Principles of Side Impact Occupant Protection:

An Investigation into Occupant to Vehicle Coupling Regimes with respect to the Euro NCAP Barrier Loadcase

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Abstract

In contrast to frontal impact, the occupant sits directly in the deformation zone of the vehicle structure during a side impact event. The goal in occupant protection is no longer one of restraining the occupant relative to the interior of the vehicle and thus decelerating it as smoothly as possible but one of protecting the occupant from the high energies of the intruding surface.

The traditional debate is whether it is better to couple the occupant and vehicle very soon after the event begins and thus begin to accelerate the occupant as early as possible or to delay the coupling as much as possible such that the velocity level of the structure is significantly decreased before the moment of coupling between the occupant and the structure.

This paper describes a study undertaken to investigate occupant/vehicle coupling regimes in side impact, specifically the Euro NCAP Side Impact Barrier loadcase. Simulation results are presented and discussed in the context of upper and lower body injury criteria and the relationship between them, to illustrate the influence of variation of the (thorax) airbag stiffness.

Furthermore, the effects of the above variations in the case of small and large vehicles are examined through scaling of the crash event severity, variation of the occupant position relative to the intruding surface and variation of the available working space in which the restraint system can act.

Insassenschutzprinzipien beim Seitenaufprall:

Untersuchung des Ankopplungsverhaltens Insasse/Fahrzeug im Lastfall Barrierenaufprall Euro NCAP

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Zusammenfassung

Im Gegensatz zum Frontalcrash sitzt der Insasse beim Seitenaufprall unmittelbar in der Deformationszone. Beim Insassenschutz ändert sich hierdurch die Zielsetzung: Statt einer Rückhaltung des Insassen relativ zum Interieur des Fahrzeugs bei einer möglichst sanften Geschwindigkeitsanpassung, hat nun der Schutz vor hohem Energieeintrag durch die eindringende Struktur höchste Priorität.

Die Debatte ist im wesentlichen, ob es nun vorteilhafter ist, den Insassen direkt nach Crashbeginn an das Fahrzeug anzukoppeln, um ihn so früh wie möglich zu beschleunigen, oder ob es nicht besser wäre, das Ankoppeln so lange wie möglich hinauszuzögern, um das Geschwindigkeitsniveau der Struktur signifikant zu reduzieren, bevor der Insasse damit in Kontakt tritt.

Die hier präsentierte Studie wurde mit dem Ziel durchgeführt, das Ankopplungsverhalten Insasse/Fahrzeug im Seitenaufprall, speziell im Lastfall Euro NCAP (Barriere), zu untersuchen. Die in diesem Zusammenhang dargestellten Simulationsergebnisse zeigen den Einfluss der Thoraxairbagsteifigkeit anhand der Verletzungskriterien von Ober- und Unterkörper auf und beschreiben die Beziehung zwischen diesen Kriterien.

Durch Skalierung der Crashschwere, Variation der Sitzposition relativ zur eindringenden Struktur und Variation des zur Verfügung stehenden Arbeitsraumes des Rückhaltesystems, wird der Einfluss der Varianten im Rahmen oben genannter Studie im Fall kleiner und großer Fahrzeuge untersucht.

1. Introduction

In contrast to frontal impact, the occupant sits directly in the deformation zone of the vehicle structure during a side impact event, Fig. 1.1, that is to say there is little or no ‘crumple zone’. The goal in occupant protection is no longer one of restraining the occupant relative to the interior of vehicle and thus decelerating it as smoothly as possible, as in frontal impact. Rather, the goal is then to protect the occupant from the high energies of the intruding surface, while minimising the forces imparted to the occupant.

The traditional debate is whether it is better to couple the occupant and vehicle very soon after the event begins and thus begin to accelerate the occupant as early as possible or to delay the coupling as much as possible such that the velocity level of the structure is significantly decreased before the moment of coupling between the occupant and the structure.

For the latter configuration to be beneficial, the initial distance between the occupant and vehicle structure needs to be greater than the actual amount of intrusion into the vehicle. In a large vehicle this may be possible, however in a smaller vehicle, the occupant sits much closer to the intruding surface. It is then the case that if the occupant is left uncoupled there may still be high velocity intrusion taking place at the point in time when the occupant comes into hard contact with the interior of the vehicle.

It may therefore be beneficial to ‘soft’ couple the occupant and the intruding structure early in the event and thus begin to accelerate the occupant to the velocity of the vehicle before hard contact occurs. This can be thought of as maintaining the distance between occupant and intruding surface.

This paper describes a study undertaken to investigate occupant/vehicle coupling regimes in side impact, specifically the Euro NCAP Side Impact Barrier loadcase. Simulation results are presented and discussed in the context of upper and lower body injury criteria and the relationship between them, to illustrate the influence of (thorax) airbag stiffness. Furthermore, the effects of the above variations in the case of small and large vehicles are examined through scaling of the crash event severity, variation of the occupant position relative to the intruding surface and variation of the available working space in which the restraint system can act.

2. Overview of Occupant Protection in Side Impact

2.1. Velocity Levels in Side Impact Events

In a side impact event the party at most risk of injury is generally the occupant of the (passive) struck vehicle. The occupant in the struck vehicle may be moving in the longitudinal direction of vehicle motion, but at the time of the side impact event the occupant is not moving in the lateral direction of vehicle motion and is therefore described as having zero velocity. Fig. 2.1 compares the velocity levels of the vehicle outer skin and the occupant during such an event.

Once contact occurs between the striking vehicle and the outer skin of the struck vehicle, (that of the door and a, b, or c-pillars), this outer skin accelerates to the velocity of the intruding vehicle within approximately 10ms. Elastic and plastic deformation takes place and energy is dissipated, in both the striking and struck vehicle, until they are both travelling at the same velocity. After this point, it remains for friction and impacts with other objects to bring the vehicle(s) to rest.

