AN ANALYSIS OF NCAP SIDE IMPACT CRASH DATA

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ABSTRACT

Since 1990, the National Highway Traffic Safety Administration (NHTSA) implemented a dynamic side impact compliance test. This compliance test, Federal Motor Vehicle Safety Standard (FMVSS) No. 214, is a nearly right angle side impact in which the striking vehicle moves at 53.6 kmph into the struck vehicle. In 1997, NHTSA began testing passenger cars in side impact in the New Car Assessment Program (NCAP). In the USA NCAP side impact, the striking vehicle is towed at a 8 kmph higher speed than in the compliance test.

An analysis has begun on the data from the first NCAP side impact tests, thirty-two in number. In the crashes, accelerometers were installed in the door and door frames of the struck vehicle. Using the accelerometers on the vehicle structure and in the side impact dummy, the crash event was investigated. One tool used in the investigation was the velocity-versus-time diagram.

First, the crush of the interior door and its relationship to the severity of the occupant injury readings was examined. A correlation was found between the single independent variable, amount of the interior door crushed by the occupant, and the Thoracic Trauma Index. Second, the data was examined to determine the extent to which the pelvis of the dummy was loaded initially before loading the torso. A weaker correlation was found between the time duration (that the pelvis was loaded before the torso) and the Thoracic Trauma Index. Finally, the effect of the two independent variables together was examined.

INTRODUCTION

Based on the most harmful event, side impact accounts for 25 percent of fatalities for passenger car and light truck crashes in the USA. [1] For passenger cars, side impact accounts for approximately 30 percent of the fatalities in passenger car crashes. Likewise, side impact accounts for roughly 15 percent of light truck fatalities. Since the use of dynamic Federal safety standards in side protection began, in recent years occupant protection in side impact crashes has received increasing interest. This interest comes from both the consumers and the automotive industry. [2,3]

In comparison with frontal collisions, the space between the occupants and the intruding element in side crashes is extremely small. In addition, the side impact crash occurs much more rapidly. Consequently, occupant protection in side crashes presents a challenge to engineers designing a vehicle for safety.

Significant research work, both theoretical and experimental in nature, has been performed to characterize the safety performance of vehicles in side crashes. Gabler et al. [4] analyzed data of 28 production vehicles that underwent side impact crash testing. They found that these vehicles varied dramatically in their ability to protect the occupant in the struck car. They were able to identify a design parameter – the door effective padding thickness (DEPTH) – that strongly correlated with occupant thoracic injury potential.

Hobbs [5] investigated the influence of car structure and padding on side injuries. He analyzed more than 40 full scale vehicle impact tests. His findings revealed that a most important factor, in influencing protection, is the vertical intrusion profile of the incoming door. It appeared that controlling the vertical intrusion profile of the door is much more important than the prevention of the intrusion itself. Hobbs says "The degree of door tilt has been found to influence the way loads are transferred to the occupant. When the door tilts in at the top, loads are concentrated on the thorax. Where it (door tilt) remains upright, the loads are more evenly distributed and it may be that earlier loading of the pelvis reduces thoracic loading, by helping to accelerate the occupant sideways." Along the same line, Saab engineers developed a collapse behavior for the B-pillar that reduces the injury readings of the occupants in a side impact. It allows the lower part of the B-pillar to behave more softly than the upper part. Saab feels this "collapse" diverts crash loading to the parts of the body that can withstand them the most, the pelvic region. Saab feels this "collapse" protects the parts more susceptible to trauma: the head, rib cage, and chest. [6]

Lau et al. pointed out that the maximum velocity of the intruding door (of the stuck car) is important because the door strikes the occupant directly. [7] They compared the door's motion to a powerful "punch" to the dummy. In their paper, they pictured the velocity of the intruding door as rising as high (in magnitude) as the velocity of the striking barrier. Strother et al. presented data from another crash that suggested the velocity of the intruding door rose to a lower level, roughly the terminal velocity of the struck car. [8]

Finite element modeling has been successfully and extensively used to simulate collision events. Using the finite element program code DYNA3D, Rao et al. [9] simulated different impact scenarios at 45 kmph for a mid-size car being impacted in the side by a moving barrier. Their simulation results indicate that one can gain an understanding of how the interior door might respond to structural changes made in the struck car. Blaisdell et al. [10], in their comprehensive examination of collision performance of automotive door system , concluded that "...merely increasing door and latch strength without considering the entire system will not necessarily provide additional occupant protection, and may be counterproductive ...." They recommend that designers graph the velocity changes for different portions of the structure with respect to the occupant. This recommended approach parallels the method used in Reference 4.

Since 1997, the NHTSA has carried out forty-six full scale side impact tests under NCAP. These tests were conducted with extensive instrumentation so as to provide data needed for conducting research aiming at improving vehicle side protection. Accelerometers were installed in various locations of the test vehicle including the door panels, A- and B-pillars, sills and floor, and vehicle center of gravity (CG). This information, combined with data recorded from occupants, is used in this study to investigate the differences in safety performance and identify design parameters that influence vehicle side crash protection. The velocity-versus-time analysis as previously referenced [4, 7, 8, 10] was used in this study. The authors feel it helps in the visualization of the kinematics of the occupant and the behavior of the intruding vehicle structure.

TEST PROCEDURE

The vehicle impact tests that generated the data used in this analysis were conducted in accordance with the test procedure of the side impact NCAP. The NCAP side impact test is based on the dynamic requirements of FMVSS No. 214, but is conducted at a higher speed. The NCAP tests, which simulate an intersection collision, were conducted with a moving deformable barrier (MDB), as the striking vehicle. The 1360 kg MDB was moving at a speed of 61 kmph and at an angle of 27 degrees off the perpendicular to impact a stationery vehicle, as shown in Figure 1.

