, reference stanchion placement, and extent zone measurements. Damage measurements included Field L and D-value, Direct L and D-value, and six equidistant C-values. A crush profile was finalized by adjusting the C-values to account for bumper taper. In some cases, the C-values were further adjusted to account for melted bumper fascia, which occurred post-crash during a second staged performance test (i.e. fire propagation tests).

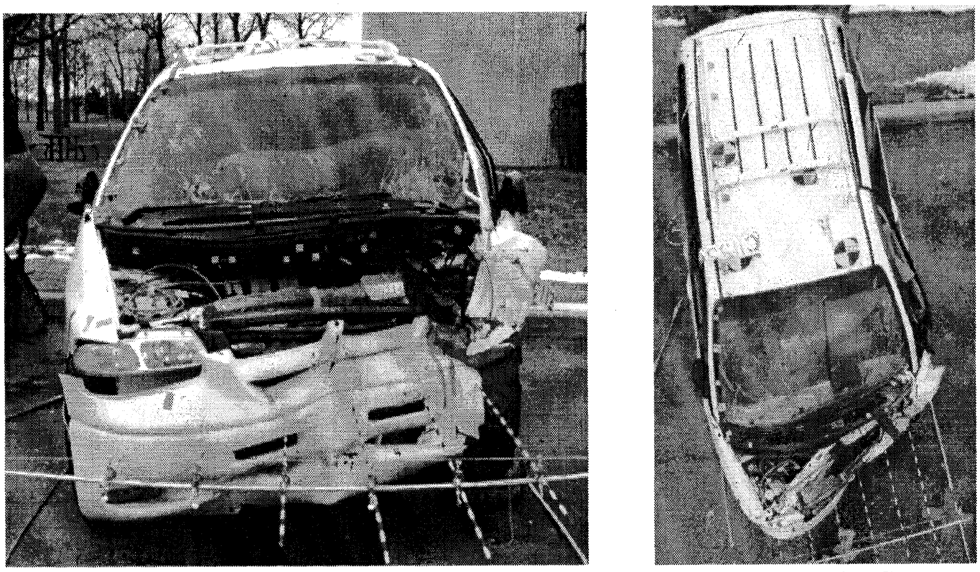


Figure 1 – Front and overhead views of a crush measurements being taken on a Dodge Caravan following a staged offset-frontal crash.

A secondary or alternative crush profile was also used in this project. This secondary crush profile is the raw crush profile as taken in the field. No adjustments were made with regard to bumper taper. The amount of bumper taper and other field adjustments are often called into question even among the most experienced field personnel, therefore, the addition of this alternative crush profile to the parameters of this project seemed to be justified. If this alternative protocol suggests a higher degree of accuracy, then much controversy and debate regarding field and exemplar vehicle measurements could be eliminated.

All of these measurements and adjustments, as well as images of each subject vehicle are documented in detail in Appendix A. A summary of the finalized crush profiles and other field measurements for each subject vehicle is provided in Table 1.

2.4 Program Subroutines and Options

The CRASH PC 2.0 program has only one subroutine that is applicable to the four impact-types studied in this project - that is, the Barrier impact subroutine. The two WinSmash versions provide the Barrier subroutine, but also a subroutine for pole impacts – i.e., the Pole subroutine.

The two WinSmash programs have additional options that supposedly compensate for changes in crash conditions and energy transfer for such things as offset-frontal impacts and vehicles that experience endshift. These are referred to as the Offset option and Endshift option, respectively. While no documentation could be found that describes when and how to use these various options, logic dictates that the Endshift option would only be employed when the nature of the vehicle damage is such that the CDC is incremented (see SAE J224). A vehicle is considered to have experienced endshift when both the right and left sides of the vehicle have moved at least four inches laterally. No documentation could be found, however, to indicate when the Offset option should be employed – i.e., at what range of percent vehicle overlap should the Offset option be implemented.

Although no documentation could be found to explain the proper use of these options, most of these options were used alone or in combination with other options, even when they did not appear to be applicable (e.g., the end-shift option was used even though no end-shifting occurred). The purpose for doing this was to study the effects of using these options or "toggles." The one exception is the Pole subroutine. The Pole subroutine was only employed for the three crashes involving pole impacts and it was not used for the three offset-frontal impacts or the rear impact.

Table 2 summarizes the program subroutines and options, and various combinations that were available and used for the three programs examined in this study.

TABLE 2
Program Subroutines, Options, and Combinations

Subroutine and Options	**CRASH PC**	**WinSmash 1.2.1**	**WinSmash 2.06**
Barrier – No additional options	Yes	Yes	Yes
Pole – No additional	na	Yes	Yes
Barrier – Offset	na	Yes	Yes
Pole - Offset	na	na	Yes
Barrier – Endshift	na	Yes	Yes
Pole – Endshift	na	Yes	Yes
Barrier - Offset and Endshift	na	Yes	Yes
Pole - Offset and Endshift	na	na	Yes

na = not available.

2.5 Input Variables to Computer Programs

2.5.1 PDOF and Vehicle Mass

Other than the crush profile, the selected computer reconstruction programs require additional data about the vehicle and the crash. These data include the principle direction of force (PDOF), vehicle mass (including occupants and cargo), and either a generic size and stiffness indicator (based on wheelbase) or a vehicle specific stiffness coefficient (in terms of a D0 and D1 value).

Since five of the seven crash tests involved in-line impacts, these five vehicles were assigned in-line PDOFs, that is, the four frontal impacts were assigned PDOFs of 360 degrees and the rear impact was assigned a PDOF of 180 degrees. The other two crash tests were oblique impacts. Since the subject vehicle was stopped and the barrier speed and approach angle were known (data supplied by GM), a simple vector analysis was used to determine the PDOF. These PDOFs were then rounded to the nearest 10 degrees in accordance with standard protocol. Both vehicles that were involved in oblique offset-frontal impacts were assigned PDOFs of 330 degrees.

Original specifications for the subject vehicles were obtained from manufacturer published specification manuals. The vehicle mass was measured by GM prior to the crash test. This value includes the mass of all the instrumentation, and anthropomorphic test devices (ATDs).

2.5.2 Generic and Specific Stiffness Coefficients

All three programs used in this project require a measure of the stiffness for the selected vehicle. The protocol for the NHTSA's field investigation projects (NASS, SCI, and CIREN) is to select a "size" and "stiffness" category from a documented list based on the year, make, and model of the selected vehicle. Table 3 shows examples of how these data appear in the CDS-NASS Coding and Editing Manual for the two vehicles used in the staged crash tests selected for this study.

TABLE 3
Generic Size and Stiffness Values from the CDS-NASS Coding and Editing Manual

Model	Includes	Start	End	Size	Stiffness	Model Code
Camaro	SS, RS, LT, Berlinetta, IROC-Z, Z28	1967	1998	3	3	9
Caravan	Mini-Ram, SE, ES, LE: WB = 119" (use 7 stiffness for end impacts, size value for side or rear impacts)	1984	1998	5	7	442
Caravan	Mini-Ram, SE, ES, LE: WB = 112" (use 7 stiffness for end impacts, size value for side or rear impacts)	1984	1998	4	7	442

This measure of vehicle stiffness is commonly referred to as the "generic" stiffness coefficient. The majority, if not all, of the impact severities coded in the larger databases were calculated using these generic stiffness values.

If a vehicle is not listed in the CDS-NASS Coding and Editing Manual, the size and stiffness categories are determined from tables of generic categories. Size category is determined by the subject vehicle's wheelbase. The range of possible wheelbase values for vehicles that are applicable to the program (passenger cars, light trucks, and vans) are grouped into seven of nine possible size categories. Table 4 shows the range of size categories for different wheel bases and vehicle types.

The stiffness category is determined by the case vehicle's stiffness parameters as documented during staged crash tests, the impacted plane (front, side, or rear), and the type of vehicle construction (frame based, unibody, front-wheel drive, etc.). If the vehicle stiffness category is not given in the CDS-NASS Coding and Editing Manual, then a stiffness category is selected from the table in the original CRASH-3 User's Guide and Technical Manual. Table 5 is representative of this table which includes eleven stiffness categories to chose from.

TABLE 4
Vehicle Size Categories by Wheelbase

	Size Category										
	1	2	3	4	5	6	7 Vans	8 Pickups	9 Front-wheel drive and others	10 Movable Barrier	11 Immovable Barrier
Wheelbase (IN)	80.9 to 94.8	94.8 to 101.6	101.6 to 110.4	110.4 to 117.5	117.5 to 123.2	123.2 to 150	109 to 130	Select Category 1 to 6 according to Wheelbase			

TABLE 5
Vehicle Stiffness Categories

	Stiffness Category										
	1	2	3	4	5 (6)	7 * Vans	8* Pickups	9** Front-wheel drive and others	10 Movable Barrier	11 Immovable Barrier
Vehicle Models	Pinto (front) Accord Honda CVCC Prelude Corolla Chevette Fiesta etc	Pinto (rear) Monza Celica Corona Spirit Pacer Gremlin Dasher etc	Supra Mustang Concord Malibu Monarch Zephyr Fairmont Firebird Cressida Monte Carlo (78 -) etc	Chevelle Monte Carlo (-77) Grand Prix Cutlass LeMans (-77) LeBaron etc	LeSabre (-76) Chev V-8 (-76) Riveria (-76) LTD (-76) Delta88 (-76) T-bird (-76) Etc	E150 Dodge B200 Chev G20 Vanagon <u>Other</u> Datsun PU Honcho 4x4 PU Scout II Chev Blazer	Courier El Camino F150 Chev Luv F250 Dodge D100 Ranchero F100 GMC 1500 Toyota SR5	Citation Phoenix Skylark Omega Reliant Aries Escort Lynx		

*Front and rear crash modes only, for side damage, pick a category (1 to 6) by wheelbase.

** Front crash mode only; for side or rear pick a category (1 to 6) by wheelbase.

The size and stiffness categories are used by the program to determine a stiffness coefficient that is used in the reconstruction algorithms to calculate the impact severity (Delta V and/or EBS). The calculated stiffness coefficient is reportedly based on several previous NCAP tests performed for this category of vehicle (but not necessarily the actual make/model). Since the NCAP tests are full-frontal impacts into a rigid barrier, these calculated stiffness coefficients are based on full engagement of the frontal structures of the vehicles. This is where much of the debate and concern over accuracy arises, as a large number of real-world crashes are not full-frontal impacts into rigid barriers.

The CRASH PC 2.0 program only allows for the selection of size and stiffness categories to determine the stiffness coefficient. The two WinSmash programs (v1.2.1 and v2.06) allow for the stiffness coefficient to be determined in this manner, but both programs also allow for the input of vehicle-specific linear stiffness coefficients in the form of slope and intercept points (D0 and D1) in place of "generic" stiffness coefficients. These D0 and D1 values are also calculated from previous crash tests and are based on a specific vehicle make and model as opposed to a group of similar vehicle types. These values can therefore differ somewhat from the generic values but are generally considered to provide more accurate stiffness data when available for a specific case vehicle.

A competent user may determine the D0 and D1 values for a specific vehicle and specific impact type if enough crash test data are available for this specific vehicle and impact type. However, calculating the specific D0 and D1 value from staged crash data is not an easy task for the typical user of these reconstruction programs. When specific stiffness coefficient values are used, they are typically purchased from a reliable engineering firm that has studied the specific crash tests and damage measurements and calculated the vehicle specific stiffness coefficient for this impact type. This method is also not without controversy and debate. There are questions regarding how accurate these stiffness coefficients are if the impact location or damage length of the crash test are not exactly the same as the subject vehicle. Additionally, there is debate on whether the stiffness coefficient should change with the depth of crush to the vehicle, a function that is not currently included in these linear stiffness coefficients.

Since every make and model is not crash tested in every crash mode, the availability of specific stiffness coefficients is also quite limited. For these reasons, as well as the additional cost of purchasing multiple stiffness coefficients for each specific make and model (about $15/vehicle), the general use of specific stiffness coefficients has been limited, and their accuracy and validity have not been determined.

Only four vehicle specific stiffness values were found and purchased for use in this project. Two different values were obtained for the front structure of a Chevrolet Camaro (full-frontal impact). One of these was based on NHTSA crash test data and the other was based on the engineering companies' "adjustment" of the same test data. One set of specific stiffness values for the Dodge Caravan was obtained (offset-frontal impact, 40% overlap). One set of values for the rear stiffness of the Chevrolet Camaro (full-rear impact) was also obtained. No vehicle specific stiffness values could be found for the other impact mode (pole impact). Therefore, no pole impacts were calculated using vehicle specific stiffness values. Two of the three offset-frontal impacts (those involving the Caravans) were calculated using vehicle-specific stiffness values. The third offset crash (Camaro) was also calculated using two different specific vehicle stiffness values, although both of these values were based on full-frontal impacts rather than offset impacts. Finally, the rear impact crash was also calculated using vehicle specific stiffness values.

2.5.3 Adjusted Versus Raw Crush Profiles

As mentioned in Section 2.3, two sets of crush profiles were obtained for each of the seven crash tested vehicles. These are referred to as the "raw" and the "adjusted" crush profiles. The protocol for measuring the crush to a case vehicle involves establishing a rectangular "box" around the damaged vehicle which is based on the original overall length and overall width of the vehicle. The sides of this box then serve as a reference line from which crush depths or C-values can be measured. The initial crush profile that is measured from this reference line is the "raw" crush profile. The protocol for obtaining the "adjusted" crush profile requires the researcher to measure an exemplar vehicle and deduct the necessary free space or bumper taper from the raw crush profile. The adjusted crush profile, therefore, is a more accurate representation of the residual crush sustained by the case vehicle.

2.5.4 Length of Crush Profile

The length of the crush profile is defined as the combined length of the direct and induced damage. This is also called the Field L and is the measurement that is used to determine the location at which each of the individual crush values is taken. The crush values are typically taken at six equidistant points along the Field L (although occasionally they are taken at two or four equidistant points along the Field L).