In parallel to this, the zero velocity occupant is accelerated to the velocity of the intruding surface, essentially that of the front end of the striking vehicle. The occupant is elastically deformed as it is brought to the velocity of the intruding surface, after which it begins to relax, accelerating to yet a higher velocity and moves away from the intruding structure once again. If the amount of elastic deformation of the occupant can be minimised, then the degree to which it accelerates away from the door during its relaxation, and so its eventual velocity, will also be minimised.

The eventual velocity of the dummy is then a result of the manner in which the dummy was accelerated and is only a secondary concern, so long as it is greater than, or at least equal to, that of the vehicle. The primary concern, is the manner in which the occupant is accelerated to that velocity, i.e. the mechanism by which the work is done on the occupant.

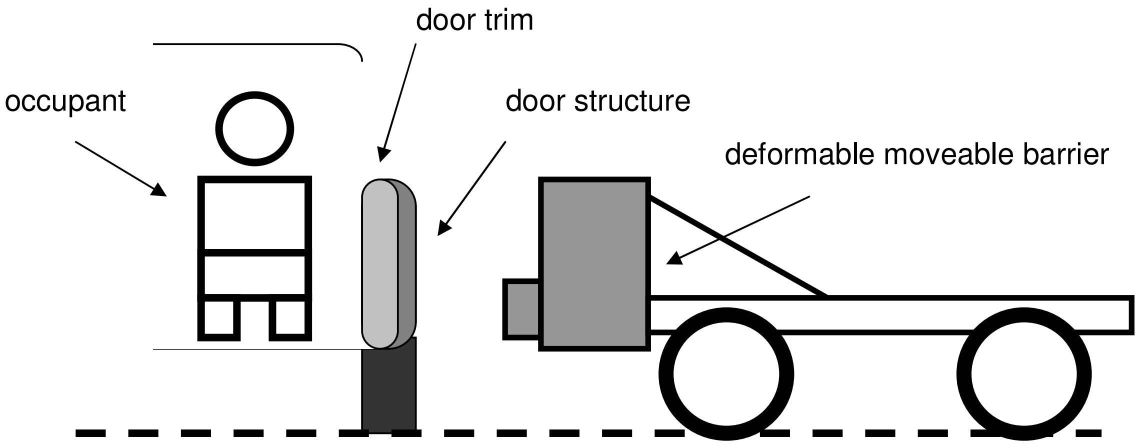


Fig. 1.1: Typical Side Impact Barrier Test Configuration

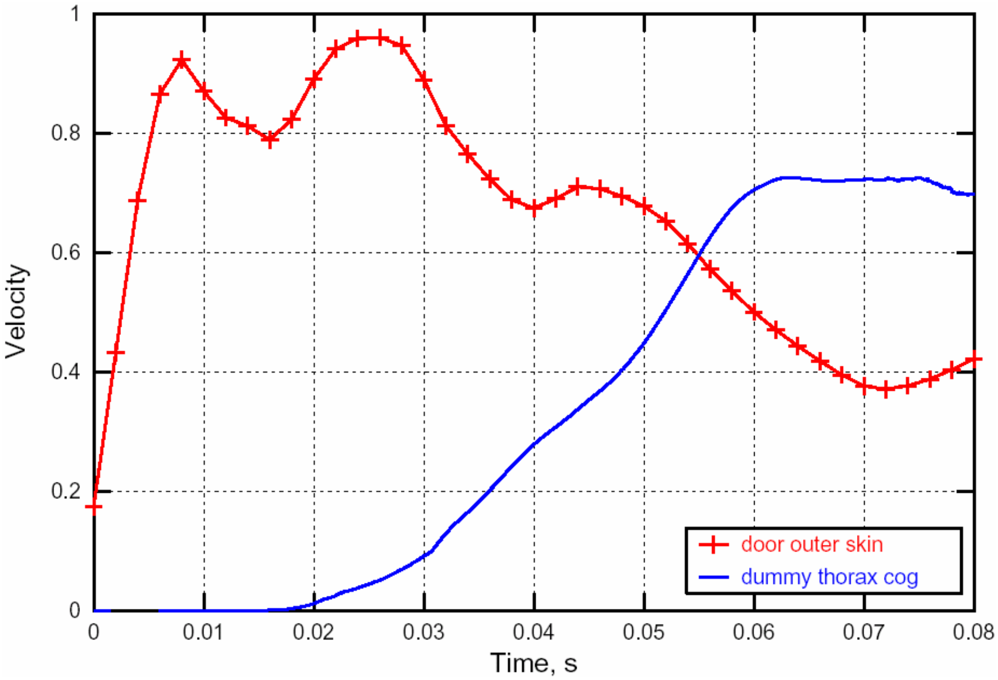


Fig. 2.1: Velocity Relation in Side Impact Event

2.2. Influence of Vehicle Class

There is clearly a very wide variety of shapes and sizes of passenger vehicles on the roads today, and it is no surprise therfore that certain varieties of these vehicles provide better protection to the occupant when struck by another vehicle than others.

Perhaps the most obvious influencing factor is the stiffness of the struck vehicle structure. This will influence the degree of intrusion into the vehicle, a very stiff vehicle will deform very little and so preserve the space between the occupant's initial position and the inner surface of the vehicle. The eventual motion the occupant experiences will then be closer to the global vehicle motion. A less stiff vehicle structure will allow more deformation (and thus energy dissipation), which means that the space between the occupant's initial position and the intruding surface is eroded.