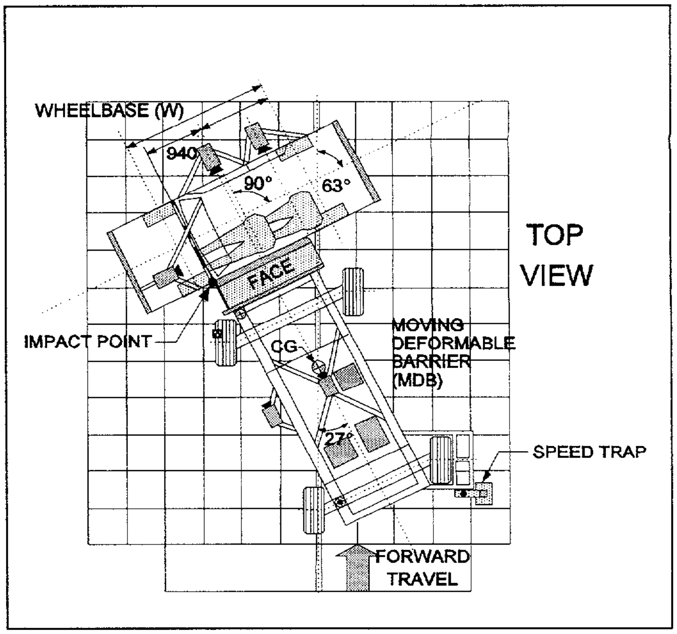

Figure 1. Test Setup.

Each impact test used two side impact dummies (SIDs) as specified in FMVSS No. 214. One SID was positioned in the driver seat, and a second SID was positioned in the rear passenger seat behind the driver, as shown in Figure 1. The dynamic response of each SID was recorded by accelerometers installed at the upper rib, lower rib, lower spine, and pelvis of each SID, as shown in Figure 2.

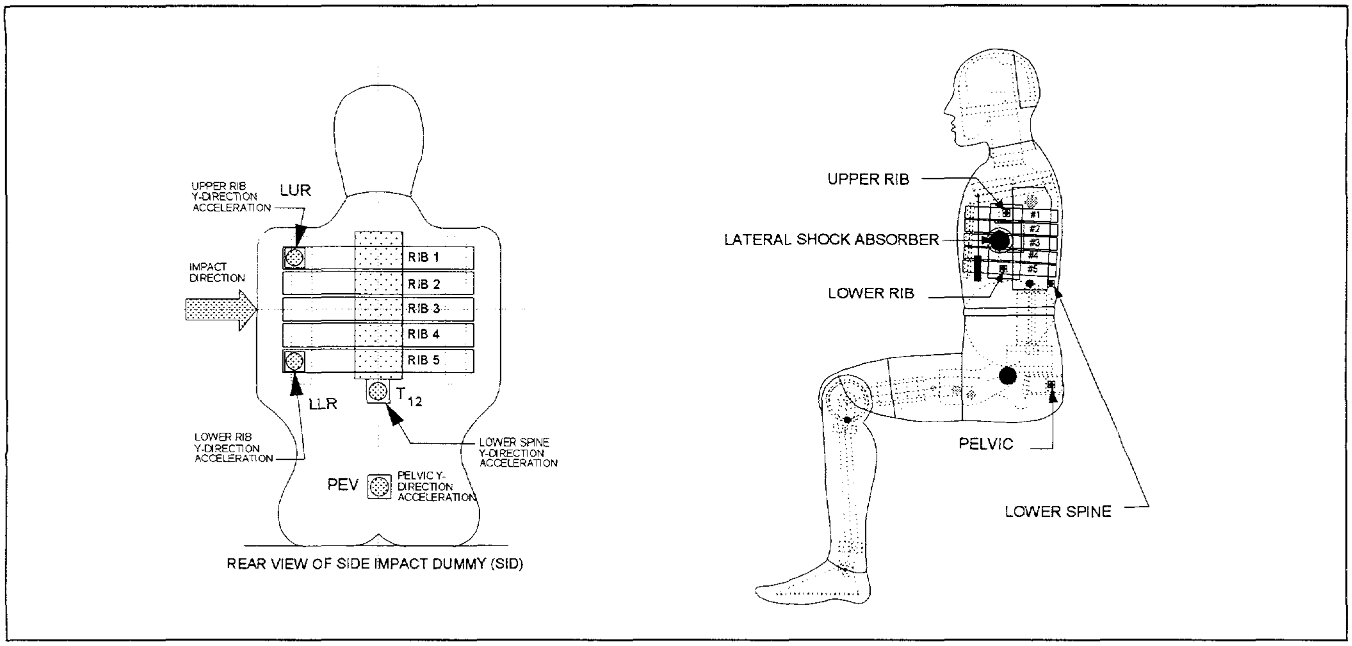

Figure 2. Rear and Side View of SID.

Twenty or so accelerometers were installed at various locations of the test vehicle to monitor the motion of the test vehicle and its structural components. Since the vehicle side doors and the door frames play an important role in side impact protection, special instrumentation was used to capture the dynamic responses o these components. For the front door, three accelerometers were installed on the interior surface of the inner door panel. For the B-pillar, two accelerometers were mounted on the interior surface of the inner door panel. Shown in figure 3 are the general locations of these accelerometers. Actual locations of these accelerometers may vary with the individual test because of the variations in vehicle design. Two accelerometers each were installed in the A-pillar and B-pillar. One accelerometer was located in the base and the other in the mid-section of the B-pillar.

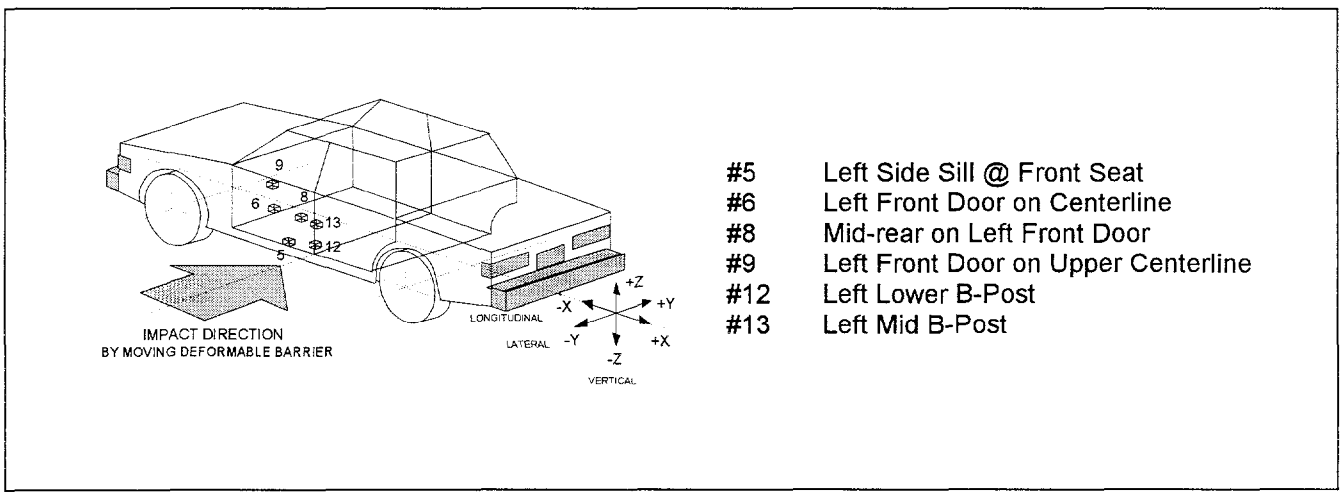

Figure 3. Location of Accelerometers.

