2003-01-0159

Vehicle Acceleration and Compartment intrusion for Far-Sided Occupants v. Near-Sided Occupants in Frontal Offset Collisions

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ABSTRACT

Vehicle acceleration and compartment intrusion play major roles in occupant injury causation, in frontal offset collisions. The knowledge of injury causation may enable the injury risk to be directly assessed from accident conditions, once a relationship between accident conditions and vehicle response is known.

To establish such a relationship, a simulation study was carried out, in which vehicle acceleration and local compartment intrusion were calculated for various crash speeds and overlap configurations. The simulation model was validated against crash-tests in terms of the local vehicle deformation, acceleration and local dash and toepan intrusion.

It was found that average acceleration generally decreased with reduced overlap, while intrusion increased for narrower overlap and impact locations more closely to the dash and/or toepan. This general trend indicates the relatively high injury risk for near-side occupants and a low risk for far-side occupants. Far-side, low-overlap (<50%) offset collisions at 45 or even 50 mph resulted in similar average acceleration and local intrusion levels as those seen in full overlap at 35 mph.

However, crush reaching into the stiff firewall may cause vehicle peak accelerations to rise above expected levels in low overlap and high speed, especially in case the engine enhances firewall deformation. Furthermore, far-side intrusions may reach similar levels as near-side intrusions in offset collisions (>33% overlap), due to induced damage and the load distributing effect of the engine.

Vehicle average acceleration and local intrusion levels may reach injurious levels for the far-side occupant in offset collisions. Vehicle crashworthiness improvements with a sole focus on near-side occupants may result in reduced protection of the far-side occupant.

INTRODUCTION

Frontal collisions comprise the majority of passenger car accidents, severe casualties and fatalities. Of these, approximately half are of a distributed nature, and half of an offset nature.

Vehicle acceleration and compartment intrusion are major injury mechanisms in offset frontal collisions. Acceleration may cause restraint related injuries or, when excessive, may cause the ride-down space to be insufficient to prevent impact between occupant body and vehicle interior. Intrusion causes a reduction of ride-down space and may further increase the impact speed between occupant body-parts and vehicle interior.

In offset collisions, the lower direct contact area causes lower deformation resistance, such that in collisions of equal severity (delta-V), the vehicle's acceleration decreases and compartment intrusion increases with lower overlap. In a 'near-side' offset (impact location on the occupant side), intrusion may be the dominant injury mechanism, while acceleration may be a more likely cause of injury, in far-side offset (impact location away from the occupant).

The knowledge of the acceleration and intrusion role in injury causation in frontal collisions is essential to perform biomechanical evaluations of real world accidents and for crash safety research. It enables biomechanical experts to assess occupant injuries based on the vehicle behavior in the real world accident. Accident reconstruction may be used to determine the vehicle acceleration and intrusion behavior based on the conditions of the accident.

Furthermore, the understanding of the two injury mechanisms allows crash safety research to further optimize vehicle dynamics in various crash conditions.

The determination and optimization of vehicle response require the establishment of a relationship between the accident conditions and the consequent vehicle behavior. Widely published crash tests have been used to identify this relationship in certain accident conditions.

Since the 1970s, frontal crash tests have been performed and regulated by the government (FMVSS 208 and NCAP) to improve the crashworthiness of vehicles and to reduce injury risk and severity in full frontal collisions. The regulated tests primarily focus on the acceleration induced injuries sustained in full frontal accidents, and consequently belt and airbag performance have greatly improved and resulted in significantly reduced injury risks. The test information includes accident conditions, vehicle acceleration traces, occasionally compartment intrusion measurements and occupant (dummy) injury risk levels. Accident reconstruction and biomechanical evaluations of broad frontal collisions may be based on comparisons of the real world accident conditions with the published test results.

Mercedez was one of the first car manufacturers to conduct offset crashtests (Baumann et al. 1990). Currently, most manufacturers, the Insurance Institute of Highway Safety (IIHS) and European, Canadian and Japanese governments conduct frontal offset crash-tests with 40% overlap against a deformable barrier to better conform to real world accident circumstances (Hobbs and Williams, 1994) and to address the more demanding conditions on the vehicle's structural integrity and compartment intrusion risk. The test data comprises of vehicle acceleration and intrusion data on the impact side (often driver side) and the injury measures of the occupant seated nearest the impact side (near-side occupant). The test data provides a basis to assess the accident's crash and injury severity. The tests show particular interest in near-seated occupants, i.e. the driver in a left-side offset or a right front passenger in a right-side offset. EuroNCAP also measures and provides ratings for the far-side occupant, although detailed vehicle and dummy response data are not readily available. Information on far-side vehicle and occupant conditions is important, especially for right-side offset collisions where the driver's injuries need to be assessed.

The full and offset frontal crash tests provide an initial relationship between accident conditions and vehicle behavior with consequent occupant injury risk.

The offset deformable barrier tests have encouraged manufacturers to increase the vehicle front stiffness to better perform in offset collisions and to reduce near-seated occupant risk. However, the stiffer front may lead to higher injury risk for the far-seated occupant.

Furthermore, it is currently unknown how vehicle speed and impact-overlap interact in the causation of local injurious vehicle accelerations and/or intrusions.

A relationship needs to be established between frontal accident conditions and the two injury mechanisms, vehicle acceleration and compartment intrusion. This knowledge could consequently be applied to perform biomechanical evaluations of the occupant and to optimize vehicle crash performance in offset crash tests for both occupants.

OBJECTIVE

The objective of this paper was to present local vehicle behavior at the near and far-side location in frontal offset collisions for various impact speeds.

METHOD

A computer simulation model of the 1994 SAAB 900 was previously developed using the computer software MADYMO (5.3, TNO 1997), and validated at the Chalmers University of Technology in Sweden (Buzeman-Jewkes et al. 1999). A multi-body approach was used for the model to allow flexibility, reduced calculation time and low expense. The model was designed and validated to predict vehicle acceleration and local compartment intrusions in frontal offset collisions of various overlap and speed configurations.

MODEL DESCRIPTION

The SAAB model consists of one body representing the vehicle compartment, in which the interior geometry of the SAAB 900 was modeled by a combination of planes and ellipsoids to enable contacts with the occupants. Four bodies were connected to the compartment with translational-revolute joints, which modeled the instrument panels and toepans on the driver and passenger side, respectively. Planes reflective of the SAAB dash and foot area were attached to the corresponding bodies for contact interactions. The joints allow local compartment intrusion at upper dash (instrument panel) and lower dash (toepan) level independently, for driver and passenger side. The stiffness of the intrusion joints were acquired from the previously mentioned crashtests by Buzeman-Jewkes (1998). The longitudinal local intrusions of driver-side dash and toepan were measured and plotted against the measured load-cell forces of those loadcells which location corresponded with the dash or toepan location. The local intrusion versus corresponding force measurements are presented in Buzeman-Jewkes (1998). A schematic drawing of the model is shown in Figure 1.