For a given structural stiffness, the mass of the vehicle then determines if the global vehicle motion is significant enough to pose a threat to the occupants. The greater the mass of the struck vehicle, the less it will be accelerated as a result of the impact. This has clear benefits for the occupant who then experiences less energy when struck by the interior of the vehicle. There is a second effect of increased mass in the struck vehicle, in that the striking vehicle needs to be decelerated more, and thus needs to dissipate more of its own energy through deformation.

However, if the mass of the struck vehicle is such that the global vehicle motion is sufficiently high to pose a threat to the safety of the occupant, as is the case in all but the heaviest vehicles, a controlled amount of deformation may be favourable. This plastic deformation provides the opportunity to dissipate some of the energy before the occupant is coupled to the structure.

A further influencing factor is the relative geometries and masses of the struck and striking vehicles and the point of impact. This is commonly referred to as compatibility. If the striking vehicle contacts the stiffest area of the struck vehicle, e.g. the door sill, then the intrusion of the struck vehicle will be lower and the eventual global motion higher. Thus, a high riding vehicle striking a relatively low riding one will cause greater deformation of the struck vehicle than a low riding vehicle striking a high riding one.

This can also be said of configurations where the striking vehicle contacts one or more of the stiff vertical pillars of the vehicle or, in the case of very small vehicles, the axles or wheel carriers. The struck vehicle may then actually be driven ahead of the striking vehicle rather than deforming.

2.3. Load Paths to the Occupant

As the occupant sits directly in the deformation area in the side impact event, the amount of space available in which to protect the occupant decreases as the event progresses. Indeed, as the structure deforms, the shape and stiffness of the inner surface of the vehicle changes. It is these local effects that make occupant protection in side impact events such a vehicle and component specific problem, in comparison to frontal impact.

The primary load path to the occupant is through the door trim to the thorax, abdomen and pelvis. Secondary contacts of the legs to the door trim are not as significant in their contribution to injury risk. However, secondary impact of the head to the b or c pillar, the top of the door or indeed the striking vehicle is a very significant contributor to injury risk. There is always a minimum amount of energy to be transferred to the dummy, that being the amount to accelerate it at least to the vehicle velocity. As such, any increase in loading through one area of the body is generally mirrored by a decrease in loading through another.

The influence of the seating on the loading of the occupant is an issue of much debate, but what is clear is that any seating which the occupant sits ‘in’ rather than ‘on’ will play a greater role. This is true of the couch like rear seats found in some top-end limousines, but more importantly of the very stiff sports or ‘bucket’ seats popular in many modern vehicles. Such seats provide a very stiff coupling between the occupant and the floor pan of the vehicle, thus transferring energy earlier in the event than if the occupant were to stand motionless until contacted by the intruding surface.

For a given vehicle mass and structural stiffness, the remaining area for increasing the protection offered to the occupant is in optimising the load transfer characteristic(s) through the load paths described above. There is a lot of opportunity for energy absorption and thus occupant protection in the door trim of the vehicle itself, including the use of crash pad and collapsible armrests etc. These features may be referred to as ‘static’ as they are always in place and as such are spatially limited by the structural design of the vehicle, often driven by stylistic and specified functional demands.

The next opportunity for optimisation of the load transfer characteristic to the occupant is through the use of non-static systems, such as airbags, which deploy into the occupant area only in the event of an impact and thus utilise working space that static systems cannot. A further advantage of airbags over mechanical static systems such as crash pads is that the stiffness characteristic may be predefined and considerably more complex. Indeed, with advances in sensoric and control technology, the airbag stiffness characteristic may be adjusted in real time during the event in response to the actual conditions.

Depending on the stiffness characteristic defined for the restraint system, the occupant may or may not be directly acted on by the intruding surface, i.e. the airbag and door trim may or may not completely deform. However, regardless of whether it is through direct contact with the vehicle structure or not, it is true to say that the occupant will always come into ‘hard coupling’ with the vehicle at some stage. This is because if the restraint system does not deform completely then it must become as stiff as the intruding surface, if only for an instant. At this point the outer skin of the occupant has the same velocity as the intruding surface.

The question is then at what point in time is it best to ‘hard couple’, and furthermore what is the best way to prepare the occupant for this hard coupling. The roles of the airbag, door trim and to some degree the seat are then switched from one of an occupant restraint system, to one of an *occupant propulsion system*.

3. Overview of Euro NCAP Side Impact Rating System

The Euro NCAP rating system is today well established as the rating consumers look to when considering the occupant safety of a new car in Europe. The side impact element of the rating involves primarily the barrier configuration, in which the vehicle is initially at a stand still, and in addition a pole configuration in which the vehicle has an initial, albeit lower, velocity and the pole is rigidly fixed to the ground, [1,2]. Apart from the initial velocity, another feature of the pole configuration that differentiates it from the barrier configuration is that the pole does not yield or deform, i.e. all of the deformation, and thus energy dissipation, must occur in the vehicle and restraint system. Thus, even though it is at a lower velocity, it is a comparably severe event. For the purposes of this study, the barrier configuration has been focused on as it is most representative of the other worldwide consumer and legal tests to which vehicles are subjected.

The measured occupant injury criteria are evaluated in four groups, (relating to head, thorax, abdomen and pelvis respectively), for which zero to four points are awarded on a sliding scale to each group, giving a maximum of sixteen points.

Further to this a number of modifiers are applied, which specify that points are deducted if certain criteria are not met. The first modifier relates to the load transferred to the dummy spine through the rigid back plate (via the seat back frame and/or seat integrated airbag housing) part, as opposed to the through the ribs. Use of this load path leads to unrealistically low rib intrusions and is therefore discouraged by means of this modifier. The second modifier relates to the opening of doors in the vehicle during the test.

A further modifier is currently under discussion, the T12 Modifier, which will penalise excessive shear force in the T12 area of the lower spine. This excessive force is a symptom of imbalance in the loading of the upper and lower parts of the dummy, which may sometimes be used to achieve low rib intrusions at the expense of higher lower body forces and accelerations.