PHYSICAL EVENT OF A SIDE CRASH AND THE VELOCITY-VERSUS-TIME DIAGRAM

During a car-to-car side collision, the physical event is a complicated transfer of momentum from the striking car to the struck car. To a large extent, the severity of the crash event, as seen by the occupant in the struck vehicle, is determined by the time rate of change for this momentum transfer. The time rate of momentum transfer, in turn, is dependent upon the relative structural stiffness and effective mass distribution, among other factors, of the individually struck cars. Because of their proximity to the impacting car and the occupant, the doors (front and rear) and the pillars (essentially the A- and B-pillars) of the struck vehicle are among the components that play a critical role in deciding how the momentum transfer is being carried out around the occupant. The doors and the pillars use their energy-absorbing capability and their material strength to channel the momentum transfer. In addition, the intruding door structure can provide an interior surface that crushes at a non-injurious level and acts to protect the occupant. The characteristics of the dynamic interaction between these components and the vehicle occupants (the SID test dummies) determine the effectiveness of the vehicle side crash protection performance.

One useful tool, to understand the dynamic interaction between the intruding door structure and the vehicle occupants during the impact, as well as to assess the efficiency of the door design in collision performance, is the velocity-versus-time diagram. This diagram graphically traces these critical structural components and the responses of the occupant. Shown in Figure 4 is a simplified illustration of a typical door construction. The door is generally comprised of the outer and inner panels (usually made of sheet metal) and the interior trim panel (usually made of plastic with or without energy-absorbing padding). Housed between the inner and outer panels (skins) are the window mechanism, remote actuating levers and rods, as well as reinforcing guard beam(s), if so equipped. The door is attached to the door frame, which is comprised of the pillar structure, roof rail, and door sill. The door frame is designed to resist collision forces and also serves to transmit crash loads from the region around the occupant (essentially the doors) to other vehicle structures during the crash. In the NCAP side tests, the motions of the striking vehicle; the doors, pillars, and occupant of the struck car; and the struck car were electronically monitored using accelerometers.

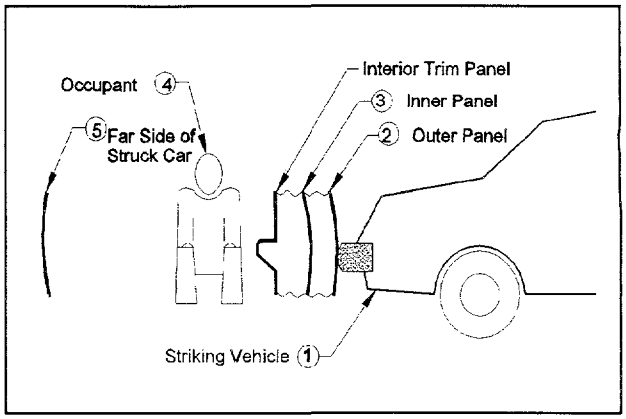

Figure 4. An Illustration of Door Cross Section and Essential Locations of the Velocity-versus-Time Diagram.

A velocity-versus- time plot, typical of the NCAP side tests, is shown in Figure 5. The outer panel (skin) is struck by the impactor (MDB) and moves together with the MDB almost immediately after contact, as shown by the curve denoted as ②. Within 3 to 5 milliseconds (msec), the velocity of the inner panel (together with the interior trim panel) rises to the speed of the striking vehicle as it (the door) continuously undergoes deformation. Sometimes the speed of the inner door panel overshoots that of the impactor, as shown by curve ③. In fact, curve ③ is representative of the velocities of the pillars as well. Dynamic contact between the door inner surface and the SID (in the area of the ribs, spine, or pelvis) generally starts 10 to 20 msec after the impact event began. After the dynamic loading of the occupant (SID) by the intruding door structure has begun, the occupant usually reaches its peak velocity around 20 to 40 msec after initial impact. Curve ④ shows a typical velocity - time trace of the SID response. This response typifies the motion of the SID's rib, spine, and pelvis. As shown in the diagram, the occupant was contacted and loaded by the intruding door structure starting at time t_0. The intruding door continued in contact with the occupant until the two separated at time t_1. The continuous deformation of the door structure can also be visualized as a two-sequence event. First, the door starts to deform under the influence of the impactor. As this deformation continues, the interior door encroaches until striking the SID which resists the door's motion with its inertia force. This inertial loading of the door by the SID and the impact loading of the occupant starts at t_0 and lasts until time t_1 when the two separates. The velocity of the impactor, curve ①, and the velocity of the struck car, curve ⑤, generally move to a common velocity, v_f. The velocity-versus-time diagram not only documents (with a high degree of clarity) the key interactions of the crash event but also supplies the necessary data needed for analyzing and assessing the vehicle's collision performance in a side crash. In the sections that follow, the data in the velocity-versus-time diagram are used in an analysis and assessment of the NCAP side impacts.

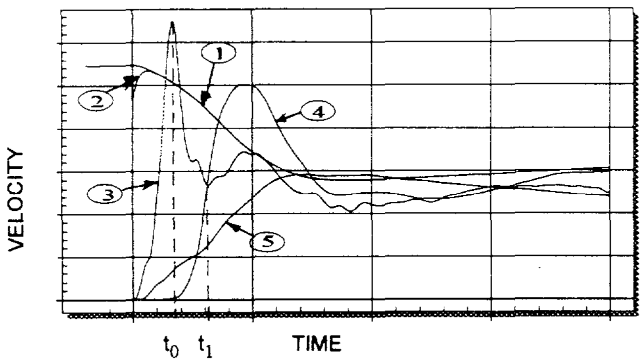

Figure 5. Velocity-versus-Time Diagram.

