# Development of Sub-system Sled Test Methodologies for Evaluation of Side Impact Countermeasures

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**Abstract:** This paper presents two new sub-system sled test methodologies developed primarily for the development and evaluation of safety counter-measures and door trim designs for enhanced side impact occupant protection. These enhancements can be helpful in meeting regulatory and non-regulatory performance requirements in both MDB (IIHS, FMVSS214/LINCAP and ECE95) and Pole (FMVSS 214, FMVSS 201) test modes. The main objectives of the test methodologies were to simulate "gap closure velocity and kinematics" between the dummy and door/side structure for design and evaluation of occupant protection countermeasures such as side airbags and door trim designs. To simulate MDB full-vehicle tests at a component level, a new sled-to-sled test methodology was developed using a combination of three sleds consisting of a bullet, a door, and a seat sled. A VIA decelerator system was used to replicate an entire door velocity profile from the start of a crash event until the end of impact. To simulate occupant responses in FMVSS 214 oblique pole impact tests, a new door sub-system sled test methodology was developed using a novel fixture design that accounts for all the key factors affecting both the 5th percentile SID-IIs and 50th percentile ES-2re dummies' responses. The results of dummy responses and kinematics from these sled tests will be presented in comparison and validation to their respective full-vehicle tests.

**Keywords:** side impact, FMVSS 214, SID-IIs, ES-2re, dummy, occupant, sub-system, test methodology, countermeasures

## 1 Introduction

During the last decade the need for development and evaluation of safety counter-measures and door trim designs for enhanced side impact occupant protection has led to a preponderance of component and sub-system sled test methodologies using door/side structure[1-28]. The various side impact sled test methodologies available in the literature were reviewed and summarized by Chou et al.[29]. In the United States, the introduction of IIHS (Insurance Institute for Highway Safety) side impact cart test using 5th percentile SID-IIs deflection-based dummies to assess occupant and structural performance has led to increased offering of side airbags (SABs) either as standard or optional content). This is due to the upper torso injury metrics (average and peak rib deflections, rib deflection rates, V*C and shoulder deflection) and their importance on overall vehicle rating (Good/Acceptable/Marginal/Poor). This has led to the need for development of improved tools (CAE and/or component/sub-system testing) to develop and assess SAB performance. Further, with the publication of NHTSA's FMVSS 214 final rule on September 11, 2007, the agency introduced the 75 degree oblique pole tests with more biofidelic and advanced SID-IIs (build level D) and ES-2re dummies with additional injury criteria for thorax, abdomen and pelvis regions. The FMVSS specified test configuration consists of a vehicle oriented at 75 degrees impacting a stationary rigid pole 254 mm (10 inches) in diameter at an initial velocity of 32 kph (20 mph). The center line of the rigid pole is aligned with the head center of gravity (C.G.) of the front row dummy. In this test mode, the vehicle must be propelled sideways so that the line of the vehicle motion forms an angle of 75 degrees with respect to its longitudinal centerline. While there is a preponderance of test methodologies related to simulation of occupant responses in MDB (Moving Deformable Barrier) test modes, the literature is sparse with sub-system test methodologies for simulating occupant responses in pole test modes[25, 28], especially FMVSS 214 oblique pole test mode with additional injury criteria for thorax, abdomen and pelvis.

Two dynamic door sub-system test methodologies for simulation of occupant responses in MDB and oblique pole side impact test modes are described in this paper. The motivation for the development of these test methodologies was to simulate "gap closure velocity and kinematics" between the dummy and door/side structure for improved design/assessment of SAB performance. The door-to-dummy gap closure velocity in this paper refers to door velocity-time history from the start of the crash event until the onset of door-dummy contact. To simulate the MDB full-vehicle test at a component level, a new sled-to-sled test methodology was developed using a combination of three sleds consisting of a bullet, a door, and a seat sled and VIA decelerator system to replicate an entire door velocity profile from start of crash event until the end of impact[30]. To simulate occupant responses in FMVSS 214 oblique pole impact tests, a new door sub-system sled test methodology was developed using a novel fixture design that accounts for all the key factors affecting both the 5th percentile SID-IIs and 50th percentile ES-2re dummies' responses[31]. The results of dummy responses and kinematics from these sled tests will be presented in comparison to their respective full-vehicle tests for validation. The test methodologies will be presented in two parts. The sled-to-sled test methodology for MDB test mode will be presented first followed by the oblique pole test methodology.

## 2 Method

### 2.1 Sled-to-Sled Test Methodology for Simulation of MDB Test Modes

The quality of a side impact simulation is influenced by many factors, most importantly, the *door-to-dummy contact velocity, door velocity profile from onset of dummy contact* (which affects momentum exchange between door and dummy), *door compliance/door-dummy contact stiffness, shape of intruding side structure* and *seat-to-side structure interaction*[32]. Another factor which might influence the dummy responses is the seat displacement, but the sensitivity of the dummy responses to this has yet to be clearly understood. The presence of a seat mounted side airbag warrants that the initial distance between the door and the dummy be accurately captured, to accurately simulate the side structure close-in velocity and distance as the airbag is deployed.

The amount of door space remaining between the door inner and outer panels at the time of dummy contact determines the extent of *door compliance* available. The dummy responses are sensitive to the door-dummy interface stiffness and hence, should be accurately assessed. The door compliance or mutual crush between the door and MDB is determined by subtracting the door lateral displacement (from double integration of door accelerometer data in the vicinity of dummy) from the MDB longitudinal displacement (also obtained from double integration of MDB C.G. accelerometer) at the time of dummy contact with door trim. This methodology accounts for the load path through the seat frame by mounting the seat on the seat tracks, though this may not be a major determinant of the simulation outcome (in terms of dummy responses). These factors affecting the quality of side impact simulation were discussed in greater detail by Aekbote et al. [30].