The front crush zone of the SAAB was built of two rows of six bodies. Three neighboring bodies of the top row were attached to each of the driver or passenger dash body (whichever was closest) by translational-revolute joints. Similarly, the three left bodies on the bottom row were attached to the driver toepan (also by translational-revolute joints), and the right three bodies to the passenger toepan. The twelve bodies could move independently through the joints, and allowed the crush zone of the vehicle model to deform locally, using the local force-deflection characteristics of the SAAB 900's crush zone. The vehicle's local stiffness was attained from a series of previously conducted crash-tests of a SAAB 900 against a barrier with 36 load-cells (Buzeman-Jewkes

1998, Buzeman-Jewkes et al. 1999a). The location of the 12 crush-zone bodies corresponded with the location of three load-cells on the barrier (Figure 2), while the cells that are not covered by the model's crush zone bodies did not show any contact force in the crash. Bodies 9 and 10 represent the same 3 loadcells due to the asymmetric loadcell configuration. Half the measured stiffness was applied for these two bodies. Actual force-deflection characteristics used for the model were published previously (Buzeman-Jewkes 1998).

Induced vehicle deformation or 'shear' deformation as observed in offset crashes, was enabled by introducing spring-damper elements (Kelvin-elements) between each neighboring set of the 12 bodies. The Kelvin elements' stiffness was previously deducted from a comparison of the total barrier force measured in a 50% offset test with the force of the corresponding barrier half measured in a full frontal test for equal vehicle deflections (Buzeman-Jewkes et al. 1999a).

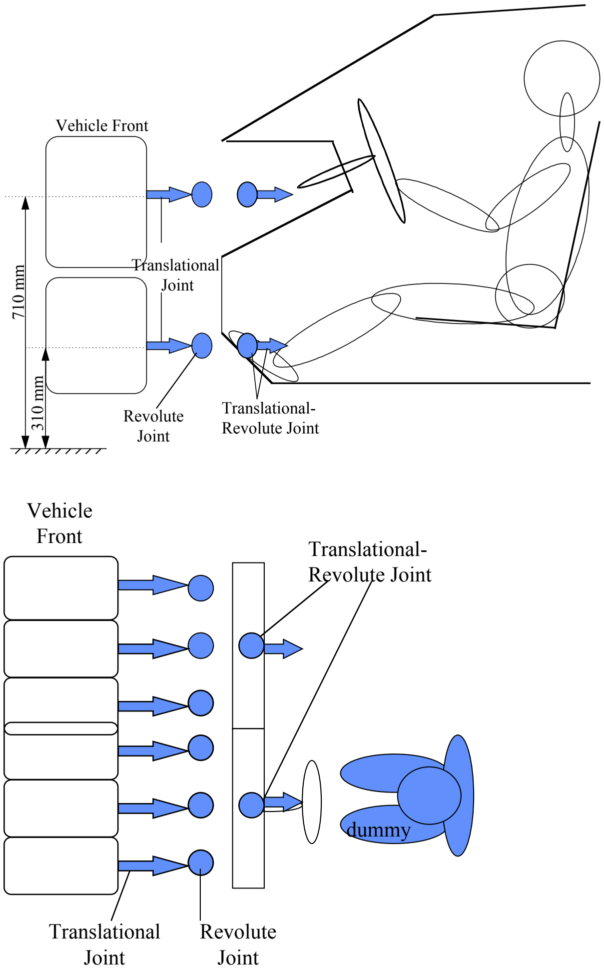

Figure 1. Side and top-view of the integrated vehicle-occupant model

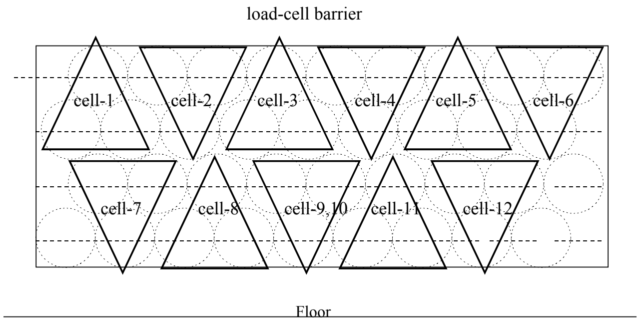

Figure 2. Location of crush-zone bodies in relation to the load-cells of the validation test.

One ellipsoid was attached to each crush zone body for initial contact with the collision partner. These ellipsoids were given a very high stiffness, such that the actual local vehicle deformation was accounted for by the joints.

Finally, an engine was created using an additional body with a contact ellipsoid in the approximate location of the actual engine. The rigid engine was connected to the vehicle compartment body by a translational joint of which the stiffness reflected the compression resistance of the various components located between the engine and the firewall. The stiffness was chosen to equal 1.0 kN/m

Body inertia were estimated in accordance with the total vehicle mass and approximate mass distribution of the validation-test vehicle (as estimated from the center of gravity). Finite element models of driver and passenger airbags and belts were added to the model. The interior geometry, belt-anchor and airbag locations were courteously provided by SAAB. General airbag deployment and belt deformation characteristics were applied. The integrated vehicle-occupant model is shown in Figure 3.

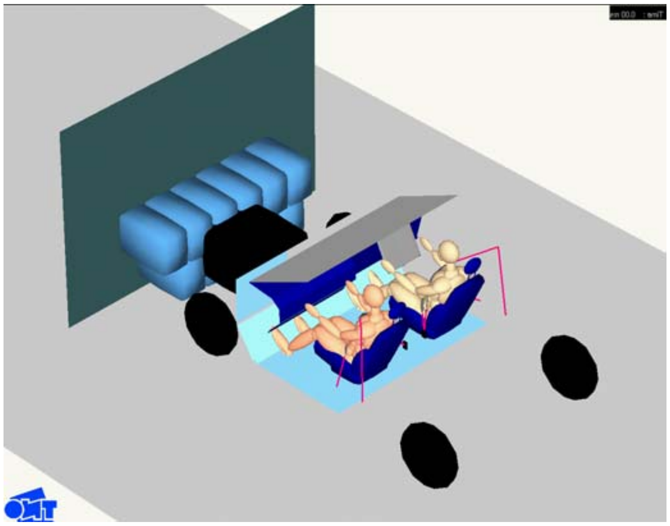

Figure 3: The integrated vehicle-occupant model of the SAAB 900

OCCUPANT MODELS

Hybrid III 50th percentile dummy models were positioned electronically in the driver and right front passenger seating positions of the car-model. A simulation was performed to position FEM seat belts correctly on the torso and abdomen/hip area of the dummies.