MAXIMUM SPEED OF THE INTRUDING DOOR

Figure 6 graphically presents the velocities of many essential points during the NCAP side impact test of the 1997 two-door Ford Thunderbird. To construct Figure 6, accelerometers at critical locations – the locations shown in Figure 3 – were integrated to obtain the velocities. During the first 140 msec, all the velocities progress to a common velocity, v_f, which is 32 kmph in the case of the Ford Thunderbird.

The velocity of the interior door goes from rest to 56 kmph in 11 msec. In the case of the Ford Thunderbird, the velocity rises quite high, above the velocity of the striking barrier. The occupant is not moving at all during these initial 23 msec. As suggested by Lau et al., the dummy is at rest and must receive quite a punch when the door intrudes inward about 132 mm.

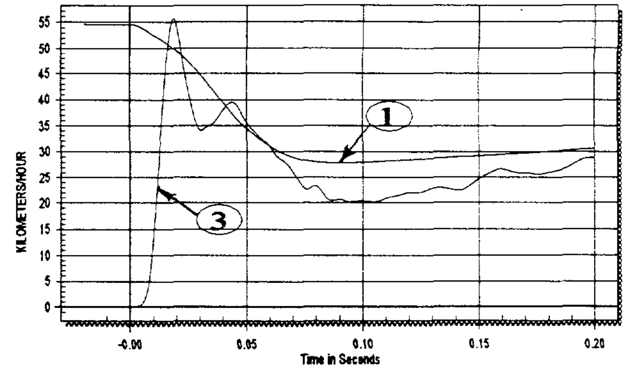

Figure 6. Interior Door Velocities of Ford Thunderbird.

In analyzing all thirty-two NCAP side impact tests, the maximum speed of the interior door varied over a range from a low of roughly 32 kmph to a high of about 59 kmph. For example, Figure 7 gives the velocity-versus-time diagram for the 1997 Toyota Corolla. In the case shown by Figure 7, the maximum speed of the door appears to rise only to about the final velocity, v_f, of the two vehicles around 10 msec.

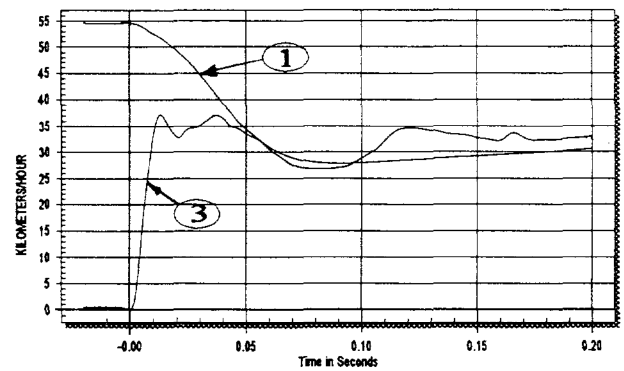

Figure 7. Velocity of the MDB and Toyota Corolla.

To quantify the range in door velocities, consider Figure 8. Shown is a corridor for the door velocity observed in twenty-seven NCAP side impact crash tests. The velocity of twenty-seven vehicles was computed at the mid B-pillar location of the struck vehicle. The two curves of the corridor are the plus one and minus one standard deviation curve for the twenty-seven tests. For perspective, the average velocity of the center of gravity of the striking vehicle – the moving deformable barrier – is drawn.

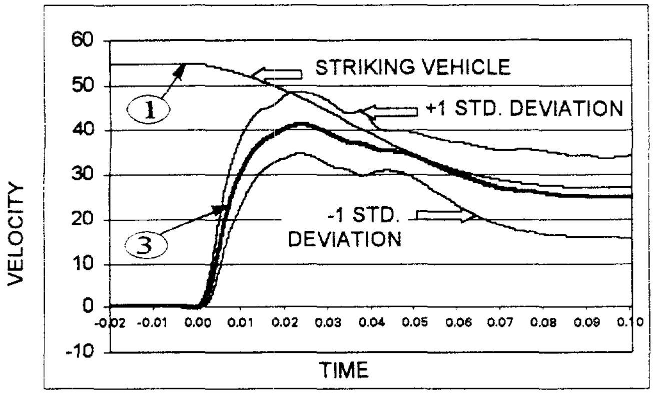

Figure 8. Average Velocity of Mid B Pillar with ± 1 Standard Deviation.

There are a possible choice of six door accelerometer locations: the left front sill, the left front door centerline, the left front door mid-rear, the left front door upper centerline, the left lower B-post, and the left mid B-post. The vehicles' mid-B pillar was chosen because, in general, this sensor performed satisfactory. Other sensors may have rotated or had curves that did not approach the final velocity. It is important to realize that for some vehicles, the peak velocity may have occurred at another accelerometer location.

Generally speaking, the maximum velocity of the door varied between two peaks for the set of all door velocities observed in these laboratory tests. One is a maximum velocity that has an apogee around the final velocity of the striking and struck vehicle. This is commonly termed the *soft stroke* of the impacting door. The second type of peak velocity occurs when the door velocity exceeds the striking vehicle's velocity. At this time, a *punch* is said to have occurred.

OCCUPANT CRUSH OF THE INTERIOR DOOR

Looking back at Figure 5, (or Figure 6 in the case of a specific car, the Ford Thunderbird), one sees the door's velocity, curve ③, rise to a maximum. In part, the interior door begins to decrease its velocity because occupant and door collide, and reaction forces are directed from the occupant, curve ④, onto the door, curve ③. The initiation of this interaction is indicated by time t_0 in Figure 5. It is 17 msec in Figure 6.

The distance between the door and the occupant is determined by computing the area between the door velocity curve and the velocity curve of the occupant (which is zero at the moment the door contacts the occupant). Integrating the velocity curve of the door, curve ③, in Figure 9, from t=0 to $t=t_0$, will compute the distance. This distance is also reported as the arm-to-door or hip-to-door distance.