In this test methodology, the entire door velocity-time history is simulated along with dynamic door compliance. This is accomplished by means of three sleds - Bullet sled, Door sled and Seat sled. At the start of the simulation the door sled and seat sled are stationary and the distance between the dummy and door is maintained the same as in full-vehicle. Figure 1 shows the schematic of the test set-up. The bullet sled impacts the door sled at an initial velocity and accelerates the door sled to a pre-determined door-to-dummy contact velocity. After attaining the peak door velocity (or dummy-to-door contact velocity), both the bullet and door sleds are decelerated along a desired velocity profile by the VIA decelerator. The schematic of the velocity-time histories of bullet and door sleds is shown in Figure 2. The door (and bullet) sled impacts the seat sled and accelerates the seat sled along the non-struck velocity of the vehicle in full-vehicle crash. The mass of the seat sled governs this momentum exchange. The seat sled is brought to rest independently after the event by an energy absorbing device such as aluminum honeycomb or hydraulic dampers. The momentum exchange between the bullet and door sleds until dummy contact (or during gap closure) is a function of mass ratio of the bullet (**$M_b$**) and door (**$M_d$**) sleds and initial velocity of the bullet sled (**$V_{bi}$**) and is governed by conservation of momentum,

$$M_b * V_{bi} = M_b * V_{bf} + M_d * V_{df} \quad (1)$$

Where **$V_{bf}$** and **$V_{df}$** are final velocities of bullet and door sleds respectively. To achieve a pre-determined dummy-to-door contact velocity (**$V_c$**), both the bullet and door sleds have to attain a common final velocity, **$V_c$**, which can be determined from Equation (1).

$$\text{Substituting } V_{bf} = V_{df} = V_c$$

$$V_c = (M_b * V_{bi}) / (M_b + M_d) \quad (2)$$

Using Equation (2) the variation of **$V_c$** with the *mass-ratio* (**$M_b/M_d$**) of bullet and door sleds is plotted in Figure 3, for an initial bullet sled velocity of 25 mph, 30 mph and 35 mph respectively.

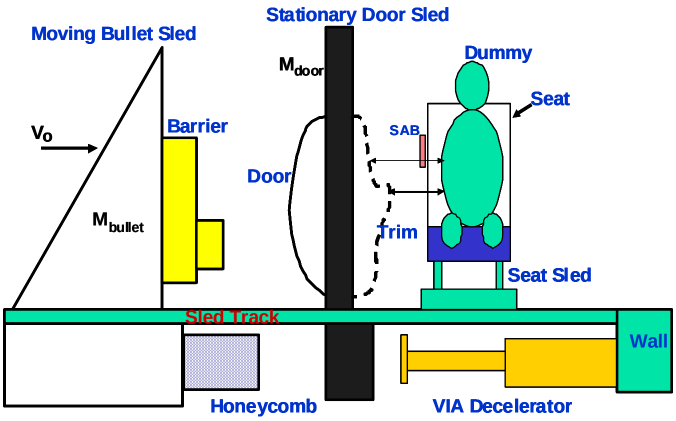


Figure 1: Schematic of the Sled-to-Sled Test Set-up

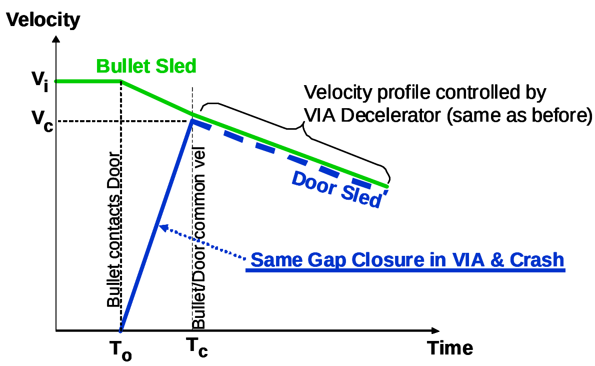


Figure 2: Schematic of Bullet and Door Sled Velocities

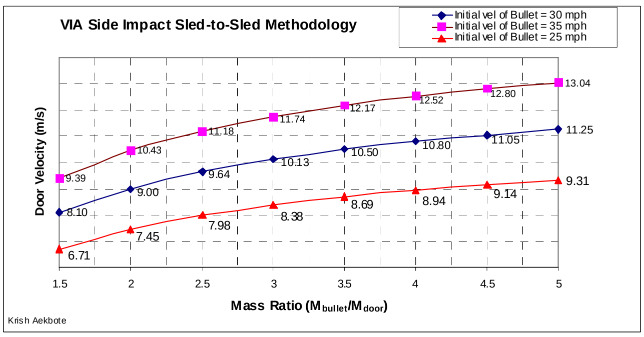


Figure 3: Variation of peak door velocity with mass ratio of Bullet and Door sleds for various initial Bullet sled velocities

### 2.1.1 Test Set-up for Sled-to-Sled Test Methodology

The test methodology consists of three sleds – Bullet sled, Door sled and Seat sled as shown in Figure 1. All three sleds are constrained to translational motion along the sled track, but capable of moving independently of each other. A rigid MDB face simulating a section of an IIHS barrier is mounted to the Bullet sled. A rigid barrier section is chosen for ease of test set-up and repeatability, however, the deformation of the barrier in full-vehicle test is accounted for in the determination of the door compliance. The width of the MDB section is chosen such that the rigid barrier does not engage the A & B pillars and Rocker section of the rigidized door frame. Figure 4 shows the rigid barrier attached to the bullet sled and its position relative to door. The door along with the door frame (A-pillar, B-pillar and Rocker) is mounted to the door sled as shown in Figure 5. The door frame is reinforced (to door sled) and rigidized to minimize deformation and enable smooth changing of new doors between tests. The orientation of the door and door frame is such that it represents the rotation of the door in longitudinal and vertical axes (of the vehicle) as determined from full-vehicle test at dummy contact. Typically in the IIHS test mode, due to the trapezoidal shape of the MDB, the B-pillar of the vehicle intrudes in-board leading to the rotation of the door in the vertical axis. The MDB face mounted to the bullet sled is aligned relative to the door as in full-vehicle test. An aluminum honeycomb of a pre-determined stiffness and cross-sectional area is mounted to the base of the bullet sled and acts as an impact interface between the bullet and door sleds as indicated in Figure 4. The property of the aluminum honeycomb (crush strength and cross-sectional area) depends on the acceleration of the door sled required to attain the peak door velocity and is discussed in the next section. The length of the honeycomb is determined based on the door compliance at dummy contact.