PARAMETER VARIATION

The vehicle model was subjected to frontal fixed, rigid barrier collisions at varying speeds and overlaps. The conditions covered a speed range of 30 to 50 mph with increments of 5 mph, each with overlaps of 33%, 50%, 67% (of the vehicle width) on both driver and passenger side, and full overlap. A total of 35 simulations was conducted. Driver and passenger seat acceleration, as well as intrusion time-histories for driver and passenger dash and toepan were calculated for each simulation. Only the longitudinal component of the dash and toepan intrusion was calculated, in accordance with the corresponding measurement in validation tests. Finally, average vehicle accelerations were calculated for each simulation, using the pulse duration from start of impact to the first (consistent) crossing of the zero-acceleration axis. Table 1 shows the simulation matrix.

Table 1. Parameter Variation Matrix of the SAAB Simulations.

Overlap/Impact Speed	30 mph	35 mph	40 mph	45 mph	50 mph
33% driver side	X	X	X	X	X
50% driver side	X	X	X	X	X
67% driver side	X	X	X	X	X
100% overlap	X	X	X	X	X
67% passenger side	X	X	X	X	X
50% passenger side	X	X	X	X	X
33% passenger side	X	X	X	X	X

SAAB VALIDATION

The SAAB model was previously validated (Buzeman-Jewkes et al. 1999b) against a 67 km/h full frontal rigid barrier test and a 58 km/h 50% offset rigid barrier test (Buzeman-Jewkes 1998) in terms of force-deflection, acceleration, vehicle dynamic crush and driver toepan and dash intrusion. Only the vehicle acceleration and intrusion comparisons are presented and discussed in this paper.

Acceleration time-histories of the vehicle's center of gravity are plotted in Figures 4a and 4b. The simulation and test results agree well, although the calculated acceleration was somewhat lower as the crash proceeded. Figure 5a and 5b compare the intrusion time-histories of toepan and instrument-panel for test and simulation in the full frontal configuration. Simulated intrusions were similar to the corresponding crash test measurements.

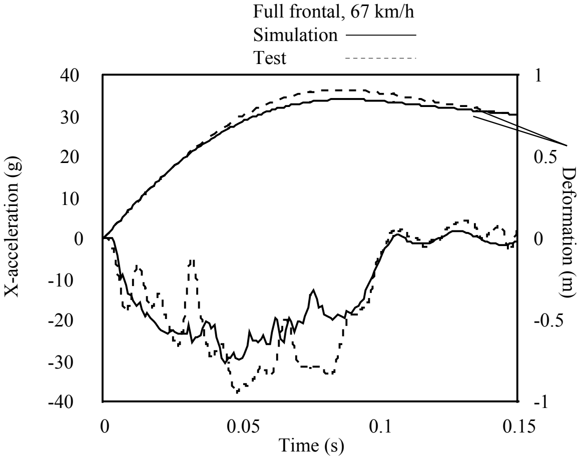

Figure 4a. Longitudinal acceleration and deformation time-history of the full frontal crash at 67 km/h.

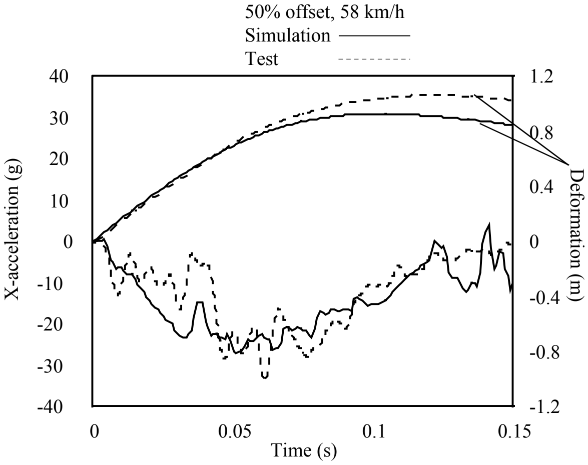

Figure 4b. Longitudinal acceleration and deformation time-history of the 50% offset crash at 58 km/h.

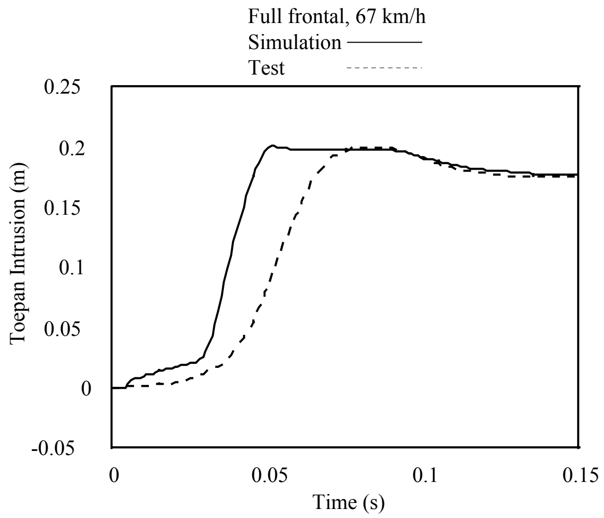

Figure 5a. Near-side toepan intrusion time-history in full frontal crash at 67 km/h, simulation and test.

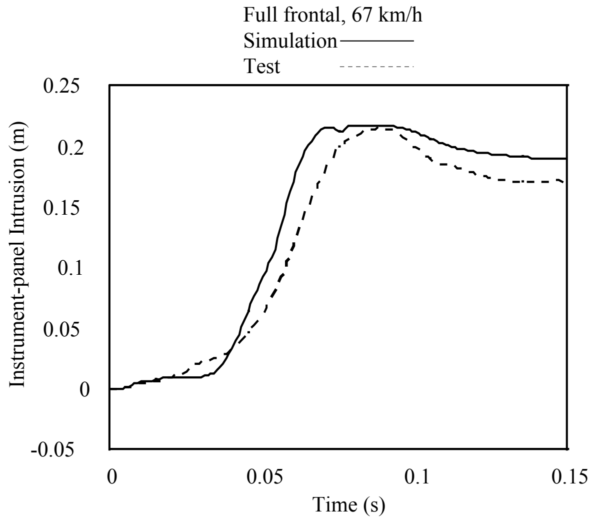

Figure 5b. Near-side instrument-panel intrusion time-history in full frontal crash at 67 km/h, simulation and test.

The model was also applied in a simulation of an NCAP test, and the vehicle acceleration and dummy head, chest and pelvis accelerations were compared to those measured in the corresponding tests. As shown in Buzeman-Jewkes et al. (1999a), the model predicted both vehicle and dummy behavior well for this simulation set-up.

The integrated vehicle-dummy multi-body model allows a great level of flexibility and simplicity in making changes from one car model to another.

PARAMETER STUDY RESULTS

Local vehicle acceleration and local compartment intrusions were compared for the various impact speeds in each overlap condition. Furthermore, a local vehicle behavior comparison was made between passenger and driver seat locations in both near-side and far-side crash conditions.

AVERAGE VEHICLE ACCELERATIONS

The average vehicle accelerations of driver and passenger seats are presented for all simulation configurations in Figures 6 and 7, respectively. A reduction in overlap amount entailed a general pattern of decreased average accelerations. The effect of the overlap amount on the average acceleration was drastic: 45 and even a few 50 mph collisions at 50% and 33% caused similar average accelerations as observed in the NCAP configuration (100% overlap at 35 mph).