At some point in time, the occupant and the interior door reach a common velocity. In Figure 5, this is marked by t_1. By computing the area between the occupant and door velocity curves from time t_0 to time t_1, one can determine the amount of door padding and structure crush and occupant chest crush. Gabler et al. [4] define Door Effective Padding Thickness (DEPTH) as the relative displacement between the door and occupant from the time of occupant-door contact until the time of occupant-door separation. Figure 9 below illustrates these areas. From the crash observer's perspective, DEPTH is the amount which the occupant's torso deforms plus the amount which the occupant crushes the door's padding and interior structure.

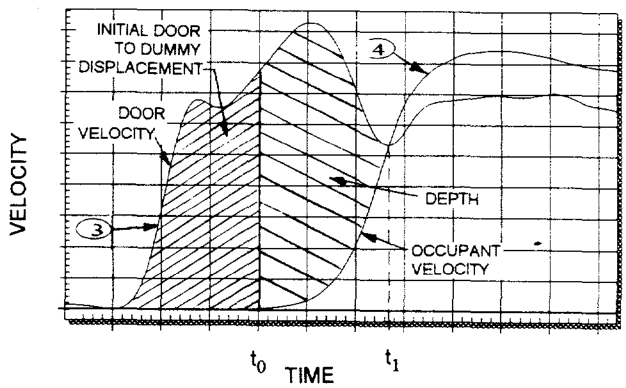

Figure 9. Door and Occupant Velocity Curves.

Figure 10 shows a plot of the Thoracic Trauma Index, TTI, for the thirty-two cars versus the occupant crush of the interior door. The data is included in Appendix 1. of this paper. A linear regression routine was compiled through the thirty-two data points and the R-value was computed to 0.48. Equation 1., below, describes this relationship. These data suggest that there is a correlation between TTI and the single variable, occupant crush of the interior door. [11]

$$TTI = -0.146\ DEPTH + 103.99 \qquad (1.)$$

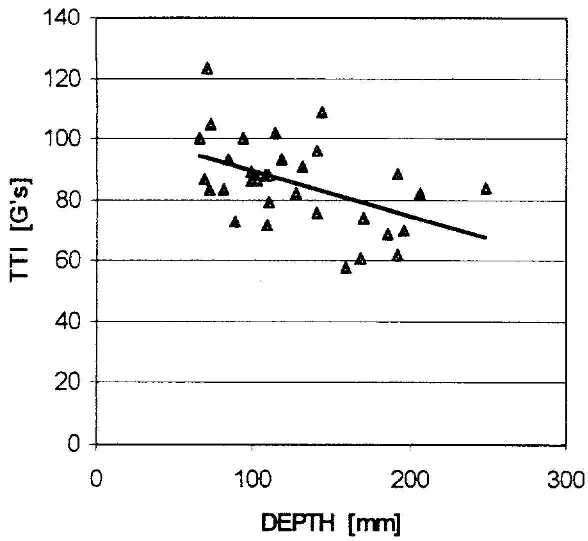

Figure 10. DEPTH vs TTI.

VERTICAL INTRUSION PROFILE OF THE INTERIOR DOOR

As Reference 6 suggests, it makes sense, from a biomechanical point of view, to have the intruding door load the parts of the occupant's body that can withstand the forces the most without trauma. Reference 6 advises that it is important to load the pelvic region during the initial occupant-door contact. As Hobbs explains, it is better to distribute the loading along the entire torso of the occupant, beginning first with the pelvis, than to have the intruding structure only strike the shoulder and torso, where many important organs are located. [5]

By referring to Figure 2, it can be seen that the dummy, SID, has a lateral accelerometer in the pelvis. There are two lateral accelerometers on the upper and lower ribs. The pelvis is a relatively rigid structure while the torso has a soft simulated arm over a stiff rib cage. If the dummy is being loaded by an interior door that is vertically aligned, then the pelvis accelerometer should have an initial response at the same time or slightly before the beginning of the rib cage acceleration. Should the pelvic signal start significantly before the signal at the rib cage, then the pelvis is contacting the door first. This *lead* is commonly referred to as the pelvic lead. The pelvic lead phenomenon has been applied to the design of some vehicles. [6] Basically, it amounts to the pelvis being impacted ahead of the thorax.

To determine the pelvic lead, one calculates the difference in time between the peak acceleration of the pelvis and the thorax (caused by impact with the intruding door), as shown in the equation below. Figure 11 shows two typical acceleration curves for the pelvis and spine.

$$\text{Pelvic Lead} = t_{torso} - t_{pelvis} \qquad (2.)$$

where,

t_{torso} = time at maximum torso acceleration, and
t_{pelvis} = time at maximum pelvic acceleration.

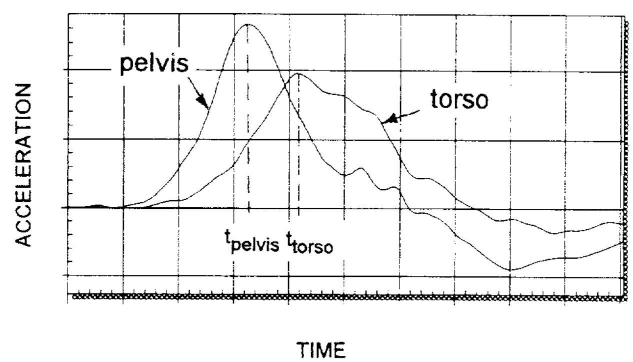

Figure 11. Occupant Response of Pelvis and Thorax.

For the thirty-two NCAP side impact tests, Figure 12 shows a plot of the Thoracic Trauma Index, TTI, versus the pelvic lead. These test data suggested that the pelvic lead will introduce beneficial effects to the thoracic portion of the SID. In other words, more pelvic lead lessens the severity of thoracic injury. These data suggest that there is a modest correlation between TTI and the single variable, pelvic lead. A linear regression routine was compiled with thirty-two data points and the R-value was computed to be 0.37, with the equation below, describing the relationship. [11]

$$\text{TTI} = -0.509 \text{ Pelvic Lead} + 95.05 \qquad (3.)$$

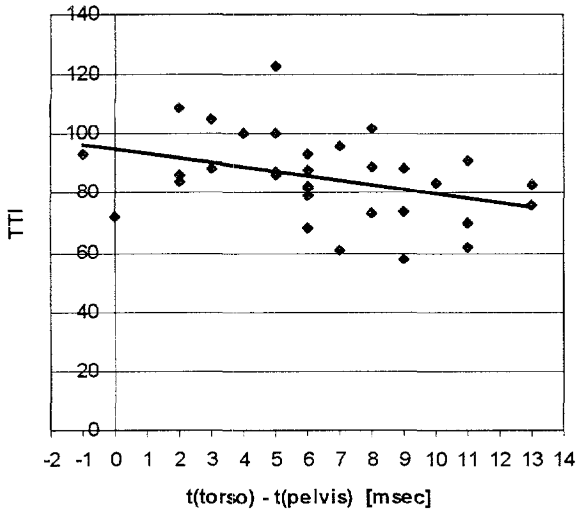

Figure 12. Pelvic Lead vs TTI.