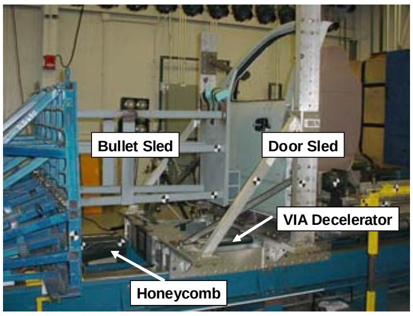


Figure 4: Bullet sled with the rigid MDB and its relative position to Door

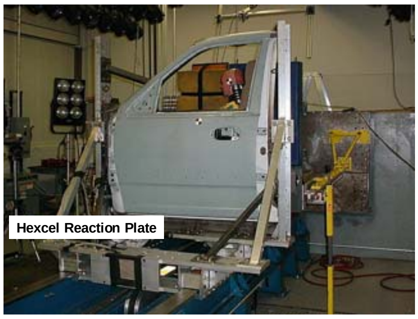


Figure 5: Door with rigidized Door frame – 'Door Sled'

The door compliance is achieved in this test methodology by the amount of rigid barrier crush into the door. While determining the mutual crush using the MDB and door displacements from full-vehicle test, the barrier deformation should be accounted for. Engineering judgment or post-test inspection can be used to estimate the bumper deformation of the barrier (1 to 2 inches typically). The offset between the rigid bumper and barrier face may have to be reduced by the extent of bumper deformation in the full-vehicle test to simulate door compliance. The length of the honeycomb may also vary, depending on the magnitude of rigid barrier crush into the door. Care should be taken to account for the stack up of aluminum honeycomb while determining the crushable length.

A VIA decelerator (consisting of a programmable orifice array) with the piston extended (full-length or partial) and attached to the fixed wall of the sled is in contact with the door sled at the start of the event. The decelerator has an in-built lag or a response delay and should be accounted for in the input. Typically, the lag or response delay can be quantified in terms of the piston stroke or time required to initiate deceleration from contact with the piston. The seat along with the seat track is mounted to the seat sled, which is capable of sliding independent of the door sled. The door sled upon impacting the seat sled may lose momentum rapidly and may render the simulation of door velocity profile and seat kinematics inaccurate. To overcome the inertia of the seat sled while mitigating the effect on door velocity profile, force is transmitted through the door sled frame to the seat sled by means of aluminum honeycomb or an EA (Energy Absorbing) device, the properties of which can be determined based on the mass and kinematics of the seat sled.

At the start of the simulation the door sled is positioned at the representative lateral distance from the dummy/seat sled. The dummy and seat initial position relative to door are the same as in the full-vehicle test. Figure 6 shows the initial position of the door and seat sleds, and the relative position of the dummy to door. The bullet sled accelerates to an initial velocity and impacts the door sled. Upon impact, the door sled accelerates to a peak door velocity within a time-to-peak duration by crushing the aluminum honeycomb, while simultaneously engaging the piston of the VIA decelerator. At the time of the peak door velocity and/or contact with the dummy and seat sled, both the bullet and door sleds are decelerated by the VIA decelerator along a pre-determined door velocity profile. The seat sled is accelerated by the door sled and eventually separates from the door sled and is brought to rest by an EA device such as aluminum honeycomb or hydraulic dampers. Thus the entire door velocity profile including the gap closure is simulated along with the dynamic door compliance and seat motion.

TUNABILITY FOR VARIOUS DOOR VELOCITY PROFILES

A good test methodology should be able to simulate a wide array of operating conditions within the physical constraints of the test set-up. Such an effort is made in this test methodology to simulate a wide array of door velocities. To better describe the tunability of this methodology, the door velocity is simply parameterized into three components - *peak door velocity*, *time-to-peak door velocity*, and *velocity profile after onset of peak door velocity*. The peak door velocity and time-to-peak velocity together constitute the *gap closure*. The schematic of peak door velocity and time-to-peak velocity are shown in Figures 7 and 8 respectively. The velocity profile after time of peak is easily governed by the VIA decelerator which is a programmable orifice array.

The peak door velocity, as noted earlier, is a function of the mass-ratio of the bullet and door sleds ($\mathbf{M_b/M_d}$) and initial velocity of the bullet sled ($\mathbf{V_{bi}}$) as shown in Figure 3. The time-to-peak door velocity is a function of the door acceleration which is governed by the interface honeycomb properties (stiffness and contact area) between the bullet and door sleds. For a given door-dummy contact velocity (**V**$_c$) and mass of the door sled (**M**$_d$), the interface force and subsequently, the honeycomb properties can be determined as shown in Figure 9.