Each of the three programs studied requires the user to input a Smash L. For end plane impacts, the protocol for the crash reconstruction programs has been to use the UEW and not the Field L as the Smash L. There has been informal discussion between crash investigators about using the Field L as the Smash L for offset-frontal impacts and using the Direct L as the Smash L for narrow pole-type impacts. It was decided that this study would be a logical place to use these different measures as the Smash L. Therefore, the UEW, Field L, and Direct L were all interchanged as the Smash L for each crash in all three programs.

2.5.5 Summary of Input Options Used

Table 6 shows the data input options that were used in each of the three programs studied. This table does not, however, depict the combinations of data input options that were employed. For example, in CRASH PC, one run might use the generic stiffness coefficients along with an adjusted profile, and the UEW as the Smash L. Another run might use the generic stiffness coefficients along with an adjusted profile, and the Field L as the Smash L.

TABLE 6
Data Input Variations Used

	CRASH PC	**WinSmash 1.2.1**	**WinSmash 2.06**
Generic Stiffness Coefficients	Yes	Yes	Yes
Specific Stiffness Coefficients	na	Yes	Yes
Adjusted Crush Profile	Yes	Yes	Yes
Raw Crush Profile	Yes	Yes	Yes
UEW as Smash L	Yes	Yes	Yes
Field L as Smash L	Yes	Yes	Yes
Direct L as Smash L	Yes	Yes	Yes

na = not available.

2.6 Implementation of Programs, Program Options, and Input Options

Since CRASH PC 2.0 has only one subroutine (Barrier Impact) and does not allow the user to input vehicle specific stiffness values, the only input variations that could be tested in this program were the two types of crush profiles (raw vs. adjusted) and the three variations of SMASH L. SMASH Ls were interchanged using the undeformed end width (UEW), the Field L (post-crash width of direct and induced damage), and Direct L (width of direct damage only) for each applicable crush profile. Therefore, six runs were made for each subject vehicle using these input parameters. A total of 42 different runs were conducted using CRASH PC 2.0 and the seven subject vehicles. Appendix B provides details on each run, their input variations, and their respective outputs.

WinSmash 1.2.1 has two subroutines that were examined (Barrier Impact and Pole Impact). Additionally, other program options and combinations of options allowed for additional runs to be made and evaluated (e.g. Offset option and Endshift option). Each vehicle also had two crush profiles (raw and adjusted) to be used with the other combinations of options. Also, four of the subject vehicles had at least one associated vehicle specific stiffness value, and one vehicle had two such vehicle specific stiffness values. Given these parameters, a total of 300 different runs were conducted using WinSmash 1.2.1 and the seven subject vehicles. Appendix C provides details on each run, their input variations, and their respective outputs.

WinSmash 2.06 also has two subroutines that were examined (Barrier Impact and Pole Impact). The ability to use combinations of options within this program increased the number of optional runs. For five of the seven subject vehicles, a total of 48 runs were required to test every possible option to each vehicle. For the one vehicle with two different specific stiffness values (Camaro – offset-frontal impact), a total of 72 runs were required to test every possible option. For the sole rear-impacted subject vehicle, only 24 runs were required to test every combination. A total of 336 runs were conducted using WinSmash 2.06 and the seven subject vehicles. Appendix D provides details on each run, their input variations, and their respective outputs.

3.0 RESULTS AND ANALYSIS

Detailed results for each computer run are provided in Appendices B, C, and D. This section of the report begins by describing a set of "Baseline" results along with comparisons to the measured velocity changes. These Baseline results are the crash severity outputs obtained by applying the standard CDS-NASS protocol to the three programs; that is, by using UEW as the Smash L, the adjusted crush profile, and generic size and stiffness values. These include the results obtained using both the Barrier and the Pole subroutines of each program, as applicable.

Additional results are provided in subsequent subsections. This includes the effects of using the Offset and Endshift options alone and in various combinations, the effects of using the raw crush profile, the effects of using vehicle-specific stiffness values, and the effects of using other field measurements (e.g. Field L and/or Direct L) for the Smash L.

3.1 Baseline Results

Table 7 shows the baseline results obtained from all three programs when the CDS-NASS protocols were applied to each of the seven crash-tested vehicles. The fourth column gives the actual or measured Delta V, to which program outputs are compared.

TABLE 7

Results for **Baseline** Conditions, Compared to Measured Changes in Speed

Test #	**Vehicle**	**Crash Type**	**Measured (kph)**	**CRASH PC**	**WinSmash 1.2.1**		**WinSmash 2.06**	
				Barrier (kph)	**Barrier (kph)**	**Pole (kph)**	**Barrier (kph)**	**Pole (kph)**
C11108	1996 Dodge Caravan	In-line Pole	**62.0**	62.0	62.8	105.5	61.9	103.9
C11591	1996 Chevrolet Camaro	In-line Pole	**63.0**	59.9	73.4	126.4	71.0	122.4
C11279	1996 Dodge Caravan	In-line Pole	**62.0**	68.0	68.4	116.0	67.2	114.0
C11167	1996 Dodge Caravan	Oblique Offset Frontal with MDB	**53.0**	50.2	36.1	-	42.2	-
C11647	1996 Chevrolet Camaro	Oblique Offset Frontal with MDB	**53.0**	48	41.8	-	46.3	-
C11226	1996 Dodge Caravan	In-line Offset Frontal with NMRB	**67.5**	41	45	-	43.0	-
C11408	1996 Chevrolet Camaro	Offset Rear with MDB	**39.0**	58.8	58.7	-	57.2	-

Shaded cells indicate results that are within 10% of the measured velocity change.

For five of the seven crashes, the CRASH PC program calculated velocity changes that are within 10% of the measured velocity changes. The results for all three pole impacts are within this tolerance range, as were results for both oblique offset-frontal impacts.

The program underestimated the one in-line offset-frontal crash by 39% and it overestimated the rear impact by 51%. Interestingly, both WinSmash programs did much better for in-line pole impacts when the Barrier subroutine was used than when the Pole subroutine was used.

The Baseline results obtained using the Barrier subroutine of the WinSmash 1.2.1 program show that only one of the seven runs produced a calculated velocity change that is within 10% of the measured velocity change, and this was for an in-line pole impact. The other two pole impacts are overestimated by 17% and 10.3%. Delta Vs for the two oblique offset-frontal crashes are both underestimated by 20% and 13% by the Barrier option in WinSmash 1.2.1. The in-line offset-frontal crash is underestimated by 33%, while the rear impact crash severity is overestimated by 51%.

None of the runs using the Pole subroutine of the WinSmash 1.2.1 program produced Delta Vs within 10% of the measured velocity change for any of the crashes. Interestingly, crash severities for all three of the in-line pole impacts are grossly overestimated by an average of 86% when the Pole subroutine is used. Thus, the Barrier option produces much better results for in-line pole impacts, than the Pole subroutine did.

The Baseline results obtained using the Barrier subroutine of the WinSmash 2.06 program show that only two of the seven runs produced a velocity change estimate that is within 10% of the measured velocity change, and both of these are for in-line pole impacts. The third pole impact is overestimated by 13%, and the two oblique offset-frontal crashes are underestimated by 20% and 13%. The in-line offset-frontal impact is also underestimated and is 36% less than the measured velocity change. The full-rear impact is overestimated by 47%.

When using the Pole subroutine of WinSmash 2.06, none of the three calculated velocity changes for the in-line pole impacts are within 10% of the measured velocity changes for these tests. As with WinSmash 1.2.1, the three pole impacts are overestimated by an average of 82%.

3.2 Offset Option

The Baseline reconstructions using UEW, adjusted crush profile, and generic stiffness values, were rerun with the Offset option activated. Table 8 shows the results that were obtained under these conditions. There is no Offset option for the CRASH PC program and the Offset option becomes disabled when the Pole subroutine is activated in the WinSmash 1.2.1 program. The Offset option is also disabled when a rear impact is selected in both the WinSmash 1.2.1 and the 2.06 programs, therefore no results are shown for these situations.

Three of the six crash runs using the WinSmash 1.2.1 program with the Offset option produced results that are within 10% of the measured velocity change. All three of these are for the offset-frontal impacts. None of the pole impact reconstructions are within 10% of the measured velocity changes. Under these conditions, all three pole impacts are overestimated by an average of 60%.

Two of the six reconstructions using the Barrier subroutine of the WinSmash 2.06 program produced results that are within 10% of the measured velocity change when the Offset option was implemented. Both of these involved offset-frontal impacts (one in-line and one oblique). The other oblique offset-frontal impact is overestimated by 17%. Under these conditions, all three pole impacts are overestimated by an average of 56%.

When using the Pole subroutine of WinSmash 2.06 with the Offset option, none of the three reconstructions for the pole impacts produced results that are within 10% of the measured velocity changes. All three pole impacts are overestimated by an average of 198%.

TABLE 8

Results for **Baseline Conditions with Offset Option On**, Compared to Measured Changes in Speed

Test #	Vehicle	Crash Type	Measured (kph)	CRASH PC	WS 1.2.1		WS 2.06	
				Barrier (kph)	Barrier (kph)	Pole (kph)	Barrier (kph)	Pole (kph)
C11108	1996 Dodge Caravan	In-line Pole	**62.0**	-	98.0	-	96.5	187.1
C11591	1996 Camaro	In-line Pole	**63.0**	-	92.4	-	89.5	165.3
C11279	1996 Dodge Caravan	In-line Pole	**62.0**	-	107.5	-	105.6	205.2
C11167	1996 Dodge Caravan	Oblique Offset Frontal with MDB	**53.0**	-	53.2	-	62.1	-
C11647	1996 Camaro	Oblique Offset Frontal with MDB	**53.0**	-	51.1	-	56.5	-
C11226	1996 Dodge Caravan	In-line Offset Frontal with NMRB	**67.5**	-	66.2	-	63.3	-
C11408	1996 Camaro	Offset Rear with MDB	**39.0**	-	-	-	-	-

Shaded cells indicate results that are within 10% of the measured velocity change.

3.3 EndShift Option

The Baseline runs were rerun with only the Endshift option activated. Table 9 shows the results that were obtained under these conditions. There is no Endshift option available for the CRASH PC program, and therefore no results are provided for these situations.

TABLE 9

Results for **Baseline Conditions with EndShift Option On**,

Compared to Measured Changes in Speed

Test #	Vehicle	Crash Type	Measured (kph)	CRASH PC	WS 1.2.1		WS 2.06	
				Barrier (kph)	Barrier (kph)	Pole (kph)	Barrier (kph)	Pole (kph)
C11108	1996 Dodge Caravan	In-line Pole	**62.0**	-	62.8	105.5	61.9	103.9
C11591	1996 Chevrolet Camaro	In-line Pole	**63.0**	-	73.4	126.4	71.0	122.4
C11279	1996 Dodge Caravan	In-line Pole	**62.0**	-	68.4	116.0	67.2	114.0
C11167	1996 Dodge Caravan	Oblique Offset Frontal	**53.0**	-	41.7	-	48.7	-
C11647	1996 Chevrolet Camaro	Oblique Offset Frontal	**53.0**	-	48.3	-	53.4	-
C11226	1996 Dodge Caravan	In-line Offset Frontal	**67.5**	-	45.0	-	43.0	-
C11408	1996 Chevrolet Camaro	Full-rear impact	**39.0**	-	58.7	-	57.2	-

Shaded cells indicate results that are within 10% of the measured velocity change.

Under these conditions, two of the seven reconstructions with the Barrier subroutine of the WinSmash 1.2.1 program produced results that are within 10% of the measured velocity change. This includes one pole impact and one oblique offset-frontal impact. Comparison to the Baseline results shows that, although the Endshift option is activated, there is no effect on the output when the PDOF is “in-line”, that is, 360 degrees or 180 degrees. The only change occurs for the two oblique impacts (330 degree PDOFs), where the output is increased an average of 16% over the Baseline output. This demonstrates that the programmer(s) did not simply include an additional algorithm that increases the output, but rather added an algorithm that takes into consideration the PDOF. Endshifting does not occur in situations with "in-line" PDOFs. The PDOF must have some obliqueness in order to produce endshifting to the vehicle. While two of the seven vehicles did sustain an oblique PDOF, neither of these vehicles truly experienced endshift. Therefore, an accurate assessment of the program's performance under these conditions is limited.

When using the Pole subroutine of the WinSmash 1.2.1 program and activating the Endshift option, the results are exactly the same as the Baseline results for the three pole impact crashes. All three of these pole crashes involved “in-line” impacts (PDOFs of 360 degrees). All three pole impacts are overestimated by an average of 86% by the Pole subroutine of WinSmash 1.2.1 with the Endshift option.

Applying the Barrier subroutine of the WinSmash 2.06 program to these same conditions produced similar results. Only the reconstructions of the two oblique offset-frontal impacts were effected by the use of the Endshift option, while the reconstructions of the five in-line impacts produced the same results as the Baseline outputs. Again, the outputs for the two oblique impacts are increased by 16% over the Baseline results. Four of the seven crashes produced results that are within 10% of the measured velocity changes. While this appears to be a better performance over the baseline results, it should be noted that none of these vehicles meet the criteria for coding an endshift.

Use of the Pole subroutine in the WinSmash 2.06 program along with the Endshift option produced the exact same results as the Baseline outputs. None of the reconstructions of the three pole impacts produced results within 10% of the measured velocity changes. All three of the pole impacts are overestimated by an average of 82%.

3.4 Combining the Offset and Endshift Options

The Baseline runs were again repeated but with both the Offset and the Endshift options activated. Table 10 shows the results that were obtained under these conditions. The Offset option becomes disabled when the Pole subroutine is activated in the WinSmash 1.2.1 program. The Offset option is also disabled when a rear impact is selected in both the WinSmash 1.2.1 and the 2.06 programs. Therefore, the combination of Offset and Endshift options was not implemented for these situations.