Figure 13 plots the Pelvic Lead vs the maximum pelvic acceleration value. As shown, the Pelvic Lead and maximum pelvic acceleration are not necessarily related to each other. In other words, greater Pelvic Lead may not necessarily develop large pelvic acceleration.

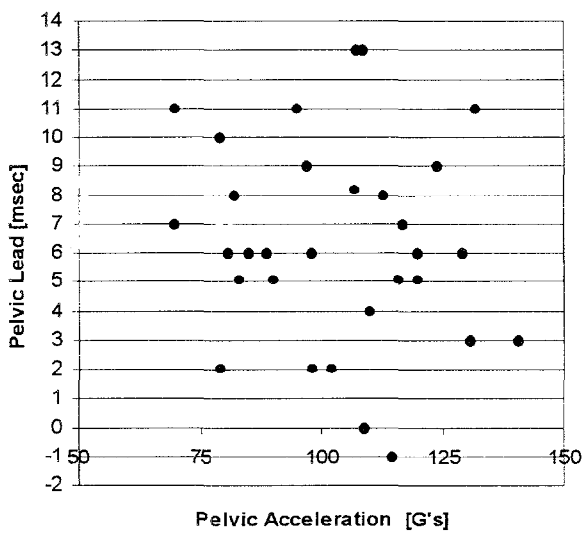

Figure 13. Pelvic Lead vs Pelvic Acceleration.

EFFECT OF COMBINING DEPTH AND PELVIC LEAD

In the Introduction section and the previous two sections, two important considerations for protecting an occupant in side impact were discussed. Using the data from thirty-two NCAP side impact tests, the dummy's response was examined first as a function of DEPTH and then as a function of pelvic lead. Alone, neither of these variables satisfactorily explains the response of the dummy in these tests. The next step in this study is to investigate if the two variables together increase our ability to explain the dummy's response.

A linear regression analysis was performed using a routine to determine the regression coefficients and confidence levels. [11] Two independent parameters, DEPTH and pelvic lead, were chosen for the regression analysis.

A relationship between these two independent variables and the Thoracic Trauma Index, TTI, was computed. The R-value for the combination of variables, DEPTH and pelvic lead, is 0.60 with the relationship described by Equation 4. [11] Figure 14 graphs the TTI, recorded in the NCAP tests, versus the linear combination of DEPTH and pelvic lead. Figure 14 illustrates that TTI increases, monotonically, as the linear combination of DEPTH and pelvic lead increases. This linear model explains about a third of the variability in the data.

$$TTI = -1.42\ \text{Pelvic Lead} - 0.14\ DEPTH + 112.5 \quad (4.)$$

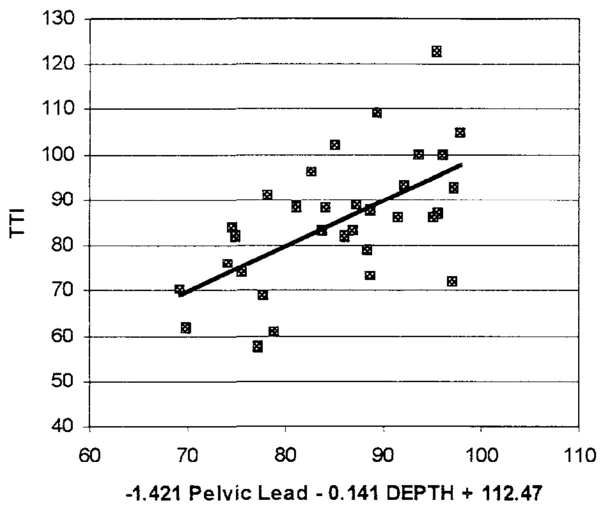

Figure 14. Linear Combination of Pelvic Lead and DEPTH.

To understand how the two independent variables interact to mechanically affect the dummy's response, the data in Figure 13 may be plotted as DEPTH versus pelvic lead. A data point would then be the value of TTI recorded in the NCAP crash test. For this type of cross plot, greater clarity is obtained by arranging the TTI values into groups and giving each group a nemonic symbol. On the cross plot, a data point would then appear under the symbol of the group to which its value belongs. To plot DEPTH versus pelvic lead, the TTI value was first converted to a star rating.

For those readers not familiar with the star rating methodology, the side star rating system is based on the thoracic injury function curve developed for the Thoracic Trauma Index. This thoracic injury function curve is contained in the final regulatory evaluation for FMVSS No. 214 [12] and is shown in Figure 15. This function relates the probability of an AIS $\geq$ 4 thoracic and upper abdominal injury to TTI in a lateral impact.

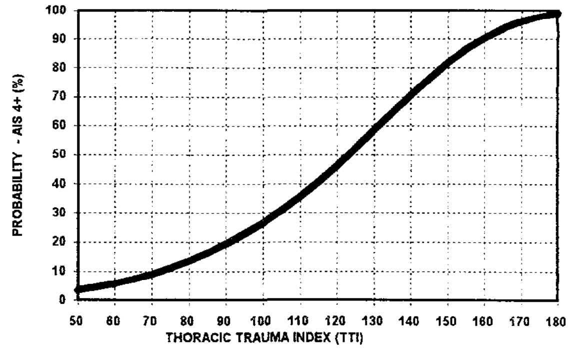

FIGURE 15. Thoracic Trauma Index Risk Function (Reference 12).

From the probability values, a star rating for an occupant was developed. The following levels are used to designate the stars:

☆☆☆☆☆	=	5% or less chance of serious thoracic and upper abdominal injury
☆☆☆☆	=	6% to 10% chance of serious injury
☆☆☆	=	11% to 20% chance of serious injury
☆☆	=	21% to 25% chance of serious injury
☆	=	26% or greater chance of serious injury

Using the risk curve, the star ratings correspond to a range of TTI values.