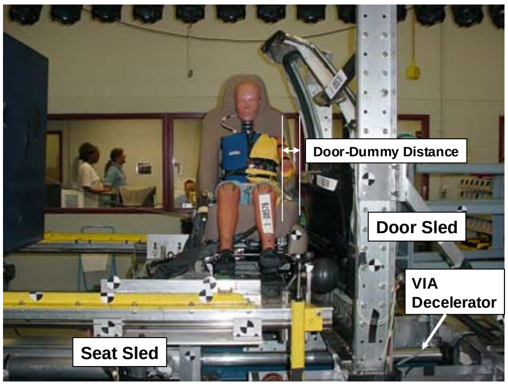


Figure 6: Initial position of Dummy and Seat relative to Door

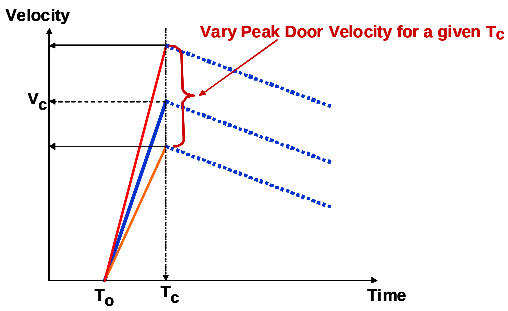


Figure 7: Schematic of peak door velocities

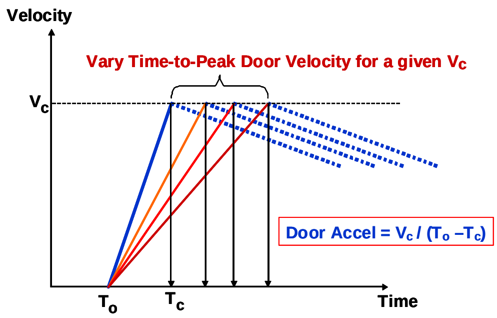


Figure 8: Variation of time-to-peak door velocity

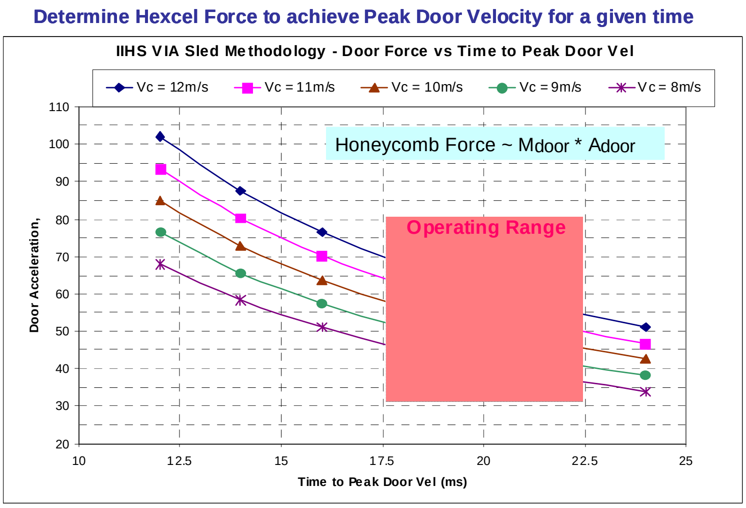


Figure 9: Door acceleration vs. Time-to-peak door velocity for a given peak door velocity

## 2.2 Sub-system Test Methodology for Simulation of FMVSS 214 Oblique Pole Tests

KEY FACTORS AFFECTING OCCUPANT RESPONSES IN A POLE TEST

Based on the sequence of events that occur during a side impact pole test and the physics underlying the occupant responses, the key factors affecting occupant responses in this mode can be summarized as follows:

- Door-to-dummy contact velocity ($V_0$)
- Dynamic Pole Intrusion into Door (not static pre-intrusion)
- Dynamic Door stiffness/compliance
- Shape of intruding Door
- Compliance of B-pillar
- Dummy Position relative to Door trim including initial gap
- Seat kinematics (with side airbag)

Hence, development of a side impact sub-system test methodology for the oblique pole impact test should account for the aforementioned factors, most importantly, the *door-to-dummy contact velocity, dynamic door compliance/door-dummy contact stiffness* (which affects momentum exchange between door and dummy), *shape of intruding door and side structure* and *seat-to-side* *structure interaction*. The presence of a seat mounted side airbag warrants that the initial distance between the door and the dummy be maintained, to accurately simulate the door/side structure close-in velocity when deploying the airbag.

The amount of door space remaining between the door inner and outer panels at the time of dummy contact determines the extent of *door compliance* available. The door compliance is determined from the door lateral displacement (from double integration of door accelerometer data in the vicinity of dummy) at the time of dummy contact with door trim.

In this door sub-system test methodology, the door sled (with the seat and dummy) oriented at 75 degrees relative to the pole is accelerated to 20 mph and impacts the stationary pole, to simulate the *door-to-dummy contact velocity* ($V_0$). Prior to the test, the stationary pole centerline is aligned with the dummy's head center of gravity, with seat positioned according to the size of the dummy used; 5th percentile SIDIIs at full-forward seat track and mid-height and 50th percentile ES-2re at mid-seat and full-down on seat track. The dummy-to-door distance is maintained the same as in full-vehicle test by positioning the seat at the same distance and seatback angle relative to the door, to simulate the *gap closure velocity and kinematics*. From the onset of door contact with the pole, the entire the door sled is decelerated based on the non-impact side velocity of the vehicle, to simulate the effect of vehicle's lateral stiffness during impact with pole, thus controlling the rate of *dynamic pole intrusion* into the door/side structure as well as *door compliance*. As mentioned previously, non-impact side velocity (measured at non-impact location on the vehicle such as B-pillar at rocker or rocker at front seat-mid location) is an indication of the lateral stiffness of the vehicle. The door sled is brought to rest after a pre-determined amount of intrusion. The amount of pole intrusion into the door is based on the time at which peak dummy responses occur, after which the door sled is brought to rest. Also, by controlling the rate of pole intrusion, the *shape of intruding door* during dummy interaction is maintained the same as in full-vehicle test. The compliance of the B-pillar affects the shape of intruding door and is accounted for in the test fixture, which will be presented next.

### 2.2.1 Test Set-up for Oblique Pole Test Methodology

The essential components of the test set-up consist of a 10 inch diameter rigid pole, VIA programmable decelerator and a door sled. The rigid pole and VIA decelerator are mounted to the concrete wall at one end of the sled track as shown in Figure 10. A VIA decelerator, consisting of a programmable orifice array with the piston fully or partially extended, contacts the base of door sled at the onset of door-pole contact. The door sled consists of door frame and part of the vehicle floor pan to retain the foot print for seat attachment. By retaining the floor pan along with the door frame, the seat relative location to door and hence, the pre-test *dummy-to-door distance is maintained as in a full-vehicle test*. The floor pan is rigidized to minimize deformation during the test and to maintain integrity of seat attachment points for smooth changing of seats between tests. The door frame consists of A-pillar, simulated B- and C-pillars, roof rail and rocker and is reinforced (to door sled) and rigidized to minimize deformation, thus enabling smooth changing of new doors between tests. The door attachment to the door frame is the same as in the full-vehicle, by means of two hinges at the A-pillar and latch/striker at the simulated B-pillar. The rigidized door frame along with the floor pan is mounted to the door sled at a 75 degree angle relative to the pole as shown in Figure 11. The height and length of the rigid pole is adjusted such that it does not engage the roof side rail and the rocker of the door frame to prevent damage to the rigidized door frame and floor pan.