For both the WinSmash 1.2.1 and 2.06 programs, the Endshift option produced no change in the results when the impact was “in-line;” therefore, the results for four of the six impacts are exactly the same as those from the runs with only the Offset option activated. The results for the two oblique impacts (330 degree PDOFs) are, however, different when the Offset and Endshift options are combined.

Applying both the Offset and Endshift options to the Baseline runs in the Barrier subroutine of the WinSmash 1.2.1 program resulted in only one calculated velocity change that is within 10% of the measured velocity change. This is for one of the in-line offset-frontal crashes and is exactly the same result as when only the Offset option was applied. Although neither of the reconstructions for the oblique offset-frontal crashes produced results that are within 10% of the measured velocity change, both impacts produced results that are 15% greater than those with just the Offset option activated. Given that none of the tested vehicles experienced endshifting, it is unclear as to whether or not this increase in output is accurate or justified.

TABLE 10
Results from Baseline **Conditions with Both Offset and EndShift Options On,**
Compared to Measured Changes in Speed

Test #	**Vehicle**	**Crash Type**	**Measured (kph)**	**CRASH PC**	**WS 1.2.1**		**WS 2.06**	
				Barrier (kph)	**Barrier (kph)**	**Pole (kph)**	**Barrier (kph)**	**Pole (kph)**
C11108	1996 Dodge Caravan	In-line Pole	**62.0**	-	98.0	-	96.5	187.1
C11591	1996 Chevrolet Camaro	In-line Pole	**63.0**	-	92.4	-	89.5	165.3
C11279	1996 Dodge Caravan	In-line Pole	**62.0**	-	107.5	-	105.6	205.2
C11167	1996 Dodge Caravan	Oblique Offset Frontal with MDB	**53.0**	-	61.4	-	71.7	-
C11647	1996 Chevrolet Camaro	Oblique Offset Frontal with MDB	**53.0**	-	59.0	-	65.3	-
C11226	1996 Dodge Caravan	In-line Offset Frontal with NMRB	**67.5**	-	66.2	-	63.3	-
C11408	1996 Chevrolet Camaro	Offset Rear with MDB	**39.0**	-	-	-	-	-

Shaded cells indicate results that are within 10% of the measured velocity change.

Applying both the Offset and Endshift options to the Baseline runs using the Barrier subroutine of the WinSmash 2.06 program resulted in only one calculated velocity change that is within 10% of the measured velocity change. This is for the reconstruction of the in-line offset-frontal crash, and the result is exactly the same as when only the Offset option was applied. Although neither of the oblique offset-frontal crashes produced results that are within 10% of the measured velocity change, both impacts produced results that are 15% greater than those with just the Offset option activated.

Applying both the Offset and Endshift options to the Baseline runs using the Pole subroutine of the WinSmash 2.06 program resulted in no results that are within 10% of the measured velocity change. Since all three pole impacts are "in-line" (PDOFs = 360 degrees), the results obtained under these conditions are exactly the same as those obtained when only the Offset option was activated. The program does not make any algorithmic changes with regard to endshifting unless the PDOF is oblique (i.e. not in-line). All three pole impacts are overestimated by an average of 198%.

3.5 Using Raw Crush Profiles

Raw crush profiles, or crush profiles that are not adjusted to compensate for bumper taper, were also used as input to the three reconstruction programs, instead of the adjusted profiles. This was done for two reasons. First, it has been reported that these reconstruction programs have a tendency to underestimate the velocity changes actually experienced and increasing the amount of crush would increase the output. Second, a raw crush profile is more easily obtained and verified than an adjusted profile. Therefore, if the use of raw crush profiles provided better and more accurate results, then time and labor would be reduced while the output accuracy was increased. Since the raw crush profile is always greater than the adjusted crush profile, it was hypothesized that use of the raw crush profile might provide slightly higher and more accurate results.

The raw crush profiles were applied to every possible set of input parameters that the adjusted crush profiles were applied to, but only the results for the Baseline runs are presented because they represent the best-case scenario for using raw crush profiles. Table 11 shows the baseline results but using raw instead of adjusted crush profiles. All results obtained from using the raw crush profiles are provided in Appendices B, C, and D.

TABLE 11
Results for **Baseline Conditions with Raw Crush Profiles**,
Compared to Measured Changes in Speed

Test #	**Vehicle**	**Crash Type**	**Measured (kph)**	**CRASH PC**	**WS 1.2.1**		**WS 2.06**	
				Barrier (kph)	**Barrier (kph)**	**Pole (kph)**	**Barrier (kph)**	**Pole (kph)**
C11108	1996 Dodge Caravan	In-line Pole	**62.0**	67.9	68.3	115.8	67.2	114.1
C11591	1996 Chevrolet Camaro	In-line Pole	**63.0**	70.7	86.6	152.5	83.6	147.3
C11279	1996 Dodge Caravan	In-line Pole	**62.0**	74.9	74.7	128.2	73.4	126.0
C11167	1996 Dodge Caravan	Oblique Offset Frontal with MDB	**53.0**	56.8	40.9	-	47.7	-
C11647	1996 Chevrolet Camaro	Oblique Offset Frontal with MDB	**53.0**	60.3	53.3	-	58.8	-
C11226	1996 Dodge Caravan	In-line Offset Frontal with NMRB	**67.5**	46.8	50.8	-	48.6	-
C11408	1996 Chevrolet Camaro	Offset Rear with MDB	**39.0**	66.8	67.1	-	65.3	-

Shaded cells indicate results that are within 10% of the measured velocity change.

The calculated velocity changes obtained using the raw crush profiles are slightly higher than those obtained with the adjusted crush profiles. This is true for the reconstruction of every crash test, using every program and every subroutine. The percentage increase is, however, not consistent across the crash reconstructions because the bumper taper (or amount of adjustment) is not consistent between the test vehicles. The Barrier subroutines in CRASH PC, WinSmash 1.2.1, and WinSmash 2.06 produced two calculated velocity changes that are within 10% of the measured velocity changes. Only five of the 21 runs using the Barrier subroutine resulted in underestimated Delta Vs. The results for the remaining 16 barrier runs are overestimated. This compares to eleven of 21 barrier runs that were underestimated when applying the same inputs except using adjusted crush profiles.

Results obtained using the Pole subroutine in both the WinSmash 1.2.1 and 2.06 also produced slightly higher Delta Vs than when the adjusted crush profiles were used. All three pole impacts produced velocity changes that overestimate the actual Delta V by an average of 110%.

Overall, using raw crush profiles resulted in only six outputs that were within 10% of the measured velocity changes (two runs within each program). This compares to eight outputs that were within 10% of the measured velocity changes when applying the same options but using adjusted crush profiles (five CRASH PC runs, one WinSmash 1.2.1 run, and two WinSmash 2.06 runs).

3.6 Using Vehicle-Specific Stiffness Values

Vehicle-specific stiffness values from barrier impact tests were purchased for the front of a Dodge Caravan (40% left overlap), the front of a Chevrolet Camaro (100% overlap), and the rear of a Chevrolet Camaro (100% overlap). These are referred to as specific stiffness values #1. An additional, but different, set of values was obtained for the front of a Chevrolet Camaro (100% overlap). These are referred to as specific stiffness values #2. No vehicle-specific stiffness values were found for the pole-type impacts. Although the specific stiffness values obtained for the front of a 1996 Chevrolet Camaro are based on a full-frontal rigid-barrier impact, these values were used in this study even though the vehicles were not tested in this mode. Since these values were purchased from a reliable engineering company, they are considered to be proprietary data and the actual values used are not included this report. These values can be obtained for a nominal cost ($15/vehicle) from Neptune Engineering, Incorporated (www.neptuneeng.com).

These vehicle-specific stiffness values were used in every possible combination of input variables in both the WinSmash 1.2.1 and 2.06 programs. While separate runs were conducted for each possible combination of input variables, only the more meaningful results are presented in this section. All runs utilizing the vehicle-specific stiffness values are provided in Appendices C and D.

Table 12 provides the results obtained when the vehicle-specific stiffness values #1 are used in the Baseline runs (UEW and adjusted crush profiles) with the Barrier subroutine of the WinSmash 1.2.1 and 2.06 programs.

The data displayed in Table 12 indicate that the vehicle-specific stiffness values for the front of the Dodge Caravan are relatively "softer" than the generic stiffness values. The results are 15% lower than those obtained using the generic stiffness values.

The vehicle-specific stiffness values for the front and the rear of the Chevrolet Camaro are relatively "harder" than the generic stiffness values. The results for the frontal impact are 8% higher than those obtained when using the generic stiffness values and 33% higher for the rear impact. This would seem to indicate that the accuracy of the specific vehicle stiffness values is somewhat questionable. This is probably related to several problem areas; such as, the specific values are based on too few test examples, the specific values are applicable to only crashes that meet the exact same criteria (e.g. exact direct damage length as tested vehicle), and/or errors generated by using different field measurement techniques (e.g. data from tested vehicles often indicate that only one, two or three crush measurements were taken as opposed to the standard of six).

TABLE 12

Results for **Baseline Conditions with Vehicle-Specific Stiffness Values #1,** Compared to Measured Changes in Speed

Test #	Vehicle	Crash Type	Measured (kph)	CRASH PC	WS 1.2.1		WS 2.06	
				Barrier (kph)	Barrier (kph)	Pole (kph)	Barrier (kph)	Pole (kph)
C11167	1996 Dodge Caravan	Oblique Offset Frontal with MDB	**53.0**	-	30.8	-	36.0	-
C11647	1996 Chevrolet Camaro	Oblique Offset Frontal with MDB	**53.0**	-	45.2	-	50.0	-
C11226	1996 Dodge Caravan	In-line Offset Frontal with NMRB	**67.5**	-	38.3	-	36.7	-
C11408	1996 Chevrolet Camaro	Offset Rear with MDB	**39.0**	-	78.4	-	76.2	-

Shaded cells indicate results that are within 10% of the measured velocity change.

Table 13 shows the results obtained when the vehicle-specific stiffness values #1 were used in the Barrier subroutines for Baseline runs but with the Offset option activated. Each program handled the input of vehicle-specific stiffness values somewhat differently. In the WinSmash 1.2.1 program, the Offset option remained functional when inputting vehicle-specific stiffness values and the Offset option therefore influenced the results. In the WinSmash 2.06 program, the Offset option appeared to remain operational, but it had no effect on the results (i.e. the results were the same as when the Offset option was deactivated).

TABLE 13

Results for **Baseline Conditions with Vehicle-Specific Stiffness Values #1 and Offset Option On,** Compared to Measured Changes in Speed

Test #	Vehicle	Crash Type	Measured (kph)	CRASH PC	WS 1.2.1		WS 2.06	
				Barrier (kph)	Barrier (kph)	Pole (kph)	Barrier (kph)	Pole (kph)
C11167	1996 Dodge Caravan	Oblique Offset Frontal with MDB	**53.0**	-	48.9	-	36.0	-
C11647	1996 Chevrolet Camaro	Oblique Offset Frontal with MDB	**53.0**	-	58.0	-	50.0	-
C11226	1996 Dodge Caravan	In-line Offset Frontal with NMRB	**67.5**	-	60.8	-	36.7	-
C11408	1996 Chevrolet Camaro	Full-rear impact with MDB	**39.0**	-	-	-	-	-

Shaded cells indicate results that are within 10% of the measured velocity change.

Under these conditions, the WinSmash 1.2.1 program produced results that were within 10% of the measured velocity changes for all three offset-frontal impacts. In two cases, the results are slight underestimates, and in one case the result was a slight overestimate.

The WinSmash 2.06 program did not perform quite as well as WinSmash 1.2.1 under these same conditions. Only one of the reconstructions of the three offset-frontal crashes produced results that are within 10% of the measured velocity changes. All three underestimated the actual Delta V, but two reconstructions underestimated the actual Delta V by an average of 39%. As discussed previously, the Offset option appears to be functional under these circumstances, but there is no effect on the output when compared to the same run without the Offset option activated. Under these conditions, only one run was within 10% of the measured velocity change as compared to two runs that were within this 10% tolerance when using generic stiffness values.

As previously mentioned, a second set of vehicle-specific stiffness values #2 was obtained for the front of a Chevrolet Camaro. This second set of values was also used with both versions of the WinSmash program for the Baseline run of this impact. Table 14 shows that this second set of stiffness values is "softer" than the first set, so that the Delta V is reduced even further.

TABLE 14

Results for **Baseline Conditions with Vehicle-Specific Stiffness Values #2,** Compared to Measured Changes in Speed

Test #	**Vehicle**	**Crash Type**	**Measured (kph)**	**CRASH PC**	**WS 1.2.1**		**WS 2.06**	
				Barrier (kph)	**Barrier (kph)**	**Pole (kph)**	**Barrier (kph)**	**Pole (kph)**
C11647	1996 Chevrolet Camaro	Oblique Offset Frontal with MDB	**53.0**	-	32.4	-	35.8	-

Shaded cells indicate results that are within 10% of the measured velocity change.

Table 15 shows the results obtained when using this second set of vehicle specific stiffness values in both programs for the Baseline runs but with the Offset option activated. Neither program produced a calculated velocity change that is within 10% of the measured velocity change using these conditions. Again, in the WinSmash 2.06 program, activation of user-defined stiffness values apparently deactivates any effect of the Offset option. The Offset option appears to turn on and off in a normal manner, but no longer has an effect on the output.

TABLE 15

Results from **Baseline Conditions with Vehicle-Specific Stiffness Values #2 and Offset Option On,** Compared to Measured Changes in Speed

Test #	**Vehicle**	**Crash Type**	**Measured (kph)**	**CRASH PC**	**WS 1.2.1**		**WS 2.06**	
				Barrier (kph)	**Barrier (kph)**	**Pole (kph)**	**Barrier (kph)**	**Pole (kph)**
C11647	1996 Chevrolet Camaro	Oblique Offset Frontal with MDB	**53.0**	-	40.7	-	35.8	-

Shaded cells indicate results that are within 10% of the measured velocity change.