☆☆☆☆☆	=	TTI $\leq$ 57
☆☆☆☆	=	57 < TTI $\leq$ 72
☆☆☆	=	72 < TTI $\leq$ 91
☆☆	=	91 < TTI $\leq$ 98
☆	=	TTI > 98

In short, the star rating methodology converts the continuous TTI into a categorical variable. Appendix 2. provides star ratings for forty-six NCAP side impact vehicles.

Figure 16 shows the test data on a graph of DEPTH versus pelvic lead. For each of the thirty-two

NCAP tests, the dummy's response is represented by its star rating. Superior descriptors, of the mechanical input into the dummy, should partition different star ratings further apart with minimal overlaps. For poorer descriptors, the star ratings should be intermixed without clear separation. In Figure 16, it can be seen that DEPTH and pelvic lead begin to separate the outcome variable, representing the dummy's response. Those dummy responses with three stars are grouped together. The four star ratings are generally higher than the three star ratings but are mixed with the three star ratings. Figure 16 suggests that for a given value of crushing door padding, a lower thoracic response may be obtained by impacting the pelvis roughly 10 ms before the torso.

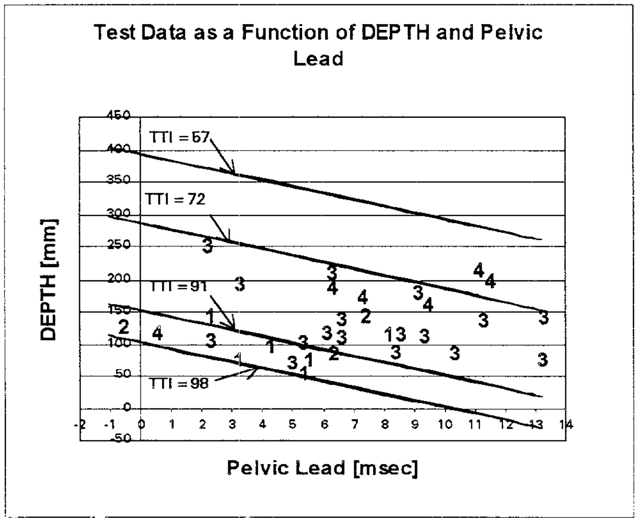

Figure 16. Linear Combination of Pelvic Lead and DEPTH at a Constant TTI.

CONCLUSIONS

The USA NCAP conducted thirty-two side impact crash tests. These tests were based on the testing methodology of FMVSS No. 214. The deformable moving barrier was traveling at 61.6 kmph just before hitting the struck vehicle. Accelerometers were installed in a variety of locations about the door panel, A-pillar, and B-pillar of the struck vehicle. In previous side impact testing, struck door accelerometers frequently exhibited anomalies because they were subjected to severe impact loading. An analysis was conducted of the accelerometers used in the thirty-two NCAP tests. It was determined that many of the accelerometers survived the side impact and produced satisfactory signals.

Using the accelerometers in the interior door, A-pillar, and B-pillar, the maximum velocity of the interior door in the struck vehicle was calculated. It was found that the speeds of the thirty-two intruding doors appeared to vary over a wide range. Some doors had a maximum speed that reached only as high as the velocity of the struck vehicle. Other intruding doors reached a speed roughly twice the final velocity of the struck vehicle.

The Door Effective Padding Thickness (DEPTH) is the relative displacement between the door and occupant from the time of occupant-door contact until the time of occupant-door separation. The DEPTH was calculated for thirty-two cars crashed in NCAP side impact. The correlation between the dummy's response and the DEPTH was modest for this data set.

The side impact dummy has accelerometers in the torso and an accelerometer in the pelvis. In a side impact, a pelvic signal starting significantly before the torso would indicate a pelvic lead and mean the door is contacting the pelvis before the torso. The pelvic lead is defined as the time of the pelvic response subtracted from the time of the thoracic response. The pelvic lead was calculated for the thirty-two cars crashed in NCAP side impact. A weak correlation between the dummy's response and the pelvic lead was found for this data set.

No single variable fully explains the response of the dummy during a side impact event. The linear combination of DEPTH and pelvic lead account for about a third of the variation of this data set. The next step in this study will be to investigate other variables with the objective of more completely describing the intensity of the mechanical input and the response of the occupant in the struck vehicle.

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Appendix 1.
Test Data for Thirty-two NCAP Side Impact Tests

Test No.	Make & Model	Model Year	Vehicle Test Wt. kg	TTI g(s)	LUR Depth mm	Pelvic Lead msec
1	Cadillac Deville 4-dr	1997	2085	57.8	159	9
2	Chevrolet Camaro 2-dr	1997	1744	86	99	5
3	Chevrolet Cavalier 2-dr	1997	1450	123	71	5
4	Chevrolet Lumina 4-dr	1997	1758	61	168	7
5	Chevrolet Malibu 4-dr	1997	1618	100	94	4
6	Dodge Intrepid 4-dr	1997	1741	72	109	0
7	Dodge Stratus 4-dr	1997	1538	75.8	141	13
8	Ford Contour 4-dr	1997	1506	73	88	8
9	Ford Crown Victoria 4-dr	1997	1995	68.6	186	6
10	Ford Escort 4-dr	1997	1328	88	108	6
11	Ford Taurus 4-dr	1997	1756	74	171	9
12	Ford Thunderbird 2-dr	1997	1814	91	132	11
13	Honda Accord 4-dr	1997	1470	96	141	7
14	Honda Civic 4-dr	1997	1241	83.1	72	13
15	Hyundai Sonata 4-dr	1997	1543	102	114	8
16	Kia Sephia 4-dr	1997	1305	93	84	6
17	Mazda 626 4-dr	1997	1424	92.9	118	-1
18	Mitsubishi Galant 4-dr	1997	1496	84	249	2
19	Nissan Maxima 4-dr	1997	1618	70	196	11
20	Pontiac Grand AM 4-dr	1997	1581	109	144	2
21	Saturn SL 4-dr	1997	1267	88.2	110	9
22	Subaru Legacy AWD 4-dr	1997	1562	88.4	192	3
23	Toyota Camry 4-dr	1997	1601	82.2	127	6
24	Toyota Corolla 4-dr	1997	1312	89	99	8
25	Toyota Tercel 2-dr	1997	1149	83.3	81	10
26	Volvo 850 4-dr	1997	1723	62	192	11
27	Buick Century	1998	1766	82	206	6
28	Buick LeSabre	1998	1805	79	110	6
29	Chevrolet Cavalier 4DR	1998	1592	105	73	3
30	Ford Escort ZX2	1998	1344	100	66	5
31	Ford Mustang	1997	1601	87	69	5
32	Mercedes Benz C-230	1998	1626	86	103	2