4. Overview of Simulation to be Discussed

The authors fully accept that when using actual component models it is never possible to totally eliminate all local and component specific effects from the analysis. However, it was considered important to use actual component models rather than generic blocks or cushions in order to achieve a good degree of relevance to the real world characteristics of such an event. In the simulation model investigated great effort has been made to make the configuration as generic as possible and thus make the discussion based on those simulations as broadly based and robust as possible. The following section describes the model investigated and the measures taken to make it as generic as possible.

4.1. Description of the Baseline Model.

The baseline model for the investigation is a PAMCRASH finite element model taken from the development phase of a mid-sized sedan. A ‘substructure’ model is used, [3], that is to say the assumption is made that the variations introduced in the study will not greatly influence the motion or deformation of the vehicle structure itself. The motion of these structural parts is then defined as a boundary condition and only the occupant and restraint system(s) are actually calculated. Indeed, only the parts to which the occupant and restraint

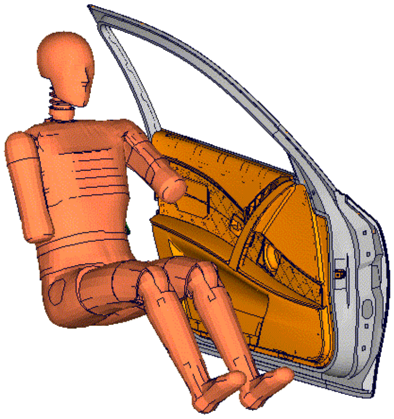
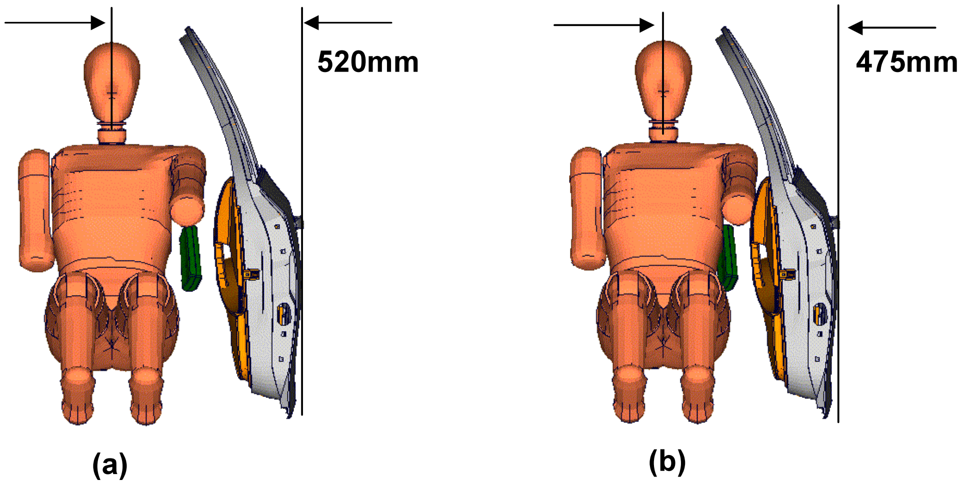


Fig. 4.1: PAMCRASH Finite Element Substructure Model



(a)

(b)

Fig. 4.2: Baseline Configuration (a) and Variant with Dummy Offset Outwards (b).

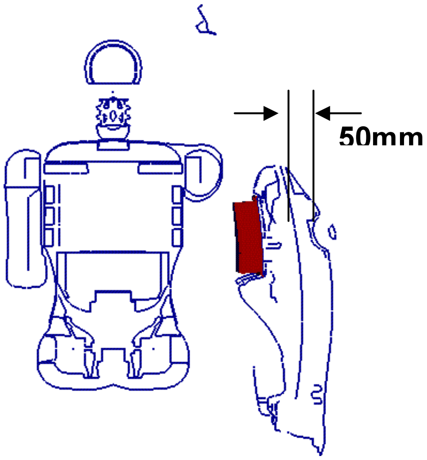


Fig. 4.3: Section Showing Baseline and Variant with a 50mm Door Pad in Thorax Area.

system has contact during the event need be included in the model, Fig.4.1. This approach is common practice and vastly reduces the computational effort required for the simulation.

In the substructure, the outer skin of the door is given a prescribed motion and all other parts are calculated. The seat has been removed from the model in order to eliminate any effect arising from loading of the dummy back plate, as described in Section 3.

A thorax airbag is incorporated into the model and is positioned in space as if it were attached to the seat, Fig.4.2. The mounting points of the airbag inflator are constrained to move in the lateral direction only. The airbag 'box' is included to give a realistic deployment characteristic to the airbag.

Finally, the Eurosid1 dummy model (v4) is positioned in the baseline model at approximately the correct location and orientation for a mid to large size sedan. This dummy model is known to be relatively robust and is correlated to the hardware dummy.

4.2. Variations Employed and Means

As outlined in the introduction, the aim of the study is to investigate side impact behaviour across a range of coupling schemes and vehicle classes. In order to achieve this with variations on a single baseline model the following actions have been taken (also listed in Table 4.1):

- variation of airbag working pressure
    - this variation of the stiffness of the restraint system is one of the prime opportunities available to optimise the system.
    - this variation is also applied as a secondary or tertiary variation in the following variations.
- variation of severity of impact event
    - for a given crash configuration, the relative masses and structural stiffnesses of the striking and struck vehicles determine the relative severity of the impact to which the occupant is subjected. By scaling the prescribed motion of the door skin in the substructure model, the severity of the impact may be varied. The upward scaling of the motion of this midsize vehicle approaches the motion of a small vehicle, while the downward scaling approaches that of a larger vehicle.