3.7 Using Field L and Direct L as the Smash L

A portion of this project was devoted to examining the effects of using either the Field L and/or the Direct L in place of the UEW as the Smash L. This was done in order to study the effects of increasing/decreasing the Smash L. Recent discussions with crash investigators and NHTSA employees indicate that use of the Direct L as the Smash L can provide better results, particularly for crashes involving pole-type impacts. Likewise, other discussions have centered on using the Field L as the Smash L in offset-frontal cases. This project provided an excellent opportunity to study the use of these alternative field measurements as the Smash L.

The Field L and the Direct L were used as the Smash L in every possible combination of input variables. A clear pattern emerged in this process, that is, as the Smash L decreased so did the output. It became obvious that using the Field L in offset-frontal impacts was not an appropriate method to improve outputs that were already considered low. Table 16 shows the results obtained for all three programs when Field L was used as the Smash L and Baseline conditions for all other variables, for both Barrier and Pole subroutines. All other results obtained using the Field L as the Smash L are provided in Appendices B, C, and D.

TABLE 16
Results for **Baseline Conditions but Using Field L as Smash L,**
Compared to Measured Changes in Speed

Test #	Vehicle	Crash Type	Measured (kph)	CRASH PC	WS 1.2.1		WS 2.06	
				Barrier (kph)	Barrier (kph)	Pole (kph)	Barrier (kph)	Pole (kph)
C11108	1996 Dodge Caravan	In-line Pole	**62.0**	48.7	48.8	82.0	48.1	80.8
C11591	1996 Chevrolet Camaro	In-line Pole	**63.0**	35.5	42.9	74.0	41.6	71.6
C11279	1996 Dodge Caravan	In-line Pole	**62.0**	49.8	49.6	84.1	48.7	82.7
C11167	1996 Dodge Caravan	Oblique Offset Frontal with MDB	**53.0**	43.7	31.7	-	37.1	-
C11647	1996 Chevrolet Camaro	Oblique Offset Frontal with MDB	**53.0**	34.3	30.3	-	33.6	-
C11226	1996 Dodge Caravan	In-line Offset Frontal with NMRB	**67.5**	38.2	41.5	-	39.7	-
C11408	1996 Chevrolet Camaro	Full-rear impact with MDB	**39.0**	49.5	49.2	-	47.9	-

Shaded cells indicate results that are within 10% of the measured velocity change.

In general, using of the Field L as the Smash L reduces the program outputs when compared to the results obtained using the UEW as the Smash L. Under these conditions, none of the calculated results are within 10% of the measured velocity changes. All six of the frontal impacts (three poles and three offset-frontals) are underestimated in the Barrier subroutines and the rear impact was still overestimated. All three of the pole impacts are overestimated when the Field L is used as the Smash L and the Pole subroutines are employed.

Table 17 shows the results for all three programs obtained when the Direct L is used as the Smash L and all other variables set to Baseline conditions, for both Barrier and Pole subroutines. All other results obtained using the Direct L as the Smash L are provided in Appendices B, C, and D.

Only one of the twenty-one Barrier subroutine runs produced results that are within 10% of the measured velocity changes. This occurred with the WinSmash 2.06 program and the reconstruction of the full-rear impact.

Two of the six reconstructions using the Pole subroutine produced results that are within 10% of the measured velocity changes. All six of these runs are underestimated, and results for the four runs that did not produce results within 10% of the measured velocity changes are underestimated by an average of 20%. While the application of the Direct L as the Smash L in the Pole subroutine did reduce the grossly overestimated results produced by using the Pole subroutine while using the UEW as the Smash L, these results were the most accurate obtained while using the Pole subroutine. However, they still were not as accurate as those obtained while using the Barrier subroutine with the UEW as the Smash L and generic stiffness values (baseline run).

TABLE 17

Results from **Baseline Conditions but Using Direct L as Smash L,**

Compared to Measured Changes in Speed

Test #	**Vehicle**	**Crash Type**	**Measured (kph)**	**CRASH PC**	**WS 1.2.1**		**WS 2.06**	
				Barrier (kph)	**Barrier (kph)**	**Pole (kph)**	**Barrier (kph)**	**Pole (kph)**
C11108	1996 Dodge Caravan	In-line Pole	**62.0**	32.2	32.0	53.8	31.5	53.0
C11591	1996 Chevrolet Camaro	In-line Pole	**63.0**	29.5	35.7	61.5	34.6	59.6
C11279	1996 Dodge Caravan	In-line Pole	**62.0**	27.3	27.0	45.8	26.5	45.0
C11167	1996 Dodge Caravan	Oblique Offset Frontal with MDB	**53.0**	31.1	22.9	-	26.8	-
C11647	1996 Chevrolet Camaro	Oblique Offset Frontalwith MDB	**53.0**	28.8	25.6	-	28.3	-
C11226	1996 Dodge Caravan	In-line Offset Frontal with NMRB	**67.5**	28.1	29.9	-	28.6	-
C11408	1996 Chevrolet Camaro	Full-rear impact with MDB	**39.0**	43.7	43.4	-	42.2	-

Shaded cells indicate results that are within 10% of the measured velocity change.

4.0 SUMMARY AND DISCUSSION

4.1 Pole vs. Barrier Subroutine

Both versions of the WinSmash program (1.2.1 and 2.06) include subroutines that attempt to compensate for loading in narrow, pole-type impacts. In both programs, applying standard CDS-NASS protocol, along with the Pole subroutine to the three stated pole impacts resulted in grossly overestimated crash severities. These results averaged 70% higher than the results obtained using the same data inputs but using the Barrier subroutine. When using the Field L or the Direct L in place of the UEW as the SMASH L, the results are reduced significantly, but they are still not as accurate as those obtained using the Barrier subroutine for pole-type impacts. Only 4 of 144 runs made using the Pole subroutine in both WinSmash 1.2.1 and 2.06 produce results that are within 10% of the measured velocity changes. The results of this study therefore do not support the use of the Pole subroutine for pole-type frontal impacts in either the WinSmash 1.2.1 or WinSmash 2.06 programs.

4.2 Offset Option

An offset option switch appears in both the WinSmash 1.2.1 and WinSmash 2.06 programs but not in the CRASH PC program. Also, in WinSmash 1.2.1, the offset option becomes inactive when the Pole subroutine is used. In WinSmash 1.2.1, the offset option can only be used in the Barrier subroutine. Use of the offset option always increased the calculated velocity change. The percentage increase averaged 43% for the six crashes that were applicable to use of the offset option, 46% for the three pole impacts and 39% for the three offset-frontal impacts. The percent increase was not exactly the same when comparing one crash to another, but the percent increase was exactly the same when comparing the two programs using the same crash. It appears that the embedded algorithm that is applied when the offset option is activated is exactly the same in both the WinSmash 1.2.1 and WinSmash 2.06 programs. There is one exception to this. In WinSmash 2.06, when a user defined stiffness value is used, the offset option no longer has any effect on the output. The option appears to still be active, but the output indicates that it has been de-activated.

For the three pole impacts in this study, use of the offset option decreased the accuracy of the calculated velocity change in all possible scenarios. It should be noted that most users would not activate the offset option for impacts of this type because the direct damage from the pole impact did not involve either bumper corner and this impact type would not be considered an offset-frontal impact.

For the three offset-frontal impacts in this study, use of the Offset option increased the accuracy of the calculated velocity change. When using WinSmash 1.2.1 and applying the CDS-NASS protocol (Barrier subroutine, UEW as Smash L, adjusted profile, and generic stiffness values), the calculated velocity changes produced are underestimated in all three offset-frontal crashes. However, when the Offset option was activated, all three runs produced velocity changes that are within 10% of the measured velocity change. Similar results occurred using the WinSmash 2.06 program, applying CDS-NASS protocol, none of the three offset-frontal crashes produced results that are within 10% of the measured velocity change, but when the Offset option was activated, two of the three were within 10% of the measured velocity change. It seems clear that when using either WinSmash 1.2.1 or 2.06 to estimate velocity changes for an offset-frontal impact, the results are much more likely to be accurate when the CDS-NASS protocols are observed and the Offset option is activated.

It is unclear at what percent overlap the Offset option should be activated (10% VOL, 20% VOL, etc) and at what percent overlap it should be deactivated (e.g. 70% VOL, 80% VOL, etc). The three subject vehicles in this study were all involved in offset impacts with approximately 40-50% vehicle overlap and using the Offset option seemed appropriate and produced good results. More studies should be conducted using a variety of percentage overlaps in order to determine the parameters of applicability for using the offset option.

4.3 Endshift Option

The Endshift option is available with the two WinSmash programs, but not with the CRASH PC program. Although it appeared as though it could be activated for all impacts studied in this project, it only had an effect on the output when the run included a PDOF that was not "in-line". In other words, for four of the six frontal impacts that had a PDOF of 360 degrees, there was no effect on the output. The same was true for the rear impact, which had an "in-line" PDOF of 180 degrees. Only for the two oblique offset-frontal impacts did the Endshift option change the output. The two oblique offset-frontal impacts each had a PDOF of 330 degrees. For both of these oblique impacts, activation of the Endshift option resulted in a 15% increase in the output. While this was consistently 15% higher when the Endshift option was activated, it was never exactly the same, even when comparing different outputs from the same crash. The range was from 15.33 to 15.48%. Apparently the algorithm that is employed when the Endshift option is activated incorporates the crush profile into the calculation, because these slight changes could be noted when everything was the same except the crush profile (raw vs. adjusted profiles).

Of the seven crashes studied, none met the criteria for endshifting (e.g. CDC incrementation), which is four inches of lateral movement by both frame rails or end structure. The one oblique offset-frontal crash involving the Chevrolet Camaro nearly met this criterion but still fell short of meeting the definition of endshift.

4.4 Combining the Endshift and Offset Options

In the WinSmash 2.06 program, both Offset and Endshift options could be activated at the same time in either the Barrier subroutine or the Pole subroutine. In the WinSmash 1.2.1 program, this was only true for the Barrier subroutine. In WinSmash 1.2.1, when the Pole subroutine was selected, the offset option became inactive and could not be used alone or in combination with the Endshift option. Also, the Endshift option had no effect on the outputs for those crashes that had an "in-line" PDOF, therefore, only the two oblique offset-frontal crashes were studied for the effect of combined use of the two options.

Both the WinSmash 1.2.1 and 2.06 programs provided consistent percentage increases in output when both options were activated for the same crash. For the Caravan oblique offset-frontal crash, activation of both options increased the output by 70% when compared to no options activated. This same percentage increase occurred in both programs. For the Camaro oblique offset-frontal crash, activation of both options resulted in a 41% increase when compared to no options activated. Again, this percentage increase was identical for both programs.

4.5 Adjusted vs. Raw Crush Profiles

The unadjusted or raw crush profile is fairly easy to obtain by the field investigators and it is easy to verify by quality-control personnel. In contrast, the adjusted crush profile, which subtracts out bumper taper, can be time consuming to obtain because it involves finding and measuring an exemplar vehicle. It is also difficult, if not impossible, to verify. A part of this study was therefore devoted to examining the importance of using the more time-consuming adjusted crush profile to achieve accurate reconstruction results.

Of the 678 crash runs executed for this project, one-half used raw crush profiles and one-half used adjusted crush profiles. The overall difference between results for the two inputs is as was expected, in that the larger values of the raw crush profiles produce slightly larger crash severity estimates than the adjusted profiles produce. Runs using raw crush profiles produced crash severities that are 12% higher on average than those runs where adjusted profiles were used.

The net effect on the accuracy of the various programs was varied. Runs that produced results that underestimated the crash severity by more than 10% using adjusted profiles sometimes produced results that were within 10% of the measured velocity changes when a raw profile was used. Runs that produced results that are within 10% of the measured velocity changes using the adjusted profile, produced results that overestimated the crash severities when the raw profiles were used. There were just as many runs that produced more accurate results with the raw profiles as there were that produced more accurate results with the adjusted profiles. However, most of the more accurate runs using raw profiles occurred under conditions that are outside the typical protocol and/or for illogical applications. For example, a raw profile may have produced a more accurate result than the adjusted profile when the Field L was used as the SMASH L and when the Endshift option was activated, even though the vehicle did not exhibit any end shifting.

Due to differences in body styling, some vehicles (such as the Chevrolet Camaro) have larger amounts of "free space" at the bumper corners. Therefore, use of the raw crush profile meant that C1 and C6 were considerably larger than the same C-values of an adjusted crush profile. This difference was not as noticeable for "boxier" shaped vehicles such as the Dodge Caravan. This difference between vehicle styling resulted in less accurate measures of vehicle crush and less consistency in the resulting outputs of the studied programs. Therefore, the results of this study support the continued use of adjusted crush profiles even though they require more effort and time.

4.6 Generic vs. Vehicle-Specific Stiffness Values

Generic stiffness values are embedded within all three programs, however, the two WinSmash programs allow the user to override these inputs in favor of vehicle-specific stiffness values. These values are entered in the form of D0 and D1 values. A few engineering companies have obtained crash test data and crash test films and generated specific stiffness values for the specific vehicles tested. These values, however, are usually provided as A, B, and G values. The end user must take these A, B, and G values and convert them to D0 and D1 values in order to use them within the programs.

There are several potential problems with using the computed D0 and D1 values. Some examples of potential problems include:

- the possibility of making a mathematical error during conversion,
- the possibility of making a units error during conversion,
- the impact configuration of the test vehicle being different than the subject vehicle (e.g. test vehicle impacted with a left 40% overlap and the subject vehicle experienced a right 30% overlap),
- variations in measurement technique applied to the test vehicle (e.g. two C-measurements or three C-measurements vs. the standard of six C-measurements), and
- variations in interpretation of the residual crush of the test vehicle.