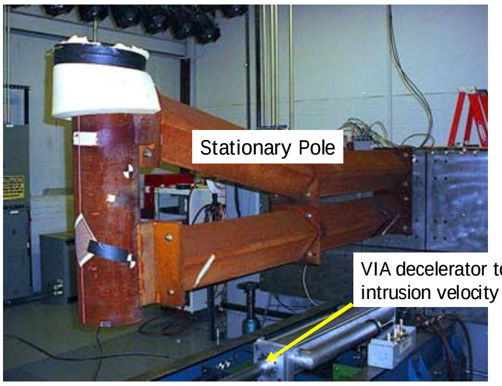


Figure 10: Rigid Pole and VIA decelerator mounted at the end of sled track

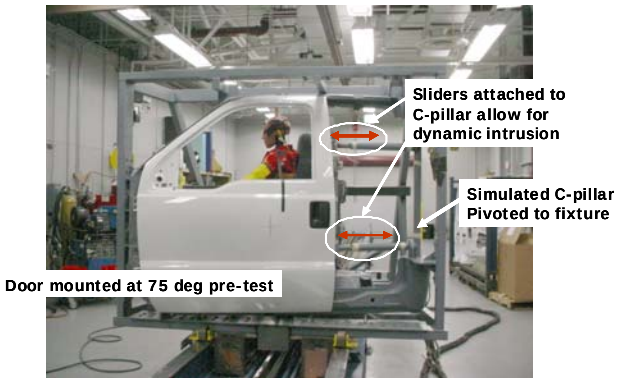


Figure 11: Door sled with the door and rigidized door frame

For the 50th percentile ES-2re dummy seated at the mid-seat track and full-down position, the pole impact location tends to be closer to the B-pillar and may even potentially contact the B-pillar depending on the size of the vehicle (smaller wheel base). In the full-vehicle test with 50th percentile dummy, the B-pillar tends to swing inboard into the vehicle with the C-pillar acting as a hinge, while the forces exerted due to door intrusion tend to pull it away from the C-pillar. A fixture was designed to simulate this complex kinematics of the B-pillar in a repeatable way without causing damage to the fixture itself. This was one of the key challenges in developing this test set-up. In order to simulate the B-pillar kinematics as in full-vehicle test, the C-pillar is pivoted, to have a rotational degree of freedom (d.o.f.). Further, the rigidized B-pillar is attached to C-pillar by means of sliders to enable a translational d.o.f., thus allowing the B-pillar to slide away from the C-pillar (up to a maximum of 12 inches). Additionally, the magnitude and rate of B-pillar motion is controlled by means of two 390 psi aluminum honeycomb blocks placed between the B-pillar and reaction plates mounted to the door sled as shown in Figure 12. The size and thickness of the honeycomb blocks can be varied to simulate the B-pillar responses and kinematics of various full-vehicles. Care should be taken to account for the stack up of aluminum honeycomb while determining the crushable length. During the sub-system test, as the pole dynamically intrudes into the door (at close proximity to the B-pillar), the B-pillar is allowed to swing inboard while simultaneously sliding away from the C-pillar.

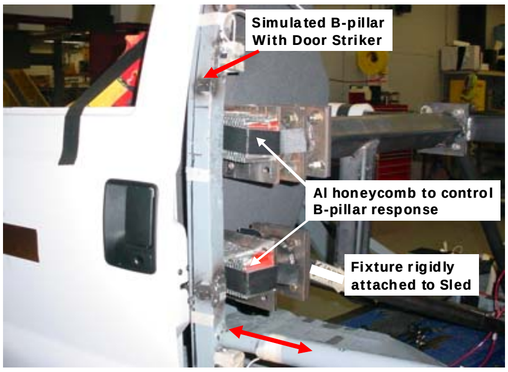


Figure 12: Test set-up for 50th percentile ES-2re dummy

Figure 13: Initial position of Dummy and Seat relative to Door

For the 5th percentile SID-IIs dummy seated at full-forward seat track and mid-height, the pole impact location on the door is away from the B-pillar and typically midway between the A and B-pillars. Depending on the size (wheel base) of the vehicle and the length of front door, the kinematics of the B-pillar may not be as significant for the 5th percentile dummy compared to 50th percentile dummy,. Hence, the B-pillar is constrained for the 5th percentile dummy in this test methodology. However, if there is any seat or seatback interaction with the B-pillar, then it may be desirable to simulate the B-pillar kinematics to capture door-to-dummy dynamic gap closure and side airbag deployment, if present.

At the start of simulation the instrumented dummy is positioned on the seat per the FMVSS 214 dummy positioning procedure for 5th percentile SID-IIs and 50th percentile ES-2re dummies, respectively. Prior to dummy positioning, the seat is placed at correct location on the seat track (full-forward for 5th percentile SIDIIs and mid-seat for 50th percentile ES-2re). Door trim-to-dummy lateral distances (at shoulder, ribs, abdomen, pelvis and knee locations) are recorded to ensure the dummy initial position and orientation is maintained as in full-vehicle test (Figure 13). Contact switches attached to arm, thorax, abdomen, pelvis and thigh are used to monitor the time at which door trim contact occurs. The door sled with the dummy is accelerated to 20 mph along the sled track and impacts the stationary rigid pole. To ensure that the dummy's initial position is not disturbed during the acceleration phase of the door sled (as determined by high speed film analysis prior to door contact with the pole), the head and shoulder may be tethered to a fixed structure on the sled by using light weight masking tape.

At the onset of door-to-pole contact, the base of door sled also engages the VIA decelerator and is decelerated along a pre-determined velocity profile. The entire door sled is decelerated along the non-impact side velocity-time history of the vehicle to simulate *door-to-dummy gap closure, door compliance, and dynamic pole intrusion along with shape of intruding door* as in the full-vehicle test. Since the pole does not engage the door frame in this test set-up, the primary resistive force for slowing the door sled is generated by VIA decelerator early in the simulation, and later by the door that provides progressively increased resistance during the event. Two accelerometers are mounted at the base of the sled to monitor the velocity-time histories of the door sled (obtained by numerical integration of acceleration-time data). To simulate the door-to-dummy gap closure kinematics, the pole is allowed to intrude into the door until the time at which peak dummy responses occur, after which the door sled is quickly brought to rest by two blocks of 390 psi aluminum honeycomb in addition to the VIA decelerator.