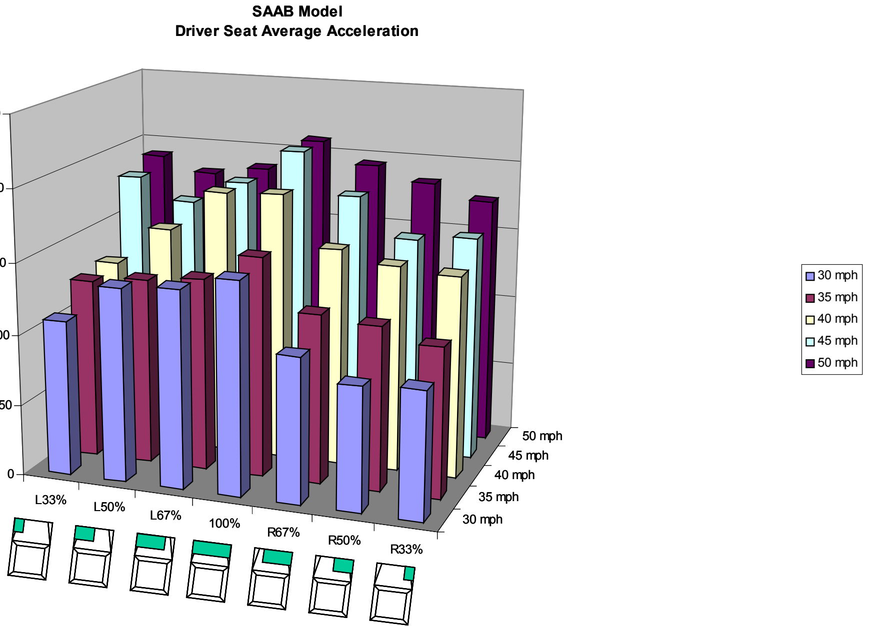

Figure 6. Average driver seat acceleration (in m/s^2) for all configurations.

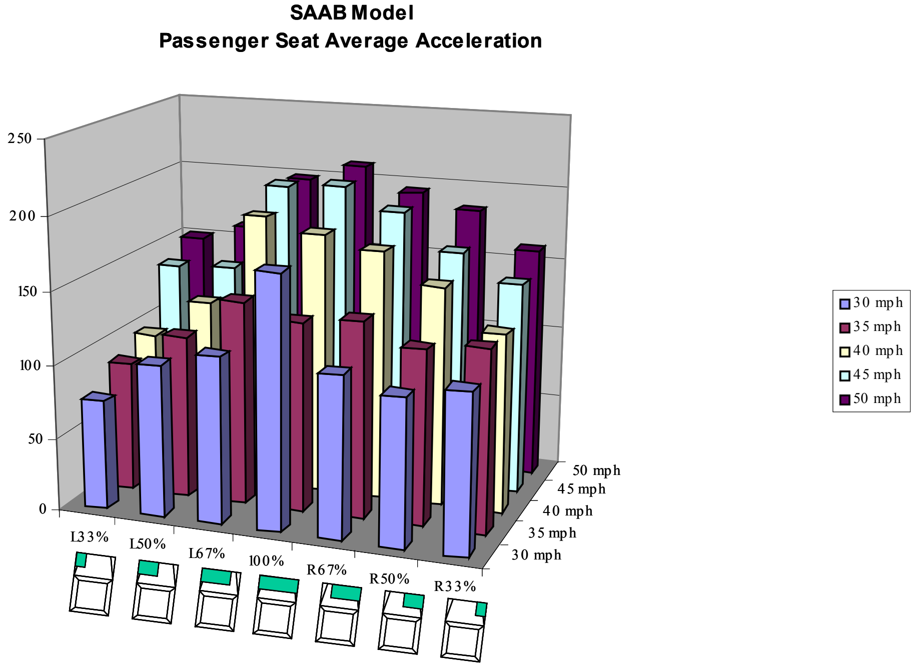

Figure 7. Average passenger seat acceleration (in m/s^2) for all configurations.

SAAB LOCAL INTRUSIONS

The dash and toepan intrusion time-histories showed monotone increases up to maximum dynamic intrusion, followed by a small decrease to residual intrusion due to rebound of the material deformations. The maximum dynamic intrusion was therefore considered a good representative of the overall intrusion behavior to make a comparison between the various crash conditions.

Driver Dash- Dynamic peak intrusions of the driver side dash are compared in Figure 8 for various speed and overlap conditions.

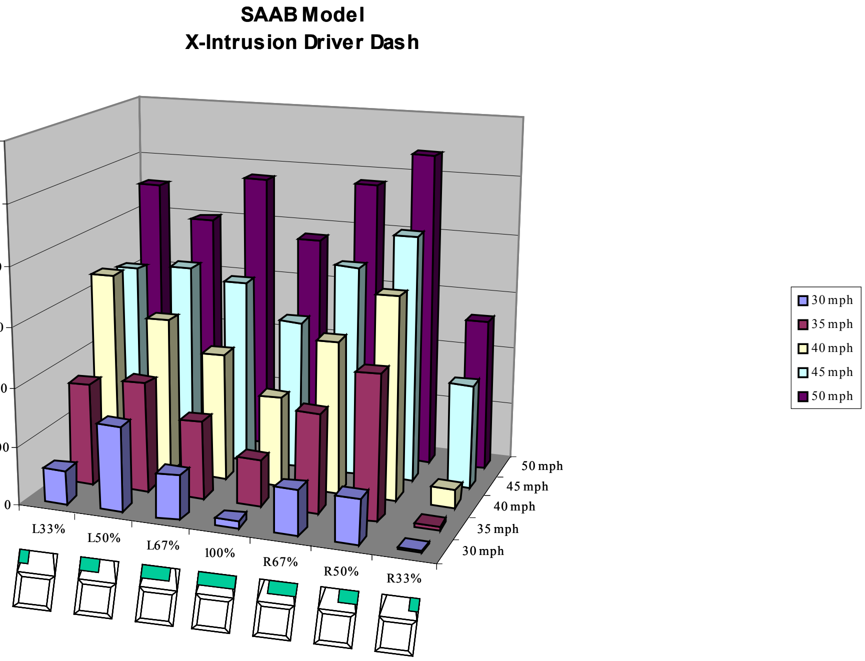
SAAB Model
X-Intrusion Driver Dash

Figure 8. Driver dash intrusion in mm at 30 to 50 mph impact speed and at various overlap configurations.

The driver dash intrusion generally decreased with wider overlap in near side offsets, then increased again as far side offsets occurred at smaller overlap (down to 50% overlap). The 33% far-side offset produced the lowest dash intrusions. Furthermore, the driver dash intruded more in passenger side offset than in driver side offset of corresponding overlaps of 50% and 67%.