Also, there is a limitation of specific data because not all make/models are crash tested, nor is every crash mode available. With respect to this project, no vehicle specific stiffness values were found that are applicable to narrow, pole-type impacts.

For this project, four vehicle-specific stiffness values were found and purchased from a single engineering company. One set of values was for a Dodge Caravan and was based on a left 40% overlap frontal impact, one was for a Chevrolet Camaro and was based on a 100% overlap rear impact, one was for a Chevrolet Camaro and was based on a 100% overlap frontal impact, and the fourth was also a Chevrolet Camaro, based on a 100% overlap frontal impact, but with adjustments made to the crush profile of the tested vehicle. These adjustments were made by the engineering company and were based on test films/images of the post-crash damage. The fact that two sets of values can be obtained for the same vehicle/same impact type is evidence of the controversy surrounding these values and their validity.

The two WinSmash programs also handled the use of these specific stiffness values in slightly different ways. In WinSmash 1.2.1, the program required that a generic stiffness value be input (as well as the specific value) before the program would advance to the next step of data input. This generic value was apparently ignored and the specific value was used in the computation (based on the different outputs), but it raises questions about how these values are used. The WinSmash 2.06 program did not require the user to input a value in the generic stiffness field, but the program appeared to then override any input with regard to the Offset option. This option could still be activated once a specific stiffness value was entered, but it no longer had an effect on the output. Again, this raises questions about how the program is using the specific stiffness values that the user enters.

Overall, use of the vehicle-specific values produced mixed results. The vehicle-specific stiffness values obtained for the Dodge Caravan apparently resulted in a "softer" stiffness than the generic values. Application of these values resulted in lower velocity changes than those generated by using the generic stiffness values. Therefore, any runs that produced an underestimate were further underestimated when the vehicle specific stiffness values were applied. Because all three programs had underestimated the velocity changes of the Caravan in the two offset impacts, use of the specific stiffness values further amplified this underestimation.

With regard to the two Caravan offset-frontal impacts and the WinSmash 2.06 program, no runs using the vehicle-specific stiffness values produced results that are within 10% of the measured velocity changes. The WinSmash 1.2.1 program, however, did produce results that were within 10% of the measured velocity change when using the vehicle-specific stiffness values. This occurred when the Barrier subroutine was used along with the UEW as the SMASH L and the offset option was activated. Under these conditions, both offset-frontal crashes involving the Dodge Caravan were calculated within 10% of the measured velocity change.

The specific stiffness values obtained for the rear of the Chevrolet Camaro apparently resulted in a "harder" stiffness than the generic values. Application of these values resulted in higher velocity changes than those generated by using the generic stiffness values. As a result, any runs that produced an overestimate were further overestimated when the vehicle specific values were applied. Because all three programs had overestimated the velocity change for this rear impact, this overestimation was further amplified when the vehicle-specific stiffness values were used. Use of the vehicle-specific stiffness values for this rear impact produced no results that are within 10% of the measured velocity change.

Two different vehicle-specific stiffness values were obtained for the front of the Chevrolet Camaro. These values are based on full-frontal impacts and not offset-frontal impacts, but they were obtained and used in order to study their effect on the program output. One value apparently resulted in a "softer" stiffness than the generic value and the other value resulted in a "harder" stiffness than the generic value. Use of the "harder" value in the WinSmash 2.06 program produced results that were within 10% of the measured velocity change. This occurred while using the Barrier subroutine along with the UEW as the SMASH L (typical CDS-NASS protocol). WinSmash 1.2.1 also produced an acceptable result using the "harder" stiffness. This occurred while using the Barrier subroutine along with the UEW as the SMASH L and the Offset option activated. Use of the "softer" stiffness value produced no results within 10% of the measured velocity change in either program.

Generic stiffness values produced reasonable results in six of the seven crashes. The full-rear impact, however, did not produce accurate results in any of the three programs. Given that the results were consistently higher than the measured velocity changes, it appears that the generic values for the rear of this type of vehicle are significantly "harder" than they actually are. Only two of the 54 runs performed on this rear impact produced results that were within 10% of the measured velocity change. In every run, the calculated velocity change was overestimated.

4.7 UEW, Field L or Direct L as the Smash L

Part of this project studied the effects of using different field measurements (UEW, Field L, and Direct L) as the SMASH L. Current protocol calls for the use of the UEW as the SMASH L, but there has been much discussion about the use of Direct L in cases involving pole impacts. Most users of these reconstruction programs recognize that, as the length of the SMASH L decreases, so does the output. The results of this study support this relationship. For pole impacts, all three programs performed reasonably well when using the Barrier subroutine and the UEW as the SMASH L. Under these conditions, none of the results grossly overestimated the measured test values. When Direct L was used in place of the UEW, the results decreased significantly and underestimated the velocity change by a range of 30% to 50%.

When the Pole subroutines in WinSmash 1.2.1 or WinSmash 2.06 were used along with the UEW as the SMASH L, the crash severities for the three pole impacts were grossly overestimated by 68% to 101%. Using the Direct L as the SMASH L in the Pole subroutines brought the results down significantly, but the results are still not as good as those obtained with the UEW and the Barrier subroutine. The results of this study therefore do not support the use of Direct L (or the Field L) as the SMASH L with either the Barrier or Pole subroutine in either offset-frontal or pole-type frontal impacts.

4.8 Comparison of Computer Programs

Overall, all three computer programs performed quite well in the reconstructing the crash severities of both the pole and barrier offset-frontal crashes. However, the CRASH PC program slightly outperformed the two WinSmash programs, even though its options are more limited. This observation is based on the fact that five out of the seven reconstructions using the Baseline conditions with CRASH PC produced results that are within 10% of the measured velocity changes. Considering that WinSmash 1.2.1 accurately estimated one pole impact (in the Baseline mode) and all three offset-frontal impacts using Baseline conditions with the Offset option activated, this program also produced satisfactory results. The WinSmash 2.06 accurately estimated crash severity for two pole impacts using the Baseline conditions, and it did a good job for two offset-frontal impacts using Baseline conditions with the Offset option activated. Its performance was therefore similar to that of WinSmash 1.2.1; that is, four out of seven reconstructions were estimated within 10% of the measured velocity changes.

With regard to ease of using these programs, the two WinSmash programs are much simpler to operate than the CRASH PC program. The CRASH PC program is an older, DOS-based program that requires use of the arrow keys as opposed to tabs and mouse-based maneuvers, and is slightly cumbersome to use in today's Windows computer environment. The two WinSmash programs are, of course, Windows-based programs and are much easier to maneuver through using the mouse and tab keys. However, given that CRASH PC demonstrated a slight edge in performance over the two versions of WinSmash for Baseline conditions, a recommendation of one program over another is difficult to justify.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Although the results of this study are based on a limited number of crash reconstructions using only two vehicles, and a limited number of crash modes, a number of useful observations and conclusions can be made. Since the three frontal pole impacts were to the passenger half of the vehicle, and three of the other four impacts used were offset-frontal impacts, the results and conclusions are most applicable to the offset-frontal type of crash. Side impacts were not included in this study. The reader is therefore cautioned to apply the following findings of this study with care and prudence.

- The Barrier subroutine should be used for all front and rear impacts and impact modes (side impacts with poles not studied),
- The Pole subroutine should not be used.
- The Offset option should be activated when using the Barrier subroutine for offset-frontal impacts involving 40-50% VOL. The accuracy and applicability of this option to larger or smaller overlaps has not been determined.
- The Endshift option should be used only when the subject vehicle damage obviously meets the criteria of vehicle endshift, which is four inches of lateral shift, and even then the results should be closely examined.
- Combinations of Offset and Endshift options should be avoided until further studies have been conducted.
- Adjusted crush profiles should be used instead of raw crush profiles, whenever possible.
- Generic stiffness values should continue to be used until more vehicle-specific stiffness values can be obtained and validated.
- UEW should be used as the Smash L for offset-frontal, full-frontal, and pole-type frontal impacts.
- A strong recommendation regarding which of the three programs should be used cannot be justified based on the results of this study. However, the CRASH PC program performed slightly better than either WinSamsh program with regard to accuracy in estimating the actual crash severity for the greatest number of staged crashes.

GLOSSARY OF TERMS AND ABBREVIATIONS

CDC
Collision Deformation Classification

Crush profile
The set of measured distances taken on a vehicle following involvement in a crash that describe the depth of crush to the impacted surface of the vehicle. The measurements are always taken perpendicular to the damaged plane of the impact surface and at equidistant points along the damaged plane.

CDS-NASS
Abbreviation for Crashworthiness Data System of the National Automotive Sampling System

CIREN
Abbreviation for Crash Injury Research and Engineering Network

C-values
The individual crush measurements that make up the crush profile. There are typically two, four or six C-values for every crush profile.

Delta V
The change in velocity of the center of gravity of a vehicle during an impact with a struck vehicle/object

Direct L
The length of damage that is due to direct contact or engagement of the case vehicle with the struck vehicle or object.

D value
The distance between the center of the direct damage length and the displaced centerline of the vehicle (or center of the damaged wheelbase for side impacts).

EBS
An abbreviation for Equivalent Barrier Speed which is the speed that a vehicle would need to have prior to impact with a rigid barrier to produce the same level of damage or crush as that sustained in the crash being reconstructed.

Field L D value
The distance between the center of the Field L and the centerline of the vehicle (or center of the damaged wheelbase for side impacts).

Field L
The combined length of the direct damage length and induced damage length for a given impact.

In-line Impact
A term used to describe an impact event to a vehicle where the direction of the deceleration or acceleration is along the longitudinal axis of the vehicle (i.e., a crash with a PDOF of 0, 360, or 180 degrees).

Oblique
A term used to describe the direction of a vehicle's deceleration or acceleration in a crash where the PDOF is not in-line.

Offset-Frontal Impact
A type of crash referenced to a particular case vehicle, in which that vehicle experiences a frontal impact for which the direct damage includes one of the two front bumper corners, but not both.

PDOF
Abbreviation for principle direction of force assigned to the impact of a case vehicle. The PDOF describes the angle of the primary deceleration or acceleration of the case vehicle relative to a direct frontal deceleration (i.e., the PDOF for an in-line frontal impact is 0 or 360 degrees; the PDOF for an in-line rear impact is 180 degrees).

SCI
Abbreviation for Special Crash Investigations

Smash L
A generic term for the length of damage used in the reconstruction programs. Current protocol is to use the UEW as the Smash L for end plane impacts and the Field L for side plane impacts.

UEW
Abbreviation for undeformed end width of the front or rear bumper. The undeformed end with is a field measurement taken from one bumper corner to the other.

APPENDIX A

Field Measurements of Test Vehicles

Test Vehicle Number: **C11108**
Test Vehicle: **1996 Dodge Caravan**
Crash Type**:** **Right-Front Pole Impact**

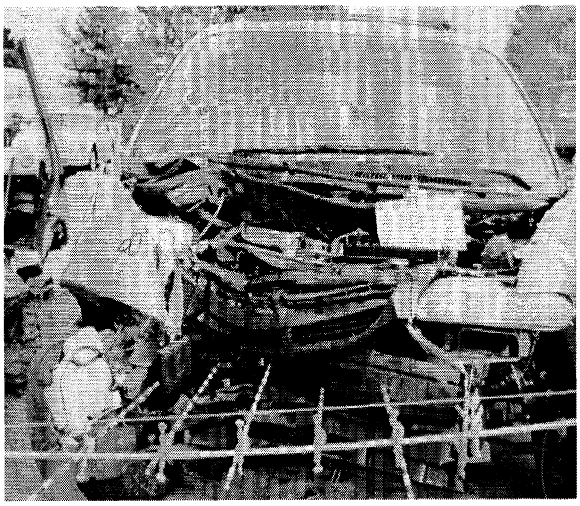
Vehicle/Crash Input Parameters (used in all runs)

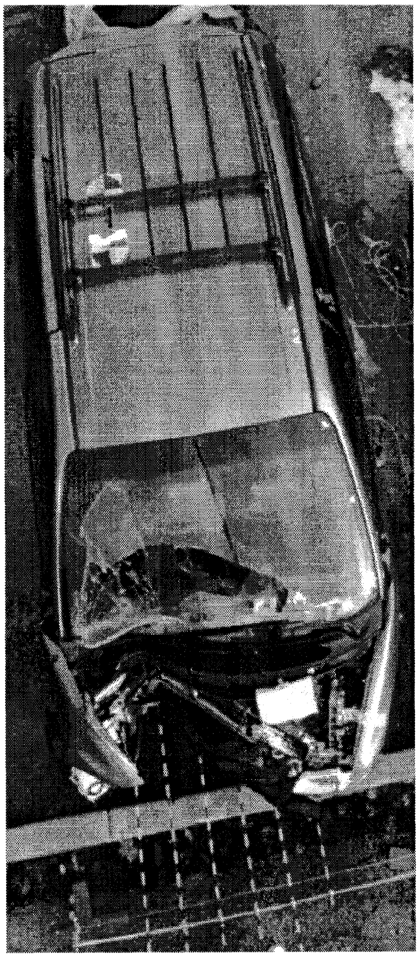
Crash Angle: **0 degrees**
Vehicle Mass: **1977 kg**
Vehicle OAW: **195 cm**
Vehicle Size Category: **4**
CDC: **12FZEN5**

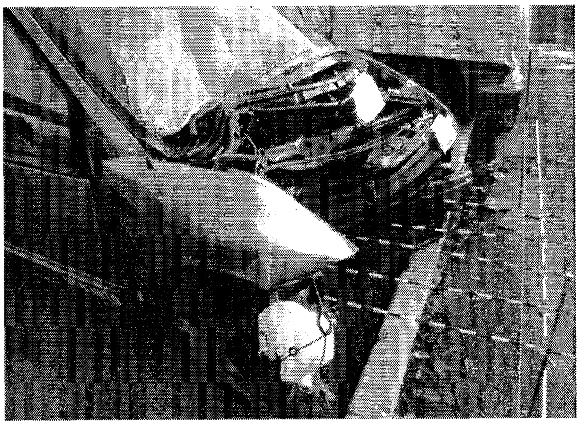
Vehicle Wheelbase: **288 cm**
Vehicle OAL: **473 cm**
Vehicle FOH: **92 cm**
Vehicle Stiffness Category: **7**
PDOF: **360**