- variation of occupant position
    - the occupant position relative to the outer skin of the vehicle is one of the prime differences between large and small car configurations. This variation has been realised by transforming the dummy model along the lateral access in the direction of the door to a position relative to the door outer skin that corresponds to a small car configuration, Fig.4.2.
- variation of working space for restraint system
    - a further difference between the configuration of a large and small vehicle is the space between the dummy and the internal surface of the vehicle (i.e. the door trim) in which the restraint system (airbag) can deploy. This variation has been achieved by the inclusion of a foam pad on the door trim to reduce the space available to the airbag, Fig. 4.3.

4.3. Limitations of Simulation

As mentioned at the beginning of this section any study based on a single system will have inherent features particular to that system. One such particular feature is the door and trim structure included in the model. In the interests of making direct comparisons of the results, however, it was deemed necessary to have a common structure across all of the variations.

Similarly, the deformation and shape characteristic of the door outer skin are particular to the class of vehicle from which the model is derived, so the height at which the barrier is striking the structure and the degree of intrusion of the door relative to the rest of the vehicle is also particular to that vehicle.

Variation	Airbag Pressure	Event Severity	Dummy Offset	Working Space
Primary	+/- 50%	+/- 25%	-45mm	-50mm
Secondary		+/- 25% pressure	+ 25% severity	+/- 25% pressure
Tertiary			+/- 25% pressure	
No. of Runs	5 (1*5 pressures)	6 (2*3 pressures)	6 (2*3 pressures)	3 (1*3 pressures)

Table 4.1: Range of Variations Applied to Baseline Model

5. Evaluation of Simulation

Although the event under investigation is the Euro NCAP Barrier test, it has been decided not to directly evaluate the results in terms of the Euro NCAP points system for a number of reasons.

The primary reason is that the study is intended to investigate the sensitivity of this single generic system to the variations applied and not to benchmark against actual vehicles. Furthermore, the configuration under investigation bears little or no resemblance to an actual vehicle and so any comparisons to actual vehicles that a discussion based on points scores might invite would be meaningless.

Instead, an arbitrary baseline value is set equal to one for each measure. The injury criteria values are then discussed relative to this value. Therefore, the ordinate axes and values compared in all of the following plots are dimensionless.

The sensitivity of the system in response to the variations outlined in Section 4.2 will be evaluated as follows:

- Average Rib Intrusion
    - it was decided to compare average rib intrusion as it is a generic measure of the upper body loading and also in order to reduce the amount of data to be presented and discussed. The Viscous Criterion is not considered as the values predicted in all but the most severe variations are within 4-point range.
- T12 Section Force (Y Component)
    - As mentioned in Section 3, there are plans to introduce a modifier to the Euro NCAP points system based on the T12 Section Force. This is included in this study to highlight its role as an indicator of the balance between upper and lower body loading, Fig. 5.1.
- Combined Abdomen and Pelvis Force (CAPF)
    - This is the sum of the peaks of each signal as opposed to the sum of the signals themselves. This measure was selected as it captures the degree of the combined lower body loading.

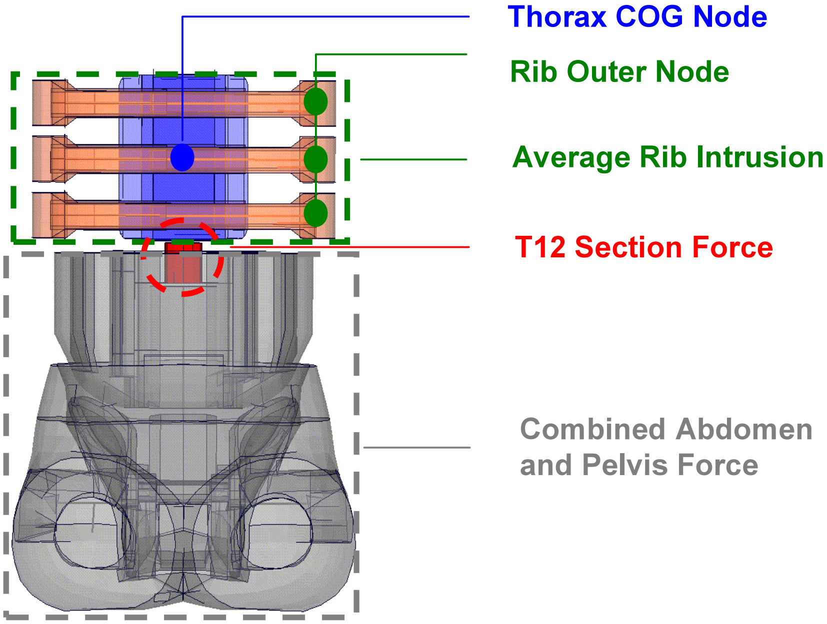


Fig. 5.1. Locations of Measured Parameters on Eurosid 1 Dummy Model

5.1. Effect of Variations on Dummy Injury Criteria

Figs. 5.2, 5.3 and 5.4 illustrate the sensitivity of the selected measures to the variations applied. The spread of variations applied allows for a number of comparisons to be made for each variation so that the trends exhibited can be viewed with a good degree of confidence.

Rib Intrusion

It can be seen that a lower pressure airbag leads to reductions in rib intrusion in all cases, Fig. 5.2(a). The exceptions being those severe cases where the airbag has difficulty deploying, i.e. with the dummy offset towards the door at 125% event severity scaling and in the baseline configuration with limited working space due to the additional pad. As is to be expected, the rib intrusion also decreases with decreased severity of event, Fig. 5.2 (b).

Fig. 5.2 (c) shows the increase in rib intrusion to be expected as the dummy is moved closer to the intruding surface, while Fig. 5.2 (d) shows an increase in rib intrusion even as the distance to the intruding surface is maintained but the working space for the airbag is reduced by means of the additional pad.