The overlap influence was as significant as the speed effect for 30 to 40 mph and overlaps of 50 to 100%, such that the dash intrusion in 50% overlap would occur at a 5 mph higher impact speed in 67% overlap and at 10 mph higher speed in full overlap. The opposite speed and overlap interaction was observed from full to far-side 67% and from 2/3 to ½ far-side overlap. Here is a sub-subsection (third level heading). It uses the Body paragraph style and is identified with a header beginning the paragraph as shown here.

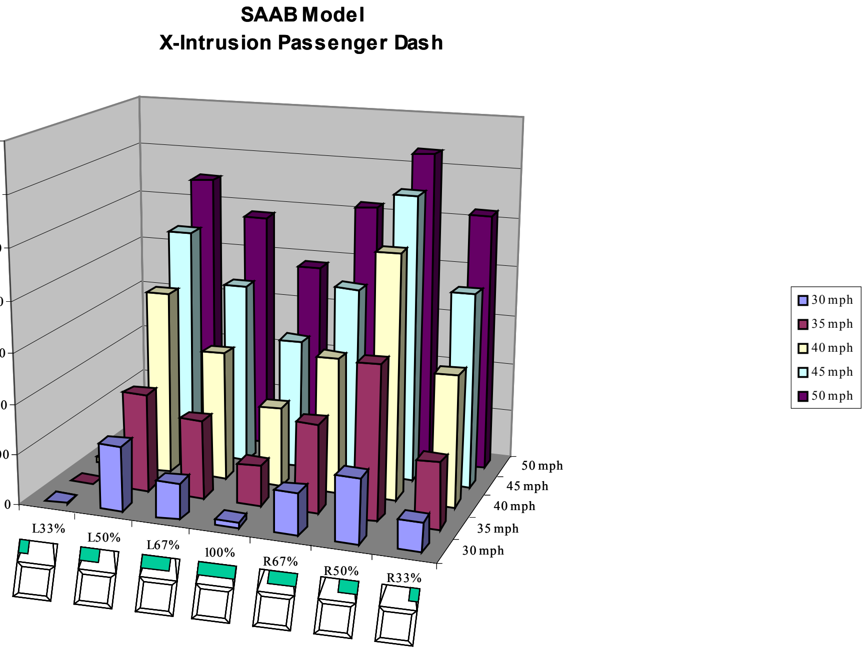
SAAB Model
X-Intrusion Passenger Dash

Figure 9. Passenger dash intrusion in mm at 30 to 50 mph impact speed and at various overlap configurations.

Passenger Dash- The passenger dash demonstrated a general trend similar to that observed for the driver dash (Figure 9). The dash intruded more in both near and far side offsets as the overlap amount reduced from 100% to 50%, with the near-side intrusions being slightly larger. Dash intrusion in near side 1/3 overlap was relatively low, while intrusion in 1/3 far side overlap was virtually zero.

The overlap influence was as or more significant than the speed effect for the passenger dash intrusion. Similar intrusions were observed for 5 to 10 mph lower impact speeds when comparing 50% versus 67% near side overlap and 67% versus 100% overlap crashes. Furthermore, virtually no intrusion occurred in the far-side 33% overlap configuration.

Near-Side versus Far-Side Dash Intrusion- Far-side dash intrusion did not exhibit a significantly different pattern for driver and passenger dash, and neither did near-side dash intrusion. However, the passenger dash showed greater intrusion levels in most configurations.

Driver and Passenger Toepan Intrusion- Figures 10 and 11 compare the dynamic maximum intrusion of the driver and passenger toepan, respectively, for various speed and overlap conditions.

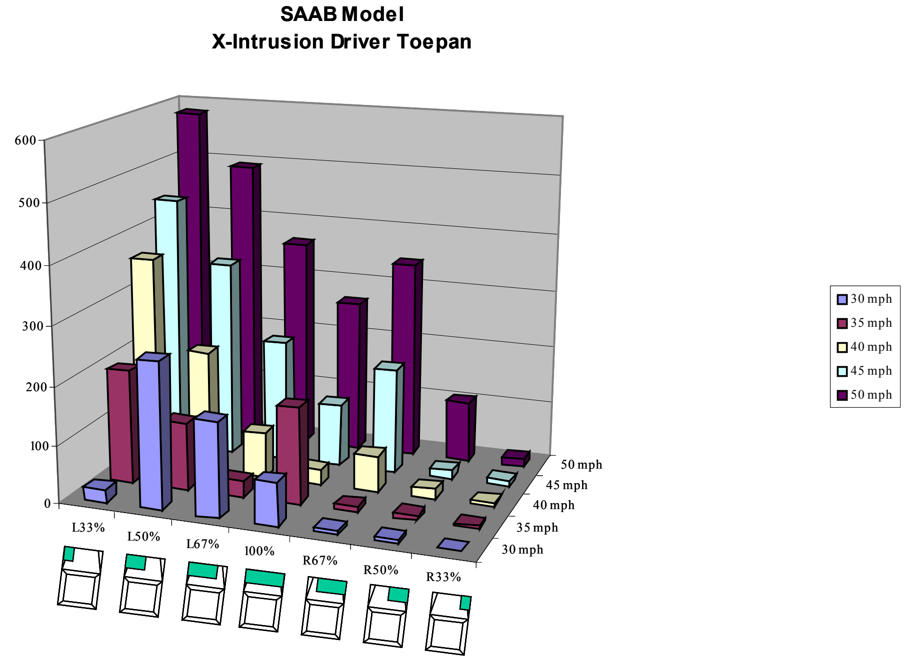

Figure 10. Driver toepan intrusion in mm at 30 to 50 mph impact speed and at various overlap configurations.

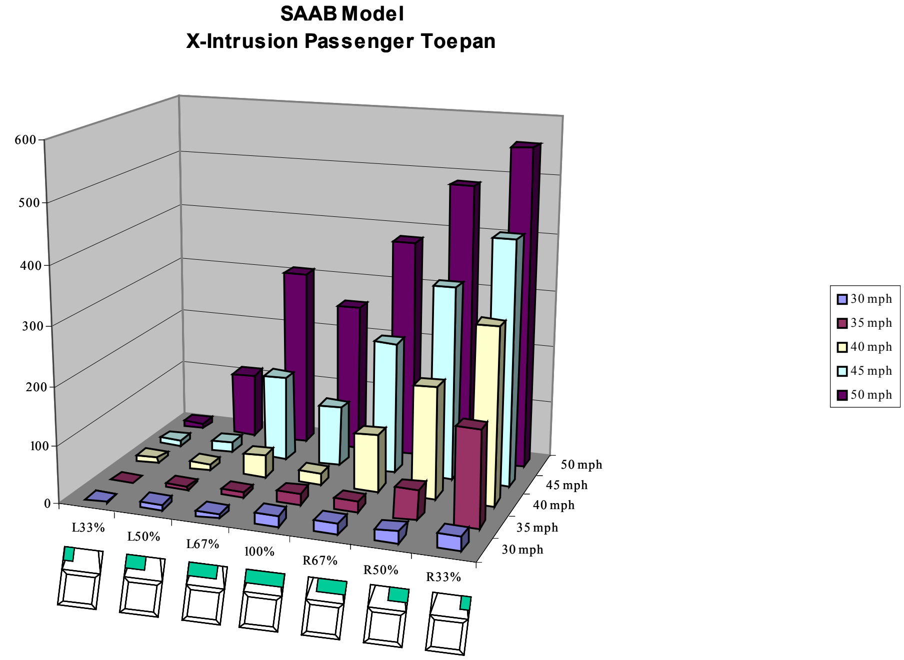

Figure 11. Passenger toepan intrusion in mm at 30 to 50 mph impact speed and at various overlap configurations.