Vehicle Field Measurements with Adjustments

UEW	Field L	Direct L	C1	C2	C3	C4	C5	C6	Field D	Direct D
154	93	40	24	35	57	90	97	70	0	+25
Stringline Adjustment			-2	-2	-2	-2	-2	-2		
Final Raw Crush Profile (RP)			**22**	**33**	**55**	**88**	**95**	**68**	**0**	**+25**
Adjustments for bumper taper			-20	-7	-2	-2	-7	-20		
Final Adjusted Crush Profile (AP)			**2**	**26**	**53**	**86**	**88**	**48**	**0**	**+25**







Test Vehicle Number: **C11591**
Test Vehicle: **1996 Chevrolet Camaro**
Crash Type: **Right-Front Pole Impact**

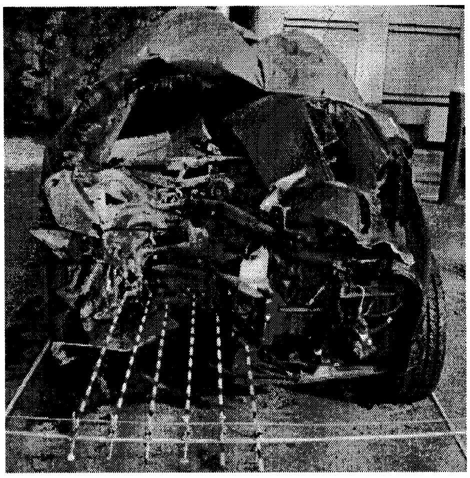
Vehicle/Crash Input Parameters (used in all runs)

Crash Angle: **0 degrees**
Vehicle Mass: **1849 kg**
Vehicle OAW: **188 cm**
Vehicle Size Category: **3**
CDC: **12FZEN4**

Vehicle Wheelbase: **257 cm**
Vehicle OAL: **491 cm**
Vehicle FOH: **115 cm**
Vehicle Stiffness Category: **3**
PDOF: **360**

Vehicle Field Measurements with Adjustments

UEW	Field L	Direct L	C1	C2	C3	C4	C5	C6	Field D	Direct D
152	52	36	53	78	116	122	119	112	0	+38
Stringline adjustment			-4	-4	-4	-4	-4	-4		
Final Raw Crush Profile (RP)			**49**	**74**	**112**	**118**	**115**	**108**	**0**	**+38**
Adjustments for bumper taper			-18	-8	-4	-4	-8	-18		
Adjustments for melted faschia, energy absorbing honeycomb plastic, etc.			-10	-10	-10	-10	-10	-10		
Final Adjusted Crush Profile (AP)			**21**	**56**	**98**	**104**	**97**	**80**	**0**	**+38**



Test Vehicle Number: **C11279**
Test Vehicle: **1996 Dodge Caravan**
Crash Type: **Right-Front Pole Impact**

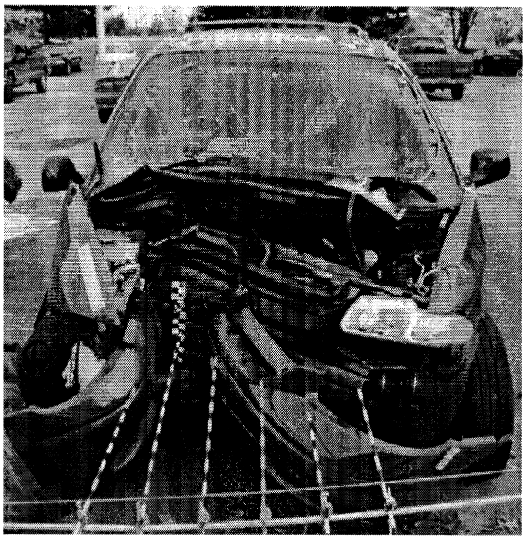
Vehicle/Crash Input Parameters (used in all runs)

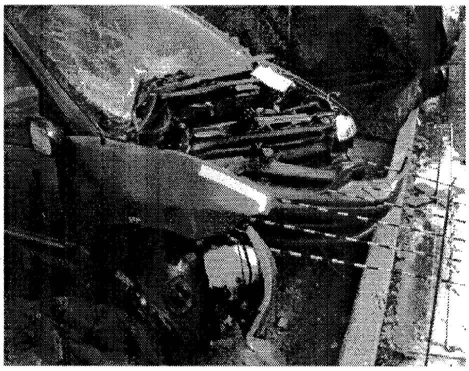
Crash Angle: **0 degrees**
Vehicle Mass: **2015 kg**
Vehicle OAW: **195 cm**
Vehicle Size Category: **4**
CDC: **12FZEN6**

Vehicle Wheelbase: **288 cm**
Vehicle OAL: **473 cm**
Vehicle FOH: **92 cm**
Vehicle Stiffness Category: **7**
PDOF: **360**

Vehicle Field Measurements with Adjustments

UEW	Field L	Direct L	C1	C2	C3	C4	C5	C6	Field D	Direct D
154	81	24	43	57	57	83	111	73	0	+27
Final Raw Crush Profile (RP)			**43**	**57**	**57**	**83**	**111**	**73**	**0**	**+27**
Adjustments for bumper taper			-20	-7	-2	-2	-7	-20		
Adjustments for melted faschia, energy absorbing honeycomb plastic, etc.			-9	0	0	0	0	0		
Final Adjusted Crush Profile (AP)			**14**	**50**	**55**	**81**	**104**	**53**	**0**	**+27**





Test Vehicle Number: **C11167**
Test Vehicle: **1996 Dodge Caravan**
Crash Type: **Oblique Offset-Frontal Impact**

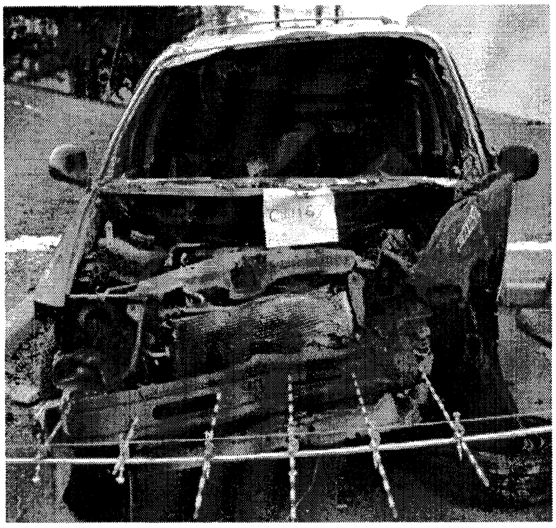
Vehicle/Crash Input Parameters (used in all runs)

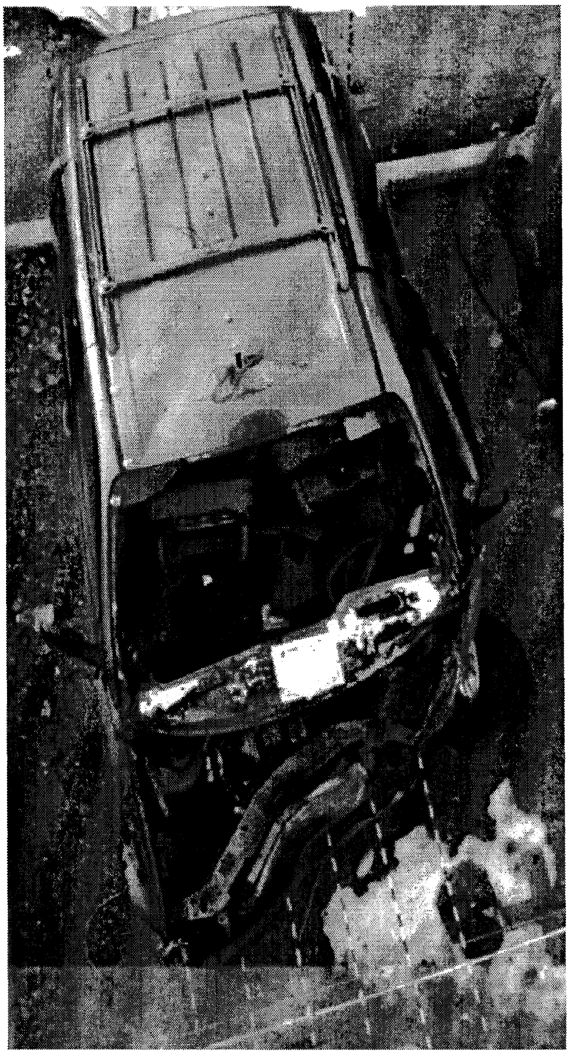
Crash Angle: **25 degrees**
Vehicle Mass: **1981 kg**
Vehicle OAW: **195 cm**
Vehicle Size Category: **4**
CDC: **11FYEW4**

Vehicle Wheelbase: **288 cm**
Vehicle OAL: **473 cm**
Vehicle FOH: **92 cm**
Vehicle Stiffness Category: **7**
PDOF: **-30 (+330)**

Vehicle Field Measurements with Adjustments

UEW	Field L	Direct L	C1	C2	C3	C4	C5	C6	Field D	Direct D
154	119	62	76	66	60	38	22	24	0	-46
Stringline Adjustment			-2	-2	-2	-2	-2	-2		
Final Raw Crush Profile (RP)			**74**	**64**	**58**	**36**	**20**	**22**	**0**	**-46**
Adjustments for bumper taper			-20	-7	-2	-2	-7	-20		
Final Adjusted Crush Profile (AP)			**54**	**57**	**56**	**34**	**13**	**2**	**0**	**-46**





Test Vehicle Number: **C11647**
Test Vehicle: **1996 Chevrolet Camaro**
Crash Type: **Oblique Offset-Frontal Impact**

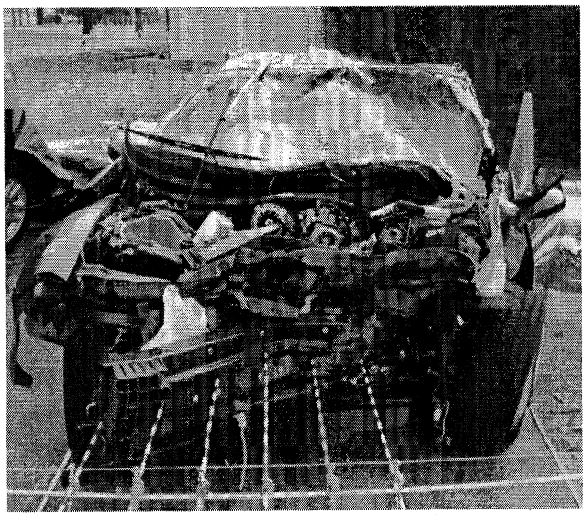
Vehicle/Crash Input Parameters (used in all runs)

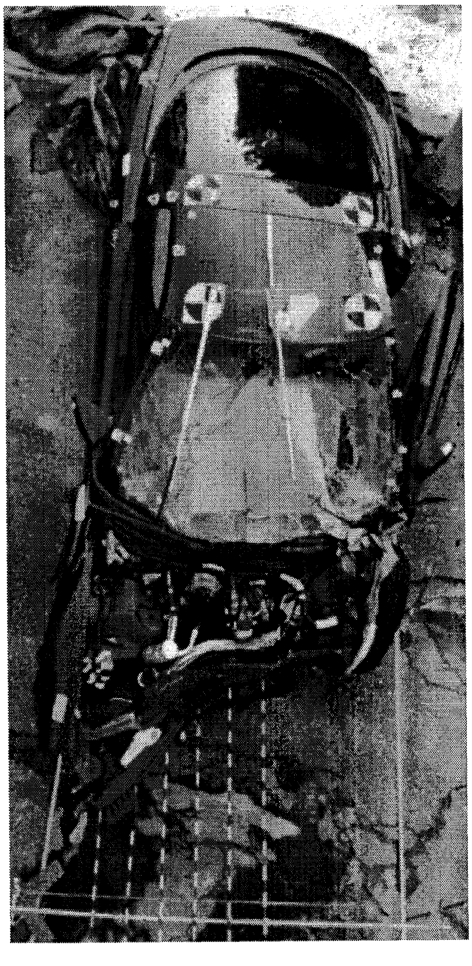
Crash Angle: **22 degrees**
Vehicle Mass: **1850 kg**
Vehicle OAW: **188 cm**
Vehicle Size Category: **3**
CDC: **11FYEW3**

Vehicle Wheelbase: **257 cm**
Vehicle OAL: **491 cm**
Vehicle FOH: **115 cm**
Vehicle Stiffness Category: **3**
PDOF: **-30 (+330)**

Vehicle Field Measurements with Adjustments

UEW	Field L	Direct L	C1	C2	C3	C4	C5	C6	Field D	Direct D
152	80	57	95	91	81	60	46	33	0	-47
Final Raw Crush Profile (RP)			**95**	**91**	**81**	**60**	**46**	**33**	**0**	**-47**
Adjustments for bumper taper			-18	-8	-4	-4	-8	-18		
Adjustments for melted faschia, energy absorbing honeycomb plastic, etc.			-10	-10	-10	-10	-10	-10		
Final Adjusted Crush Profile (AP)			**67**	**73**	**67**	**46**	**28**	**5**	**0**	**-47**





Test Vehicle Number: **C11226**
Test Vehicle: **1996 Dodge Caravan**
Crash Type: **In-Line Offset-Frontal Impact**