Appendix 2.
Star Ratings for Forty-six NCAP Side Impact Tests

Test No.	Make & Model	Model Year	Driver Upper Rib G's	Driver Lower Rib G's	Driver Spine G's	Driver Pelvic G's	Driver Star Rating	Passenger Star Rating
1	Cadillac Deville 4-dr	1997	47.2	44.3	68.3	96.9	☆☆☆☆	☆☆☆☆
2	Chevrolet Camaro 2-dr	1997	83.3	81.9	88.4	83.0	☆☆☆	☆☆☆☆
3	Chevrolet Cavalier 2-dr	1997	107.5	135.8	110.2	115.8	☆	☆☆
4	Chevrolet Lumina 4-dr	1997	54.4	61.1	61.4	69.5	☆☆☆☆	☆☆☆
5	Chevrolet Malibu 4-dr	1997	82.9	95.2	105.6	109.8	☆	☆☆☆
6	Dodge Intrepid 4-dr	1997	78.3	80.4	64.5	108.9	☆☆☆☆	☆☆☆
7	Dodge Stratus 4-dr	1997	74.0	75.8	75.8	108.7	☆☆☆	☆☆
8	Ford Contour 4-dr	1997	63.9	69.5	76.4	82.0	☆☆☆	☆☆☆☆
9	Ford Crown Victoria 4-dr	1997	69.3	65.5	67.8	80.9	☆☆☆☆	☆☆☆☆
10	Ford Escort 4-dr	1997	78.0	99.0	77.0	120.0	☆☆☆	☆☆☆
11	Ford Taurus 4-dr	1997	71.0	78.0	70.0	97.0	☆☆☆	☆☆☆
12	Ford Thunderbird 2-dr	1997	71.5	87.7	93.4	131.8	☆☆☆	☆
13	Honda Accord 4-dr	1997	94.4	78.0	97.4	117.0	☆☆	☆☆☆
14	Honda Civic 4-dr	1997	78.5	86.9	79.3	107.2	☆☆☆	☆☆☆
15	Hyundai Sonata 4-dr	1997	113.9	109.1	89.7	112.8	☆	☆☆
16	Kia Sephia 4-dr	1997	79.0	90.9	95.1	84.7	☆☆	☆
17	Mazda 626 4-dr	1997	70.7	90.4	95.4	114.5	☆☆	☆☆☆
18	Mitsubishi Galant 4-dr	1997	70.0	74.0	94.0	98.0	☆☆☆	☆☆
19	Nissan Maxima 4-dr	1997	65.9	63.3	73.7	95.3	☆☆☆☆	☆☆☆
20	Pontiac Grand AM 4-dr	1997	104.0	94.5	114.4	102.2	☆	☆☆☆
21	Saturn SL 4-dr	1997	86.0	83.9	90.4	123.8	☆☆☆	☆☆☆
22	Subaru Legacy AWD 4-dr	1997	84.5	81.2	92.2	130.8	☆☆☆	ND
23	Toyota Camry 4-dr	1997	76.4	82.0	82.4	88.6	☆☆☆	☆☆☆
24	Toyota Corolla 4-dr	1997	81.8	75.3	96.4	106.9	☆☆☆	☆☆☆
25	Toyota Tercel 2-dr	1997	86.7	91.6	74.9	79.2	☆☆☆	☆☆☆☆
26	Volvo 850 4-dr	1997	57.4	50.5	66.5	70.5	☆☆☆☆	ND
27	Buick Century	1998	76.0	77.0	86.8	128.8	☆☆☆	☆☆☆
28	Buick LeSabre	1998	63.3	64.8	93.2	98.1	☆☆☆	☆☆☆
29	Chevrolet Cavalier 4DR	1998	99.2	74.4	110.7	140.7	☆	☆☆☆
30	Ford Escort ZX2	1998	85.9	99.2	100.9	119.8	☆	☆☆☆☆
31	Ford Mustang	1997	76.5	80.4	94.3	90.1	☆☆☆	☆☆☆
32	Mercedes Benz C-230	1998	67.1	80.8	91.0	79.5	☆☆☆	☆☆☆☆
33	Mazda 626	1998	56.7	67.5	93.3	135.7	☆☆☆	☆☆☆
34	Dodge Neon	1998	93.7	87.0	94.0	102.0	☆☆	☆☆☆
35	Pontiac Bonneville	1998	74.4	72.9	94.1	111.5	☆☆☆	☆☆
36	Honda Civic 2DR	1998	85.1	107.9	78.9	92.1	☆☆	☆☆☆
37	Nissan Altima	1998	81.5	89.8	87.1	93.0	☆☆☆	☆☆☆
38	Toyota Avalon	1998	47.6	51.4	61.1	106.3	☆☆☆☆☆	☆☆☆☆
39	Toyota Corolla	1998	76.1	75.5	74.6	108.2	☆☆☆	☆☆☆
40	Mitsubishi Eclipse	1998	111.2	98.3	132.4	108.6	☆	ND
41	VW Jetta	1998	46.5	61.0	89.9	115.6	☆☆☆	☆☆
42	Nissan Sentra	1998	82.0	78.0	98.0	116.0	☆☆☆	☆☆☆
43	Honda Accord 4DR	1998	67.7	71.4	67.9	77.4	☆☆☆☆	☆☆☆☆
44	Olds Intrigue	1998	79.1	59.9	90.4	98.2	☆☆☆	☆
45	Toyota Lexus ES300	1998	53.0	54.0	61.0	107.0	☆☆☆☆☆	☆☆☆☆
46	Hyundai Elantra	1998	73.6	77.4	97.1	127.7	☆☆☆	☆