T12 Section Force

Fig. 5.3(a) illustrates a reduction in T12 section force predicted with increasing stiffness as the thorax experiences a greater proportion of the loading. This highlights that in the baseline the lower body is loaded more than the upper body.

As is to be expected, Fig. 5.3 (b) shows that increased severity of impact event leads to a corresponding increase in T12 section force. It is also interesting to note that at a closer proximity to the door, as in the offset cases, the sensitivity to and increase in severity is significantly higher than in the baseline.

It is particularly interesting to note, in Fig. 5.3 (c), that in the ‘baseline’ runs the T12 force decreases as the dummy is moved closer to the door. This corresponds to the increased upper body loading seen in Fig. 5.2(c). However, at a higher severity of impact, the effect reverses as the pelvis now experiences a significantly higher loading. This highlights that there is a critical distance from the intruding surface for a given severity of impact, about which the upper/lower body loading and thus injury criteria balances.

Combined Abdomen and Pelvis Force

In contrast to the increase in rib intrusion with increasing airbag stiffness, the CAPF is seen to decrease as the airbag stiffness increases, Fig. 5.4(a), clearly indicating that the lower body now takes a lower proportion of the loading as the upper body experiences more.

The marked increase in lower body sensitivity to impact severity as the dummy moves closer to the door, that was suggested by the T12 section force in Fig. 5.3(a), is clearly depicted in Fig. 5.4(b). Indeed, Fig. 5.4(c), further highlights this with the influence of offset being amplified at higher impact severities.

Fig. 5.4(d) does not show any clear sensitivity of the CAPF to the working space available to the airbag. This is not surprising when one considers that the lower body is not contacted at all by the bag itself. Furthermore, the degree of deployment of the airbag, particularly the de-powered variant, in this smaller working space is significantly reduced.

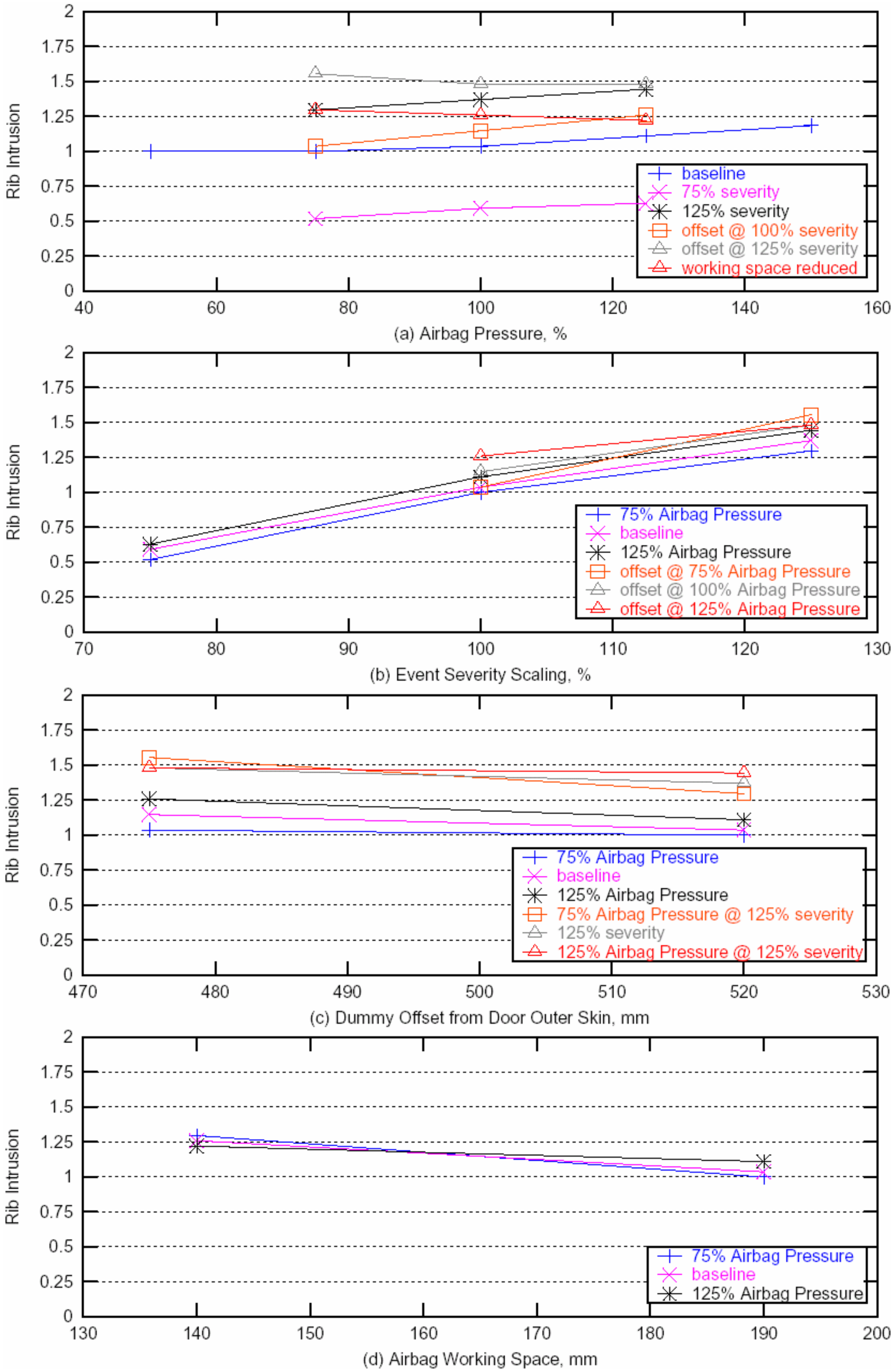
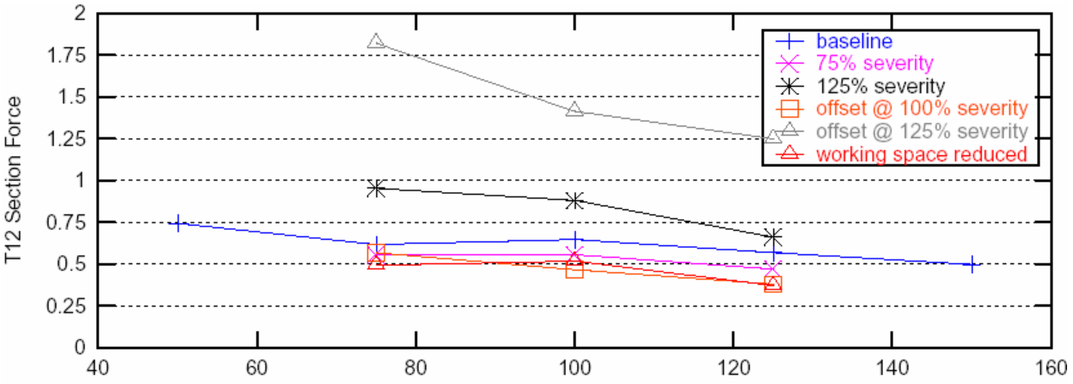
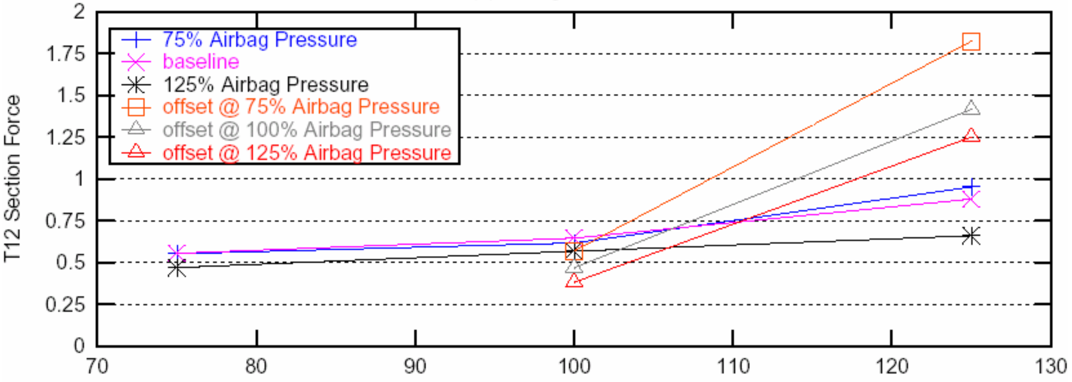