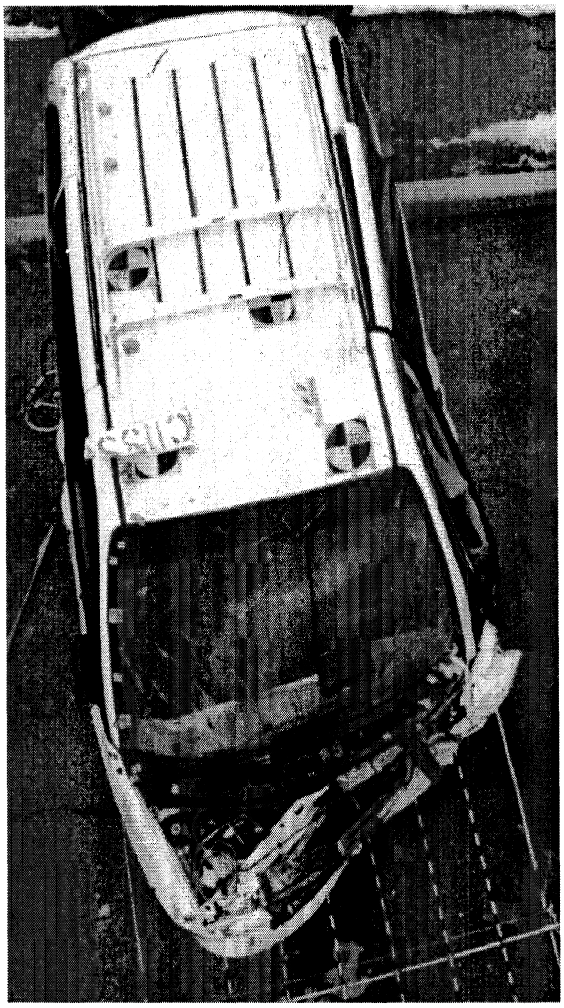
Vehicle/Crash Input Parameters (used in all runs)

Crash Angle: **0 degrees**
Vehicle Mass: **2003 kg**
Vehicle OAW: **195 cm**
Vehicle Size Category: **3**
CDC: **12FYEW4**

Vehicle Wheelbase: **288 cm**
Vehicle OAL: **473 cm**
Vehicle FOH: **92 cm**
Vehicle Stiffness Category: **3**
PDOF: **360**

Vehicle Field Measurements with Adjustments

UEW	Field L	Direct L	C1	C2	C3	C4	C5	C6	Field D	Direct D
154	131	68	81	64	53	33	17	17	0	-43
Final Raw Crush Profile (RP)			**81**	**64**	**53**	**33**	**17**	**17**	**0**	**-43**
Adjustments for bumper taper			-20	-7	-2	-2	-7	-20		
Final Adjusted Crush Profile (AP)			**61**	**57**	**51**	**31**	**10**	**0**	**0**	**-43**



Test Vehicle Number: **C11408**
Test Vehicle: **1996 Chevrolet Camaro**
Crash Type: **In-Line Offset-Rear Impact (about 70% Vehicle Overlap)**

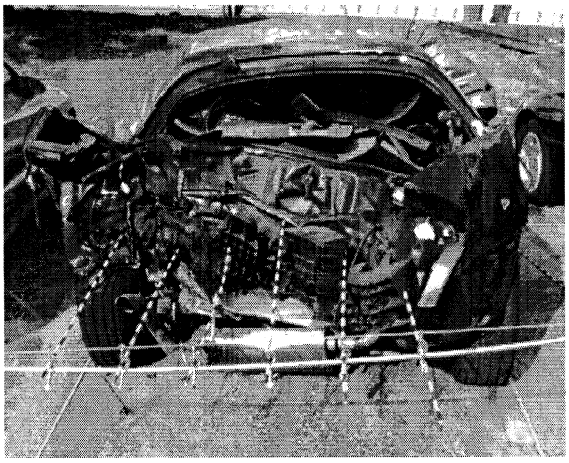
Vehicle/Crash Input Parameters (used in all runs)

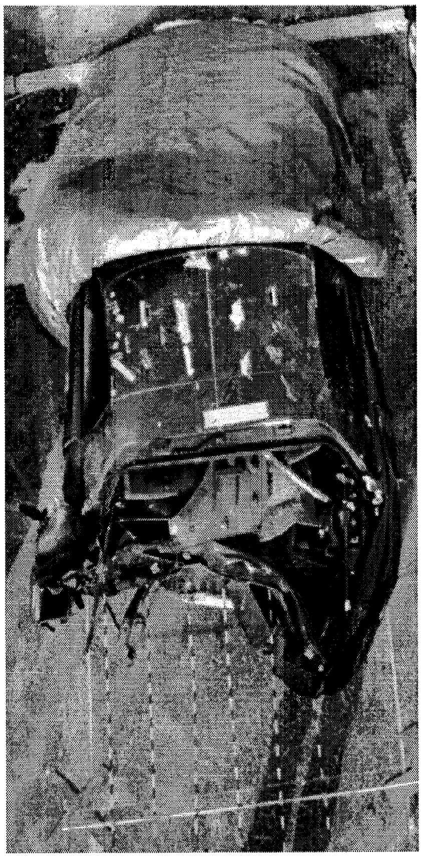
Crash Angle: **180 degrees**
Vehicle Mass: **1811 kg**
Vehicle OAW: **188 cm**
Vehicle Size Category: **3**
CDC: **06BYEW6**

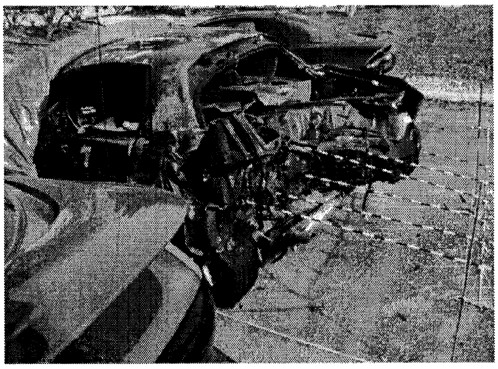
Vehicle Wheelbase: **257 cm**
Vehicle OAL: **491 cm**
Vehicle FOH: **115 cm**
Vehicle Stiffness Category: **3**
PDOF: **180**

Vehicle Field Measurements with Adjustments

UEW	Field L	Direct L	C1	C2	C3	C4	C5	C6	Field D	Direct D
154	108	84	107	107	107	101	89	45	0	-35
Final Raw Crush Profile (RP)			**107**	**107**	**107**	**101**	**89**	**45**	**0**	**-35**
Adjustments for bumper taper			-12	-5	-1	-1	-5	-12	0	+25
Adjustments for melted faschia, energy absorbing honeycomb plastic, etc.			-10	-10	-10	-10	-10	-10		
Final Adjusted Crush Profile (AP)			**85**	**92**	**96**	**90**	**74**	**23**	**0**	**-35**







APPENDIX B

Results from CRASH PC Runs

Program Inputs - Subroutine, Stiffness, Smash L, Crush Profile, Toggle Options	Vehicle Tested - Results in kph						
	C11108	C11591	C11279	C11167	C11647	C11226	C11408
B, G, UEW, AP	62.0	59.9	68.0	50.2	48.0	41.0	58.8
B, G, FL, AP	48.7	35.5	49.8	43.7	34.3	38.2	49.5
B, G, DL, AP	32.2	29.5	27.3	31.1	28.8	28.1	43.7
B, G, UEW, RP	67.9	70.7	74.9	56.8	60.3	46.8	66.8
B, G, FL, RP	53.2	41.8	54.7	49.6	43.3	43.5	56.2
B, G, DL, RP	35.1	34.8	29.9	35.3	36.4	32.0	49.6

B = Barrier subroutine
P = Pole subroutine
G = Generic stiffness values
Sp1 = Specific stiffness values #1
Sp2 = Specific stiffness values #2
UEW = Undeformed end width used as Smash L
FL = Field L used as Smash L

DL = Direct L used as Smash L
AP = Adjusted crush profile used
RP = Raw crush profile used
O = Offset toggle activated
S = Shift toggle activated
O + S = Both offset and shift toggle activated

APPENDIX C

Results from WinSmash 1.2.1 Runs

Program Inputs - Subroutine, Stiffness, Smash L, Crush Profile, Toggle Options	Vehicle Tested - Results in kph						
	C11108	C11591	C11279	C11167	C11647	C11226	C11408
B, G, UEW, AP	62.8	73.4	68.4	36.1	41.8	45.0	58.7
B, G, FL, AP	48.8	42.9	49.6	31.7	30.3	41.5	49.2
B, G, DL, AP	32.0	35.7	27.0	22.9	25.6	29.9	43.4
B, G, UEW, AP, O	98.0	92.4	107.5	53.2	51.1	66.2	na
B, G, FL, AP, O	76.1	54.1	78.0	46.7	37.1	61.0	na
B, G, DL, AP, O	49.9	45.0	42.4	33.7	31.3	44.0	na
B, G, UEW, AP, S	62.8	73.4	68.4	41.7	48.3	45.0	58.7
B, G, FL, AP, S	48.8	42.9	49.6	36.6	35.0	41.5	49.2
B, G, DL, AP, S	32.0	35.7	27.0	26.4	29.6	29.9	43.4
B, G, UEW, AP, O + S	98.0	92.4	107.5	61.4	59.0	66.2	na
B, G, FL, AP, O + S	76.1	54.1	78.0	54.0	42.8	61.0	na
B, G, DL, AP, O + S	49.9	45.0	42.4	38.9	36.1	44.0	na
B, G, UEW, RP	68.3	86.6	74.7	40.9	53.3	50.8	67.1
B, G, FL, RP	53.1	50.6	54.2	35.9	38.6	46.8	56.2
B, G, DL, RP	34.8	42.1	29.5	25.9	32.6	33.7	49.5
B, G, UEW, RP, O	107.3	110.2	118.6	61.4	66.4	76.2	na
B, G, FL, RP, O	83.4	64.4	86.0	54.0	48.1	70.3	na
B, G, DL, RP, O	54.7	53.6	46.8	38.9	40.6	50.7	na
B, G, UEW, RP, S	68.3	86.6	74.7	47.2	61.5	50.8	67.1
B, G, FL, RP, S	53.1	50.6	54.2	41.5	44.6	46.8	56.2
B, G, DL, RP, S	34.8	42.1	29.5	29.9	37.7	33.7	49.5
B, G, UEW, RP, O + S	107.3	110.2	118.6	70.9	76.6	76.2	na
B, G, FL, RP, O + S	83.4	64.4	86.0	62.3	55.6	70.3	na
B, G, DL, RP, O + S	54.7	53.6	46.8	45.0	46.9	50.7	na
B, Sp1, UEW, AP	na	na	na	30.8	45.2	38.3	78.4
B, Sp1, FL, AP	na	na	na	27.1	32.8	35.4	65.6
B, Sp1, DL, AP	na	na	na	19.5	27.7	25.5	57.9
B, Sp1, UEW, AP, O	na	na	na	48.9	58.0	60.8	na
B, Sp1, FL, AP, O	na	na	na	43.0	42.1	56.1	na
B, Sp1, DL, AP, O	na	na	na	31.0	35.5	40.4	na
B, Sp1, UEW, AP, S	na	na	na	35.6	52.1	38.3	78.4
B, Sp1, FL, AP, S	na	na	na	31.3	37.8	35.4	65.6
B, Sp1, DL, AP, S	na	na	na	22.6	31.9	25.5	57.9
B, Sp1, UEW, AP, O + S	na	na	na	56.4	67.0	60.8	na
B, Sp1, FL, AP, O + S	na	na	na	49.6	48.6	56.1	na
B, Sp1, DL, AP, O + S	na	na	na	35.8	41.0	40.4	na
B, Sp1, UEW, RP	na	na	na	35.2	58.8	43.7	90.7
B, Sp1, FL, RP	na	na	na	30.9	42.6	40.3	76.0
B, Sp1, DL, RP	na	na	na	22.3	36.0	29.0	67.0

B = Barrier subroutine
P = Pole subroutine
G = Generic stiffness values
Sp1 = Specific stiffness values #1
Sp2 = Specific stiffness values #2
UEW = Undeformed end width used as Smash L
FL = Field L used as Smash L

DL = Direct L used as Smash L
AP = Adjusted crush profile used
RP = Raw crush profile used
O = Offset toggle activated
S = Shift toggle activated
O + S = Both offset and shift toggle activated

Program Inputs - Subroutine, Stiffness, Smash L, Crush Profile, Toggle Options	Vehicle Tested - Results in kph						
	C11108	C11591	C11279	C11167	C11647	C11226	C11408
B, Sp1, UEW, RP, O	na	na	na	56.5	76.2	70.2	na
B, Sp1, FL, RP, O	na	na	na	49.7	55.3	64.8	na
B, Sp1, DL, RP, O	na	na	na	35.9	46.7	29.0	na
B, Sp1, UEW, RP, S	na	na	na	40.6	67.9	43.7	90.7
B, Sp1, FL, RP, S	na	na	na	35.7	49.2	40.3	76
B, Sp1, DL, RP, S	na	na	na	25.8	41.6	29.0	67
B, Sp1, UEW, RP, O + S	na	na	na	65.3	88.0	70.2	na
B, Sp1, FL, RP, O + S	na	na	na	57.4	63.9	64.8	na
B, Sp1, DL, RP, O + S	na	na	na	41.4	53.9	46.7	na
B, Sp2, UEW, AP	na	na	na	na	32.4	na	na
B, Sp2, FL, AP	na	na	na	na	23.5	na	na
B, Sp2, DL, AP	na	na	na	na	19.8	na	na
B, Sp2, UEW, AP, O	na	na	na	na	40.7	na	na
B, Sp2, FL, AP, O	na	na	na	na	29.5	na	na
B, Sp2, DL, AP, O	na	na	na	na	24.9	na	na
B, Sp2, UEW, AP, S	na	na	na	na	37.4	na	na
B, Sp2, FL, AP, S	na	na	na	na	27.1	na	na
B, Sp2, DL, AP, S	na	na	na	na	22.9	na	na
B, Sp2, UEW, AP, O + S	na	na	na	na	47.0	na	na
B, Sp2, FL, AP, O + S	na	na	na	na	34.1	na	na
B, Sp2, DL, AP, O + S	na	na	na	na	28.8	na	na
B, Sp2, UEW, RP	na	na	na	na	41.8	na	na
B, Sp2, FL, RP	na	na	na	na	30.3	na	na
B, Sp2, DL, RP	na	na	na	na	25.6	na	na
B, Sp2, UEW, RP, O	na	na	na	na	53.2	na	na
B, Sp2, FL, RP, O	na	na	na	na	38.6	na	na
B, Sp2, DL, RP, O	na	na	na	na	32.6	na	na
B, Sp2, UEW, RP, S	na	na	na	na	48.2	na	na
B, Sp2, FL, RP, S	na	na	na	na	35.0	na	na
B, Sp2, DL, RP, S	na	na	na	na	29.5	na	na
B, Sp2, UEW, RP, O + S	na	na	na	na	61.5	na	na
B, Sp2, FL, RP, O + S	na	na	na	na	44.6	na	na
B, Sp2, DL, RP, O + S	na	na	na	na	37.6	na	na
P, G, UEW, AP	105.5	126.4	116.0	na	na	na	na
P, G, FL, AP	82.0	74.0	84.1	na	na	na	na
P, G, DL, AP	53.8	61.5	45.8	na	na	na	na
P, G, UEW, AP, O	na	na	na	na	na	na	na
P, G, FL, AP, O	na	na	na	na	na	na	na
P, G, DL, AP, O	na	na	na	na	na	na	na
P, G, UEW, AP, S	105.5	126.4	116.0	na	na	na	na