# 3 Results and Discussion

## 3.1 Sled-to-Sled Test Methodology for Simulation of MDB Test Modes

Initial runs were made to debug the test set-up and tune the VIA decelerator. Further, several runs were made to simulate different door velocity profiles from different vehicles to verify the tunability of the test methodology. A new door assembly (with door trim and door components intact) was used for each test. Pre- and post- calibration tests were performed on the dummy after each test to ensure health of the transducers and overall data collection system. The SID-IIs dummy responses across all the body regions (Neck, Thorax, Abdomen, Pelvis and Upper Leg) from the sled tests were compared and validated to full-vehicle tests. It is worthwhile to mention that it was not the intent of this methodology to correlate the head kinematics as the effort was focused on thorax, pelvis and upper leg due to implications for design and performance of door trim/armrest, pelvis foam, seat and SAB. Films were analyzed to compare the dummy and structural kinematics between the sled and full-vehicle tests to ensure good validation. To validate the structural responses, accelerometers were mounted on door inner sheet metal at the beltline (front, mid and rear), vicinity of H-point, rigidized B-pillar, door sled and seat sled – to monitor and compare velocities and displacements. The bullet sled was instrumented with accelerometers to monitor the velocity and displacement. Contact switches were used to monitor the door-to-dummy contact.

The t-zero for SAB firing time was based on the contact of the bullet sled honeycomb with the door sled, and not based on the barrier/bumper contact with the door outer sheet metal as in full-vehicle test. In order to maintain the structural integrity of the test set-up on the sled, the rigid barrier does not contact any of the side structure (rigidized A and B-pillar), except for the door outer. As the rigid barrier intrudes into the door, the door sled does not pick up any momentum until the bullet sled honeycomb contacts the door sled. This was overcome by shifting the t-zero of the event from door outer sheet metal to honeycomb contact (between bullet and door sleds). The initial position of the SID-IIs dummy was maintained the same as in full-vehicle tests including the SAB firing time (from t-zero).

The comparison of the SID-IIs Thorax responses (sled tests indicated in blue and red and full-vehicle test in green) is shown in Figures 14 and 15, which show good correlation in both peak magnitudes and time history. Figure 16 show the comparison of the pelvic loads and acceleration responses. The deviation (from full-vehicle test) in the pelvic responses may be due to the variation in the position of the rigid barrier with respect to the door compared to the full-vehicle test. A sensitivity analysis was not conducted to elucidate this further. The door inner velocities on the sled compare well with full-vehicle tests as shown in Figure 17.

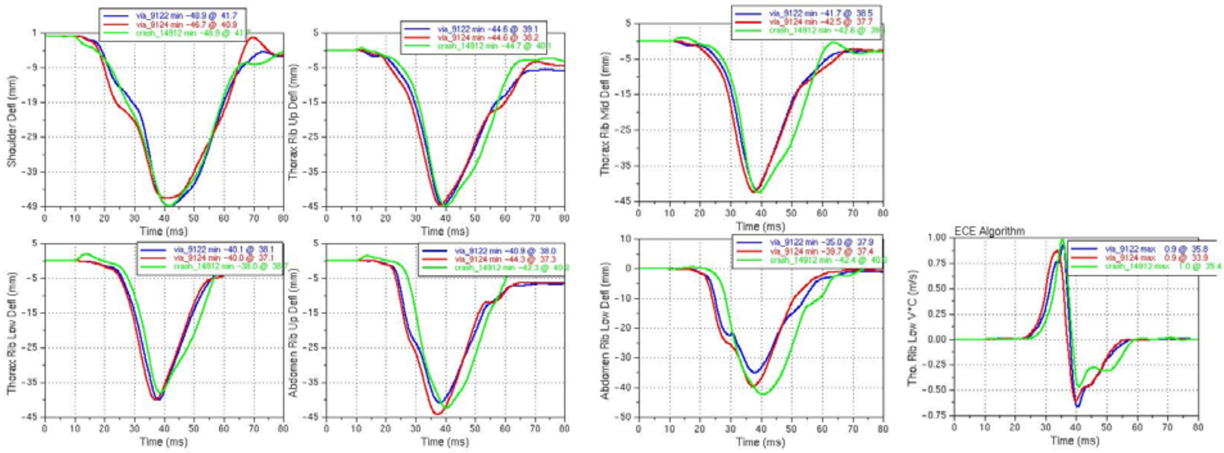


Figure 14: Comparison of SID-IIs Thorax responses

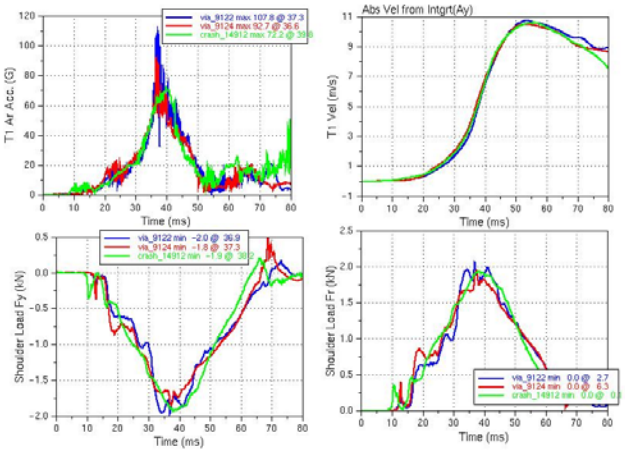


Figure 15: Comparison of SID-IIs Shoulder and T1 responses

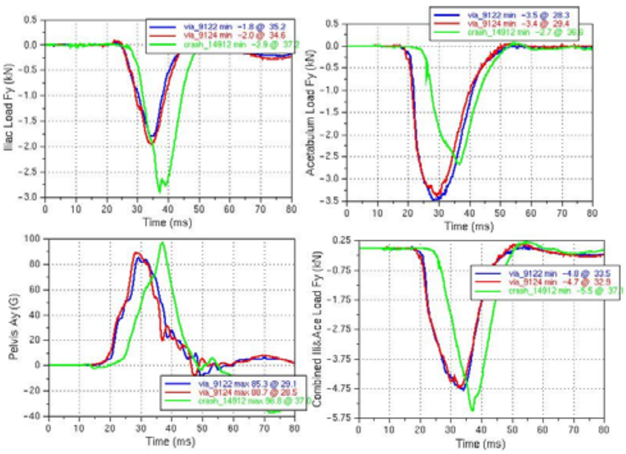


Figure 16: Comparison of Pelvis responses

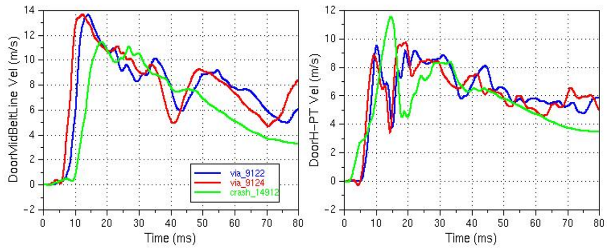


Figure 17: Comparison of door velocity responses

## 3.2 Sub-system Test Methodology for Simulation of FMVSS 214 Oblique Pole Test Modes

The validation of this test methodology was conducted in two phases – 5th percentile dummy SID-IIs (D) and 50th percentile dummy (ES-2re), both without side airbag. Initial runs were made to debug the test set-up and tune the VIA decelerator. Further, several runs were made to simulate door/B-pillar velocity profiles to verify the repeatability, reproducibility, and integrity of the test fixture. A new door assembly (with door trim and door components intact) and seat was used for each test. Pre- and post- calibration checks were performed on the dummy after each test to ensure validity of the transducers and overall data collection system. The dummy data was collected at 12.5 KHz and was filtered per SAE J211 specifications.