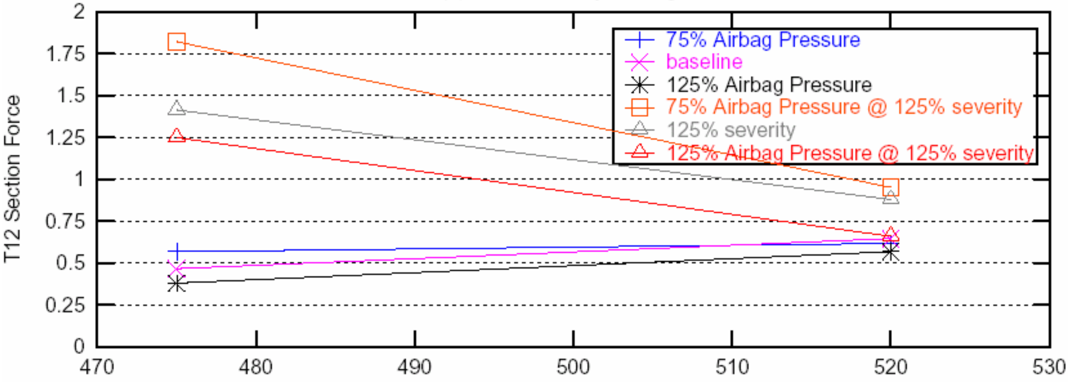
Fig. 5.2: Effect of Variations on Rib Intrusion.