Driver and passenger toepan intrusions were of the same magnitude for corresponding crash conditions. Toepan intrusion demonstrated its dependence on vehicle speed and impact location clearly. The toepan intruded more as speed increased and as the center of impact more closely approached the toepan location. The significant effect of the overlap amount was reflected by the fact that similar intrusions were observed on the diagonals representing a one increment speed increase with a simultaneous near-side overlap increase of one increment (from 1/3 to ½ or from ½ to 2/3). For example, the toepan intruded as far in 33% near-side overlap at 35 mph as in 50% near side overlap at 40 mph.

However, some distinctions can be made for the toepan intrusion pattern. Driver toepan intrusion at 30 mph was higher than at 35 and 40 mph in near-side ½ and 2/3 offset and in full overlap impacts. The driver toepan also intruded further at 35 mph than at 40 and 45 mph in 100% overlap configuration. Finally, both toepans experienced relatively high intrusions at 2/3 far side overlap for speeds above 35 mph.

It should be noted that only the 33% far-side offset configuration showed both lower vehicle acceleration and lower compartment intrusions in comparison to the NCAP conditions.

DISCUSSION

VALIDATION RESULTS

The acceleration and local intrusions were predicted well with this relatively simple simulation model. The model is of great use in accident reconstructions of frontal offset collisions and in crash safety research, as it can be used to establish relationships between accident conditions and vehicle response, while the vehicle response is a predictor of occupant injury risk. The model allows quick and easy adjustments to different car models, by changing the vehicle inertial properties, local force-deflection curves for the vehicle crush zone, and by changing interior (and exterior) geometry. The model requires force-deflection data of each of the load-cells in a load-cell barrier test.

OVERLAP AND SPEED EFFECTS

Average Acceleration- It was expected that vehicle acceleration would increase with vehicle speed and to decrease with lower overlap amounts.

The average acceleration of driver and passenger seat demonstrated the expected pattern. The effect of one increment overlap reduction was of the same magnitude as a 10 mph impact speed decrease.

Acceleration Pulses- Acceleration pulses are shown in Appendix A. They also showed a general trend in accordance with the expectations. The vehicle acceleration increased with speed until a plateau of approximately 300 to 350 m/s2 was reached. This plateau like behavior has previously been described by Campbell (1974) and by Wood et al. (1993), and has been modeled in accident reconstruction with the force saturation model (Strother et al. 1986) and the power-law model, Woolley (2001).

However, at higher speeds, low overlaps exhibited high acceleration peaks in the later stage of the collision. The increased acceleration peak at lower overlap may be a result of excessive crush into the firewall. The firewall and compartment are often stiffer than the actual vehicle front's crush zone (Wood et al. 1993), as they form the protective cage for the occupants.

The relatively high peak accelerations for low overlaps was more pronounced in passenger side overlaps. In the SAAB the transverse engine is positioned towards the passenger side of the vehicle front structure. The presence of the engine reduces the available crumple zone of the vehicle front locally, such that the firewall and compartment are more often involved in the vehicle deformation. The effect of the engine location on acceleration and compartment intrusion was previously addressed by Buzeman-Jewkes et al. (1999a).

Intrusions- Toepan intrusions also showed a general trend as expected: the intrusion primarily increased with speed and for offsets with low overlap and impact locations closer to the toepan. The overlap and impact location effects were as significant as the speed effect.

However, dash intrusions appeared to more depend on overlap amount, not on the impact proximity to the dash. Dash intrusion was noted to be higher in both near and far-side 67% and 50% overlap than in collisions with full distribution. Lower overlap collisions need more crush depth than full overlap crashes to absorb the same collision energy, such that the crush zone is more often insufficient and intrusion more likely to occur. In 2/3 overlap, the far-side of the vehicle still sustains direct crush, which is greater than that in full overlap, such that far-side intrusion is more likely to occur in 2/3 overlap. In 50% overlap, there is no direct deformation of the far-side crush zone. However, induced or shear crush may expand to the far-side of the crush zone, causing far-side intrusion to be greater in 50% far-side overlap than in 100% or even 67% overlap. The effect of induced deformation on far-side intrusion is even more profound when the (transverse) engine distributes the deformation over a wider area of the firewall. Buzeman-Jewkes et al. (1999a) also observed the influence of the engine location on intrusion depth.

Passenger dash intrusions were higher than those on the driver side. Again, this may be explained by the passenger side location of the SAAB engine, since the stiff engine would transfer the vehicle deformation from crush zone to firewall/compartment as soon as the crush reaches the engine.

CONSEQUENCES FOR OCCUPANT INJURY

The average vehicle acceleration may be a satisfactory predictor of occupant injury provided that the occupant does not impact the interior components. In case of occupant impact with the interior, the injury risk depends on the magnitude of the acceleration peaks. Thoracic and head injuries may be well predicted by the average acceleration. However, average acceleration may not adequately assess lower leg and pelvic injuries, as lower extremities impact the knee-bolster or instrument panel in most frontal collisions.

The results of this simulation study indicate that far-side occupants may be protected from serious head, thoracic and lower extremity injuries up to speeds of 45 mph or even 50 mph for low overlap collisions (<50%), as the average accelerations of these high speed, low overlap collisions were similar to or below those of the NCAP configuration and as dash and toepan intrusions were low. However, the far-side occupant is subjected to relatively high dash intrusions for 50% and 67% overlaps and may have similar injury risks as the near-side occupant in these configurations.

The SAAB results indicate that the far-side occupant may be subjected to higher vehicle acceleration peaks and/or dash intrusions than observed in full overlap, for impact speeds above 35 mph and at 50% or 67% overlap. It may be insufficient to focus on the near-side occupant in offset crash tests when assessing the crash worthiness and safety performance of a vehicle.

Vehicle manufacturers may be pushed toward stiffening their vehicles to pass the high demanding 40 mph, 40% overlap deformable barrier tests, which would increase the vehicle acceleration to reduce the near-side compartment intrusion. An increased stiffness may thus have adverse results for the far-side occupant injury risk, and possibly for the injury risk of the near-side occupant. These adverse effects may be particularly important in lower speed collisions, as the acceleration mechanism plays a more dominant role.