In the development and validation of this oblique pole sled test methodology, primary effort was focused on the dummy's thorax, abdomen and pelvis regions due to its implications for design and evaluation of door trim/armrest geometry and stiffness, pelvis EA foam, seat and different SABs including head-thorax combo, pelvis-thorax combo, and thorax only. Hence, the SID-IIs and ES-2re dummy responses across the thorax, abdomen and pelvis body regions from the sled tests were compared and validated to full-vehicle tests. Analysis of high speed films was conducted to compare the dummy and structural kinematics between the sled and full-vehicle tests to ensure good validation. To validate the structural responses, accelerometers were mounted on the rigidized B-pillar and door sled – to monitor accelerations for analyses and comparisons of velocities and displacements. In addition, contact switches were used to monitor the door trim-to-dummy contact during the crash event.

### 3.2.1 VALIDATION WITH THE SID-IIs DUMMY

In the first phase of the validation, the structural integrity of the test set-up was closely monitored for excessive deformation, to ensure repeatability and reproducibility. As noted earlier, seat was placed full-forward on seat track at mid-height (for power seat) and the B-pillar was constrained for the 5th percentile dummy. In order to ensure validity of this test methodology in capturing the overall momentum exchanges that occur between dummy and door, additional injury criteria such as shoulder, thorax and abdomen rib deflections, upper spine (T1) and pelvis responses are compared, though, resultant lower spine acceleration (T12) and combined pelvic load are the only regulatory criteria besides HIC(36) for the SID-IIs dummy in this test mode. The multiple responses for the VIA sled are repeat tests to quantify the test-to-test variability.

Figure 18 compares the responses of lower spine (T12) accelerations (Ay and resultant), lateral velocity, and displacement, which show good correlation to full-vehicle test. The T12 responses are primarily affected by the loading to the abdomen ribs and pelvis (manifested as load transfer through lumbar shear). This is also evident from comparison of abdomen rib deflections and pelvic responses which match very well to full-vehicle tests. The comparison of pelvic loads is shown in Figure 19, showing good agreement with those of the full-vehicle test. Finally, the comparison of thorax and abdomen rib deflections is shown in Figure 20, indicating that the sled test responses match well with the full-vehicle, except for the lower thorax rib deflection. It is worth mentioning that the door trim used in the sled tests was missing a decorative wooden appliqué in the thorax region, and upon close inspection, may have led to a reduction in lower thorax rib deflection.

The comparison of dummy responses between the sled and full-vehicle tests seems to indicate that the overall momentum exchanges that occur between the different body regions of the dummy and door seem to have been captured in this test methodology. This is also evident from the comparisons of lateral accelerations and velocities of lower spine (T12) and pelvis, which match well with the full-vehicle test, thus indicating correct overall gross motion kinematics and proper momentum transfer to the dummy.