B = Barrier subroutine
P = Pole subroutine
G = Generic stiffness values
Sp1 = Specific stiffness values #1
Sp2 = Specific stiffness values #2
UEW = Undeformed end width used as Smash L
FL = Field L used as Smash L

DL = Direct L used as Smash L
AP = Adjusted crush profile used
RP = Raw crush profile used
O = Offset toggle activated
S = Shift toggle activated
O + S = Both offset and shift toggle activated

Program Inputs - Subroutine, Stiffness, Smash L, Crush Profile, Toggle Options	Vehicle Tested - Results in kph						
	C11108	C11591	C11279	C11167	C11647	C11226	C11408
P, G, FL, AP, S	82.0	74.0	84.1	na	na	na	na
P, G, DL, AP, S	53.8	61.5	45.8	na	na	na	na
P, G, UEW, AP, O + S	na	na	na	na	na	na	na
P, G, FL, AP, O + S	na	na	na	na	na	na	na
P, G, DL, AP, O + S	na	na	na	na	na	na	na
P, G, UEW, RP	115.8	152.5	128.2	na	na	na	na
P, G, FL, RP	90.0	89.2	93.0	na	na	na	na
P, G, DL, RP	59.0	74.2	50.6	na	na	na	na
P, G, UEW, RP, O	na	na	na	na	na	na	na
P, G, FL, RP, O	na	na	na	na	na	na	na
P, G, DL, RP, O	na	na	na	na	na	na	na
P, G, UEW, RP, S	115.8	152.5	128.2	na	na	na	na
P, G, FL, RP, S	90.0	89.2	93.0	na	na	na	na
P, G, DL, RP, S	59.0	74.2	50.6	na	na	na	na
P, G, UEW, RP, O + S	na	na	na	na	na	na	na
P, G, FL, RP, O + S	na	na	na	na	na	na	na
P, G, DL, RP, O + S	na	na	na	na	na	na	na

B = Barrier subroutine
P = Pole subroutine
G = Generic stiffness values
Sp1 = Specific stiffness values #1
Sp2 = Specific stiffness values #2
UEW = Undeformed end width used as Smash L
FL = Field L used as Smash L

DL = Direct L used as Smash L
AP = Adjusted crush profile used
RP = Raw crush profile used
O = Offset toggle activated
S = Shift toggle activated
O + S = Both offset and shift toggle activated

APPENDIX D

Results from WinSmash 2.06 Runs

Program Inputs - Subroutine, Stiffness, Smash L, Crush Profile, Toggle Options	Vehicle Tested - Results in kph						
	C11108	C11591	C11279	C11167	C11647	C11226	C11408
B, G, UEW, AP	61.9	71.0	67.2	42.2	46.3	43.0	57.2
B, G, FL, AP	48.1	41.6	48.7	37.1	33.6	39.7	47.9
B, G, DL, AP	31.5	34.6	26.5	26.8	28.3	28.6	42.2
B, G, UEW, AP, O	96.5	89.5	105.6	62.1	56.5	63.3	na
B, G, FL, AP, O	75.0	52.4	76.6	54.6	41.0	58.4	na
B, G, DL, AP, O	49.2	43.6	41.7	39.4	34.6	42.1	na
B, G, UEW, AP, S	61.9	71.0	67.2	48.7	53.4	43.0	57.2
B, G, FL, AP, S	48.1	41.6	48.7	42.8	38.8	39.7	47.9
B, G, DL, AP, S	31.5	34.6	26.5	30.9	32.7	28.6	42.2
B, G, UEW, AP, O + S	96.5	89.5	105.6	71.7	65.3	63.3	na
B, G, FL, AP, O + S	75.0	52.4	76.6	63.1	47.4	58.4	na
B, G, DL, AP, O + S	49.2	43.6	41.7	45.5	40.0	42.1	na
B, G, UEW, RP	67.2	83.6	73.4	47.7	58.8	48.6	65.3
B, G, FL, RP	52.3	48.9	53.2	41.9	42.6	44.8	54.6
B, G, DL, RP	34.3	40.7	29.0	30.3	36.0	32.3	48.2
B, G, UEW, RP, O	105.7	106.4	116.5	71.7	73.2	73.0	na
B, G, FL, RP, O	82.1	62.2	84.5	63.0	53.1	67.3	na
B, G, DL, RP, O	53.9	51.8	46.0	45.5	44.8	48.5	na
B, G, UEW, RP, S	67.2	83.6	73.4	55.1	67.9	48.6	65.3
B, G, FL, RP, S	52.3	48.9	53.2	48.4	49.2	44.8	54.6
B, G, DL, RP, S	34.3	40.7	29.0	35.0	41.6	32.3	48.2
B, G, UEW, RP, O + S	105.7	106.4	116.5	82.8	84.5	73.0	na
B, G, FL, RP, O + S	82.1	62.2	84.5	72.7	61.3	67.3	na
B, G, DL, RP, O + S	53.9	51.8	46.0	52.5	51.8	48.5	na
B, Sp1, UEW, AP	na	na	na	36.0	50.0	36.7	76.2
B, Sp1, FL, AP	na	na	na	31.6	36.2	33.9	63.8
B, Sp1, DL, AP	na	na	na	22.8	30.6	24.4	56.3
B, Sp1, UEW, AP, O	na	na	na	36.0	50.0	36.7	na
B, Sp1, FL, AP, O	na	na	na	31.6	36.2	33.9	na
B, Sp1, DL, AP, O	na	na	na	22.8	30.6	24.4	na
B, Sp1, UEW, AP, S	na	na	na	41.6	57.7	36.7	76.2
B, Sp1, FL, AP, S	na	na	na	36.5	41.9	33.9	63.8
B, Sp1, DL, AP, S	na	na	na	26.4	35.3	24.4	56.3
B, Sp1, UEW, AP, O + S	na	na	na	41.6	57.7	36.7	na
B, Sp1, FL, AP, O + S	na	na	na	36.5	41.9	33.9	na
B, Sp1, DL, AP, O + S	na	na	na	26.4	35.3	24.4	na
B, Sp1, UEW, RP	na	na	na	41.1	64.8	41.8	88.3
B, Sp1, FL, RP	na	na	na	36.1	47.0	38.6	73.9
B, Sp1, DL, RP	na	na	na	26.1	39.7	27.8	65.2

B = Barrier subroutine
P = Pole subroutine
G = Generic stiffness values
Sp1 = Specific stiffness values #1
Sp2 = Specific stiffness values #2
UEW = Undeformed end width used as Smash L
FL = Field L used as Smash L

DL = Direct L used as Smash L
AP = Adjusted crush profile used
RP = Raw crush profile used
O = Offset toggle activated
S = Shift toggle activated
O + S = Both offset and shift toggle activated

Program Inputs - Subroutine, Stiffness, Smash L, Crush Profile, Toggle Options	Vehicle Tested - Results in kph						
	C11108	C11591	C11279	C11167	C11647	C11226	C11408
B, Sp1, UEW, RP, O	na	na	na	41.1	64.8	41.8	na
B, Sp1, FL, RP, O	na	na	na	36.1	47.0	38.6	na
B, Sp1, DL, RP, O	na	na	na	26.1	39.7	27.8	na
B, Sp1, UEW, RP, S	na	na	na	47.4	74.9	41.8	88.3
B, Sp1, FL, RP, S	na	na	na	41.7	54.3	38.6	73.9
B, Sp1, DL, RP, S	na	na	na	30.1	45.9	27.8	65.2
B, Sp1, UEW, RP, O + S	na	na	na	47.4	74.9	41.8	na
B, Sp1, FL, RP, O + S	na	na	na	41.7	54.3	38.6	na
B, Sp1, DL, RP, O + S	na	na	na	30.1	45.9	27.8	na
B, Sp2, UEW, AP	na	na	na	na	35.8	na	na
B, Sp2, FL, AP	na	na	na	na	26.0	na	na
B, Sp2, DL, AP	na	na	na	na	21.9	na	na
B, Sp2, UEW, AP, O	na	na	na	na	35.8	na	na
B, Sp2, FL, AP, O	na	na	na	na	26.0	na	na
B, Sp2, DL, AP, O	na	na	na	na	21.9	na	na
B, Sp2, UEW, AP, S	na	na	na	na	41.4	na	na
B, Sp2, FL, AP, S	na	na	na	na	30.0	na	na
B, Sp2, DL, AP, S	na	na	na	na	25.3	na	na
B, Sp2, UEW, AP, O + S	na	na	na	na	41.4	na	na
B, Sp2, FL, AP, O + S	na	na	na	na	30.0	na	na
B, Sp2, DL, AP, O + S	na	na	na	na	25.3	na	na
B, Sp2, UEW, RP	na	na	na	na	46.1	na	na
B, Sp2, FL, RP	na	na	na	na	33.4	na	na
B, Sp2, DL, RP	na	na	na	na	28.2	na	na
B, Sp2, UEW, RP, O	na	na	na	na	46.1	na	na
B, Sp2, FL, RP, O	na	na	na	na	33.4	na	na
B, Sp2, DL, RP, O	na	na	na	na	28.2	na	na
B, Sp2, UEW, RP, S	na	na	na	na	53.2	na	na
B, Sp2, FL, RP, S	na	na	na	na	38.6	na	na
B, Sp2, DL, RP, S	na	na	na	na	32.6	na	na
B, Sp2, UEW, RP, O + S	na	na	na	na	53.2	na	na
B, Sp2, FL, RP, O + S	na	na	na	na	38.6	na	na
B, Sp2, DL, RP, O + S	na	na	na	na	32.6	na	na
P, G, UEW, AP	103.9	122.4	114.0	na	na	na	na
P, G, FL, AP	80.8	71.6	82.7	na	na	na	na
P, G, DL, AP	53.0	59.6	45.0	na	na	na	na
P, G, UEW, AP, O	187.1	165.3	205.2	na	na	na	na
P, G, FL, AP, O	145.4	96.7	148.8	na	na	na	na
P, G, DL, AP, O	95.3	80.4	81.0	na	na	na	na
P, G, UEW, AP, S	103.9	122.4	114.0	na	na	na	na

B = Barrier subroutine
P = Pole subroutine
G = Generic stiffness values
Sp1 = Specific stiffness values #1
Sp2 = Specific stiffness values #2
UEW = Undeformed end width used as Smash L
FL = Field L used as Smash L

DL = Direct L used as Smash L
AP = Adjusted crush profile used
RP = Raw crush profile used
O = Offset toggle activated
S = Shift toggle activated
O + S = Both offset and shift toggle activated

Program Inputs - Subroutine, Stiffness, Smash L, Crush Profile, Toggle Options	Vehicle Tested - Results in kph						
	C11108	C11591	C11279	C11167	C11647	C11226	C11408
P, G, FL, AP, S	80.8	71.6	82.7	na	na	na	na
P, G, DL, AP, S	53.0	59.6	45.0	na	na	na	na
P, G, UEW, AP, O + S	187.1	165.3	205.2	na	na	na	na
P, G, FL, AP, O + S	145.4	96.7	148.8	na	na	na	na
P, G, DL, AP, O + S	95.3	80.4	81.0	na	na	na	na
P, G, UEW, RP	114.1	147.3	126	na	na	na	na
P, G, FL, RP	88.6	86.2	91.4	na	na	na	na
P, G, DL, RP	58.1	71.7	49.7	na	na	na	na
P, G, UEW, RP, O	205.3	198.8	226.8	na	na	na	na
P, G, FL, RP, O	159.6	116.3	164.5	na	na	na	na
P, G, DL, RP, O	104.6	96.8	89.5	na	na	na	na
P, G, UEW, RP, S	114.1	147.3	126.0	na	na	na	na
P, G, FL, RP, S	88.6	86.2	91.4	na	na	na	na
P, G, DL, RP, S	58.1	71.7	49.7	na	na	na	na
P, G, UEW, RP, O + S	205.3	198.8	226.8	na	na	na	na
P, G, FL, RP, O + S	159.6	116.3	164.5	na	na	na	na
P, G, DL, RP, O + S	104.6	96.8	89.5	na	na	na	na

B = Barrier subroutine
P = Pole subroutine
G = Generic stiffness values
Sp1 = Specific stiffness values #1
Sp2 = Specific stiffness values #2
UEW = Undeformed end width used as Smash L
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