CONCLUSIONS AND RECOMMENDATIONS

- The simple multi-body model was able to predict vehicle acceleration, local compartment intrusions and dummy reponses well. The model may be a very useful tool in research of near and far-side occupant injury patterns in a wide variety of offset frontal collisions.
- The simulation model can be applied in accident reconstruction investigations, to better correlate impact speed to the vehicle local crush and predict vehicle acceleration and local compartment intrusions. The determination of vehicle response may simultaneously be combined with assessment of near and far-side occupant injury risk, as the vehicle model may include dummies in various positions of the vehicle.
- Vehicle average accelerations decreased drastically with overlap, such that similar accelerations were found for 45 mph or even 50 mph impacts with low overlap (1/3 to ½) as for the NCAP configuration.
- Acceleration peaks were highest for high speeds and at lower overlaps, and were influenced by the presence of the engine block.
- Toepan intrusion was significantly reduced as the center of the impact location moved away from the toepan location: the NCAP

set-up revealed similar intrusions as a 40 mph far-side 67% overlap configuration at 40 mph, or a far-side 50% overlap configuration at 45 mph.

- Dash intrusion was inversely related to overlap amount. Near and far-side dash intrusion were similar for 50% and 67% overlap, and a 30 mph 50% overlap or 35 mph 67% overlap collision resulted in similar dash intrusions as a 40 mph full overlap crash. Dash intrusion was low in 1/3 far side overlaps.
- Far-side occupants may have similar injury risk in low overlap frontal collisions at speeds up to 45 or even 50 mph compared to their injury risk in a NCAP set-up.
- In frontal offset collisions with higher overlap, the crush zone may not be sufficient to prevent deformation of the stiff firewall, even at 30 to 35 mph impact speeds. In these configurations, the dash intrusions and peak accelerations may pose a threat to both near and far-side occupants. This threat may be more pronounced on the side of the engine location.
- Focus on the near-side occupant injury risk in frontal offset collisions may have adverse effects on the far-side occupant risk.
- It is important to assess both near and far-side occupant injury risk in frontal offset crash-testing, and in determining strategies for vehicle crash worthiness improvements.
- It is recommended to continue the research of far-side occupant risk in frontal offset collisions for other vehicle model categories, and to study near and far-side occupant response as well. Furthermore, simulations may be used to predict suggested crashworthiness improvement (like increased front structural stiffness) effects on both near and far-side occupants.

ACKNOWLEDGEMENTS

The author would like to thank Chalmers for the permission to use the computer model for further research.

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APPENDIX A

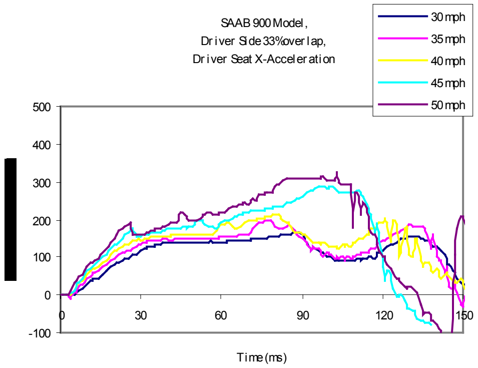
Figures A 1a-g present the time-histories of driver seat accelerations at 30 to 50 mph for each of the overlap configurations, from 33% driver-side overlap through 33% passenger side overlap. Similarly, the passenger seat accelerations are shown in Figures A 2a-g.

For increasing impact speed or delta-V the driver and passenger seat accelerations generally increased up to a certain level, at which the vehicle crush zone experienced a force/acceleration plateau. The acceleration curves reflected an earlier acceleration onset and longer pulse duration with increasing speed, once the plateau was reached.

The driver seat acceleration pulses also generally increased with overlap amount for 30, 35 and sometimes 40 mph. At 45 and 50 mph, the same relationship between acceleration and overlap amount is primarily observed in the first phase of the collision (for time less than approximately 80 to 100 ms), after which higher peak accelerations are shown for collisions with lower overlap amounts. This observation is somewhat more pronounced in the impacts with passenger side overlap. Left (driver) side 1/3 and 2/3 overlap collisions at 45 and even 50 mph resulted in similar peak and average accelerations as those occurring in 100% overlap at 35 mph, for both driver and passenger seats.

The passenger seat acceleration clearly demonstrated an increasing relationship with overlap for all speeds, although the 45 and 50 mph acceleration pulses had higher peaks at 2/3 near-side and ½ far-side overlap than in any other configuration.

Driver and passenger seats generally exhibited similar accelerations for comparable crash configurations. However, passenger side impacts resulted in relatively high vehicle accelerations on both driver and passenger side.



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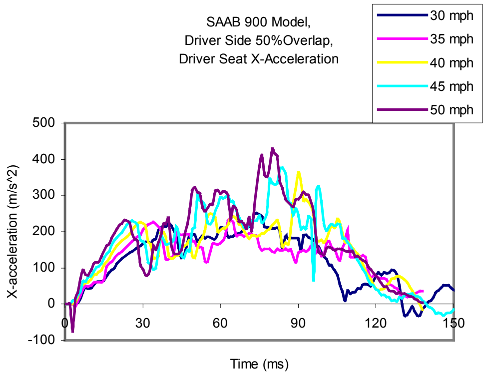

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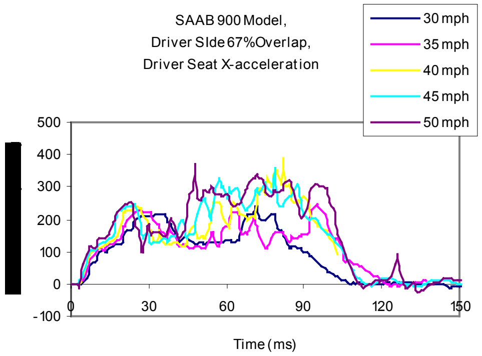

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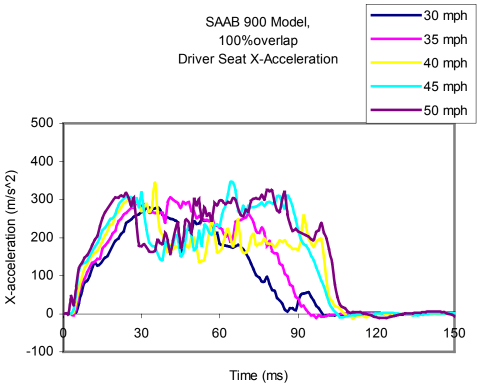

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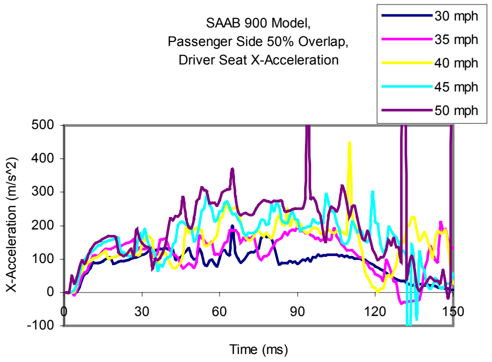