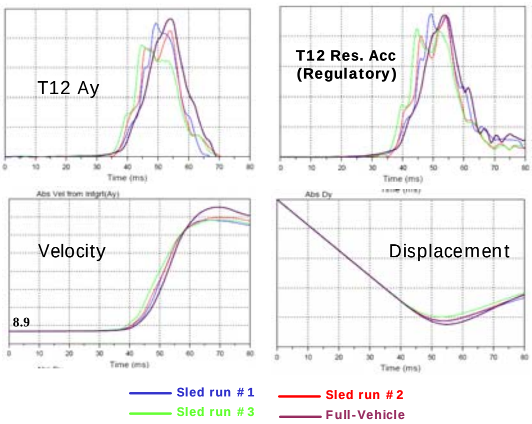


Figure 18: Comparison of SID-IIs T12 responses

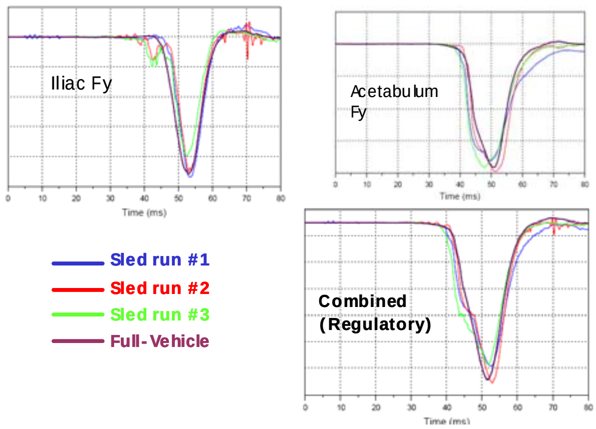


Figure 19: Comparison of SID-IIs Pelvic loads

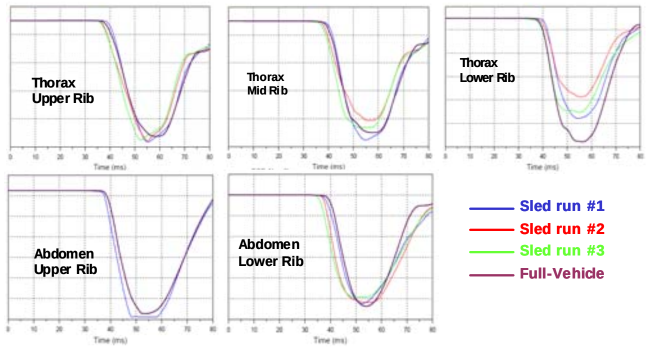


Figure 20: Comparison of SID-IIs rib deflections

### 3.2.2 VALIDATION WITH THE ES-2re DUMMY

As noted earlier, the seat was placed at the mid seat track and the full-down position for all the tests with the ES-2re dummy. In addition to the regulatory criteria (rib deflections, total abdomen load and pubic symphysis load), lower spine (T12) and pelvis responses were compared to full-vehicle test, thus ensuring the validity of the test methodology and capturing the overall momentum transfer to different body regions of the dummy. Figure 21 shows the comparison of rib deflections of the ES-2re dummy, which match fairly well with the full-vehicle test, except for the mid rib deflection. The mid rib deflection is under predicted in the sled test, and as discussed earlier with SID-IIs validation, maybe due to the absence of a decorative wooden appliqué (aligned with mid rib) on the door trims used in the sled tests. The comparison of total abdomen loads is shown in Figure 22, which indicates reasonable correlation to the full-vehicle test, though the sled tests seem to lack the steep unloading seen in the full-vehicle test. Again, this may be due to variation in deformation and kinematics of the armrest between the sled and full-vehicle tests, though the total abdomen load is similar. Figure 23 compares the pubic symphysis forces and pelvic responses (acceleration, velocity and displacement), showing good correlation with the full-vehicle test. The lower spine (T12) responses compared in Figure 24 indicate good match to the full-vehicle test.

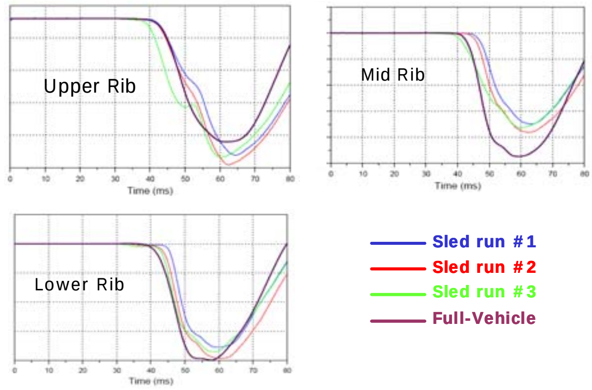


Figure 21: Comparison of ES-2re rib deflections

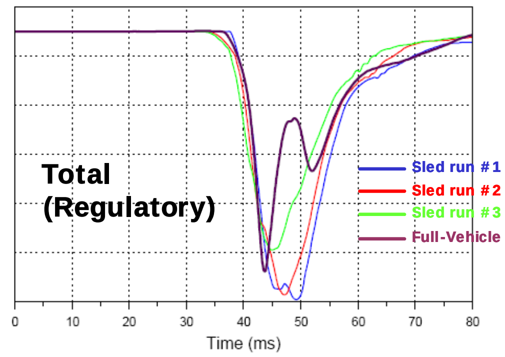


Figure 22: Comparison of ES-2re total abdomen loads

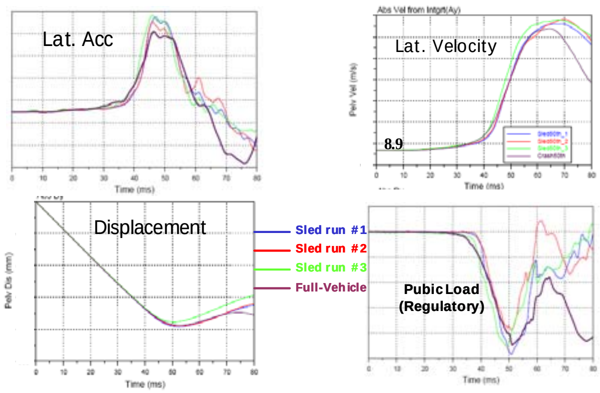


Figure 23: Comparison of ES-2re pelvis and pubic symphysis forces

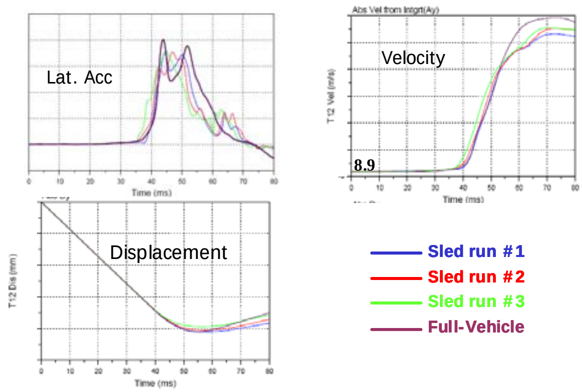


Figure 24: Comparison of ES-2re T12 responses

## 4 Conclusions

A new side impact sled-to-sled test methodology has been developed using a combination of three sleds (Bullet, Door and Seat sleds) and VIA decelerator system to simulate an entire door velocity profile from start of crash event until the end. The methodology was validated in IIHS test mode by comparison to a full-vehicle test. Based on the results of the sled tests, the methodology is capable of simulating 'gap closure' as evident from the comparison of door velocities. Based on the correlation of the SID-IIs dummy responses, this test methodology reproduces the key events taking place in a full vehicle side impact test. All the key variables including the tunable parameters of the test methodology were presented and discussed.

A new door sub-system sled test methodology has been developed to simulate occupant responses in FMVSS 214 oblique pole tests with both 5th percentile SID-IIs and 50th percentile ES-2re dummies. The novel fixture design used in this test methodology accounts for all the key factors affecting occupant responses in this test mode namely, door-to-dummy gap closure velocity, shape of intruding door, dynamic pole intrusion, and door/b-pillar compliance. The effect of vehicle's lateral stiffness during pole engagement was simulated, by decelerating the door sled along non-impact side velocity of the vehicle and ensuring the pole did not engage the rigidized door frame during the whole event. The methodology has been validated to full-vehicle tests with both 5th percentile and 50th percentile dummies. Based on the correlation of the SID-IIs and ES-2re dummy responses, this test methodology has demonstrated capabilities in simulating the key momentum exchanges that occur during a full vehicle oblique pole test. This is evident from good correlations when lower spine (T12) and pelvis accelerations and velocities are compared, indicating that the momentum exchanges between door and different body regions of the dummy are captured. Therefore, both the test methodologies can be used for the development of door trim geometry and stiffness, pelvis/thorax EA foams, and seat mounted side airbags because of its unique capability to simulate the door-to-dummy gap closure velocity and kinematics.

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