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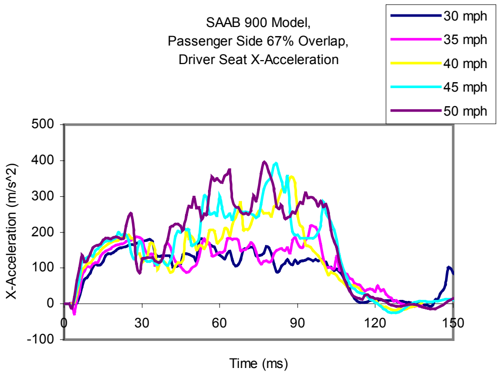

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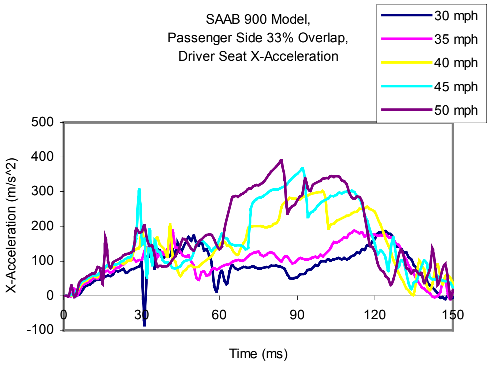
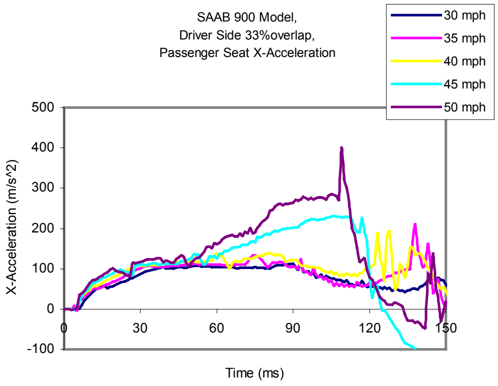
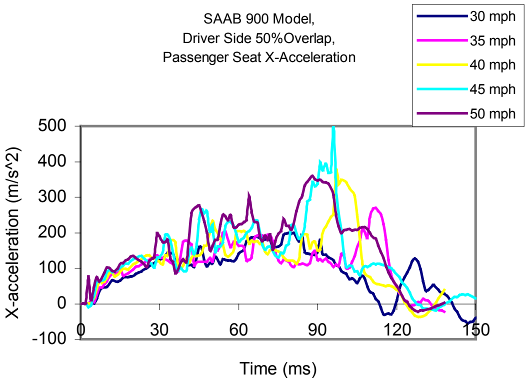


g)

Figure A 1a-g: Driver Seat Acceleration at 30 to 50 mph for various Overlap Configurations



a)



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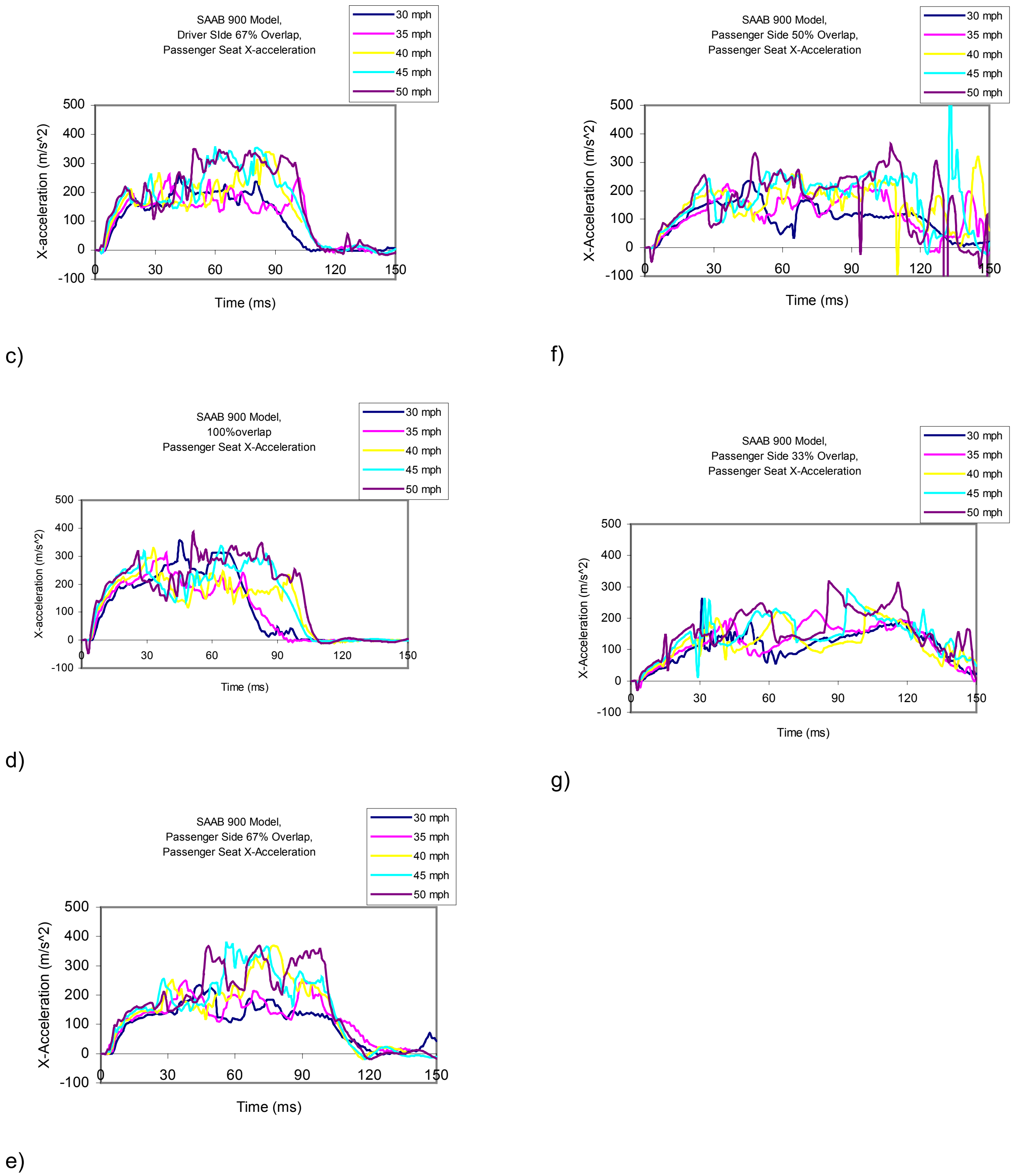

Figure A-2a-g: Passenger Seat Acceleration at 30 to 50 mph for various Overlap Configurations