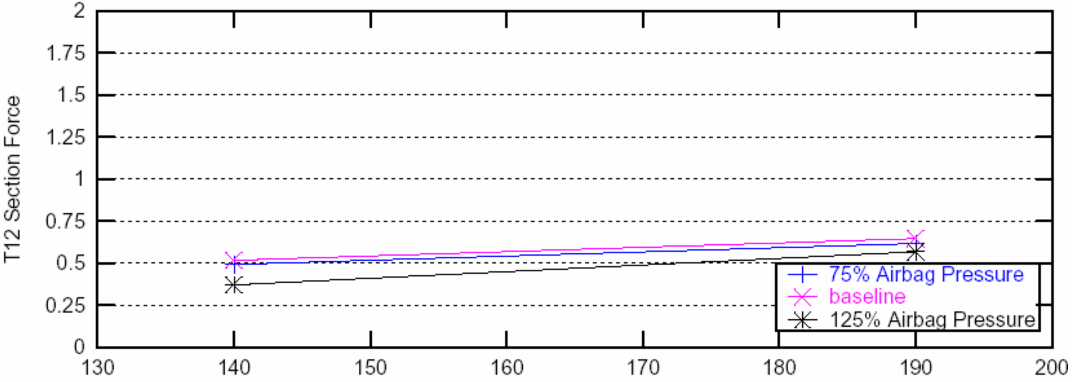
(a) Airbag Pressure, %



(b) Event Severity Scaling, %

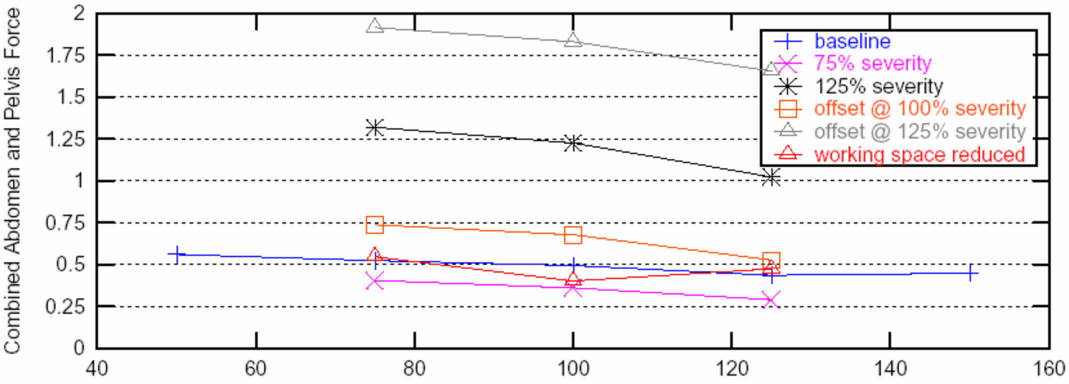


(c) Dummy Offset from Door Outer Skin, mm

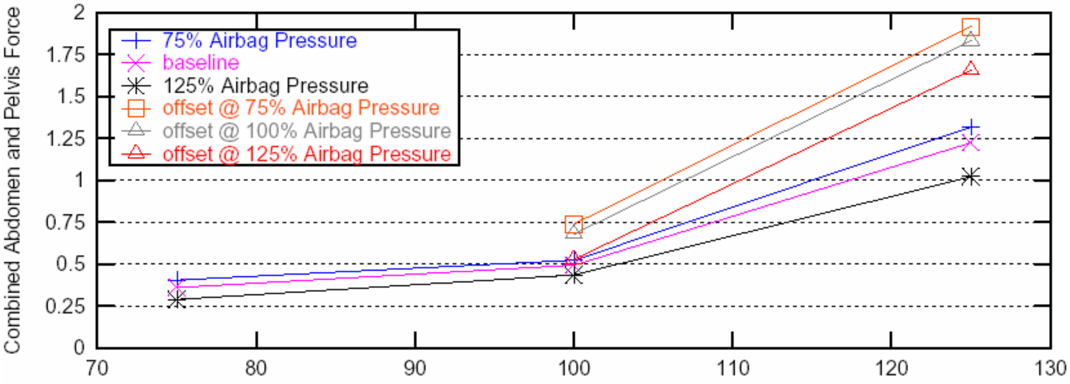


(d) Airbag Working Space, mm

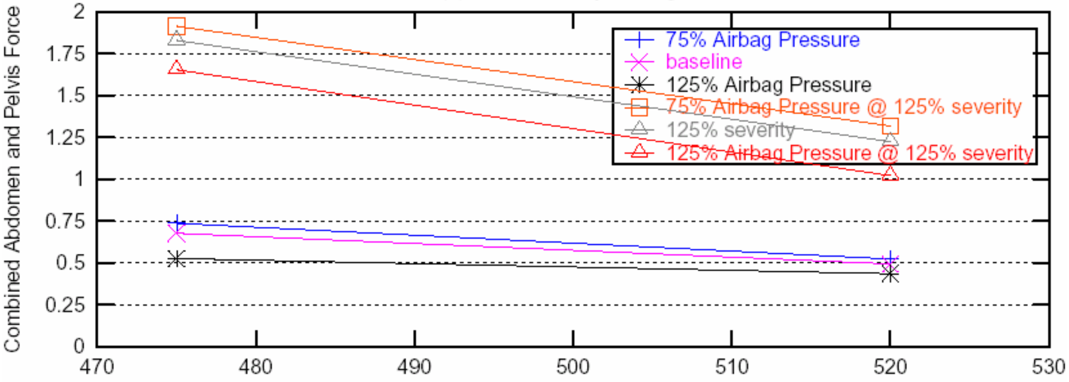
Fig. 5.3: Effect of Variations on T12 Section Force.



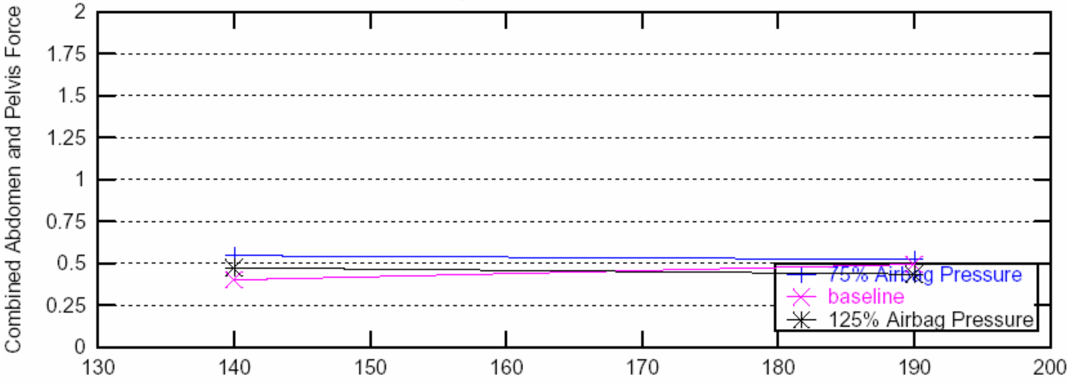
(a) Airbag Pressure, %



(b) Event Severity Scaling, %



(c) Dummy Offset from Door Outer Skin, mm



(d) Airbag Working Space, mm

Fig. 5.4: Effect of Variations on Combined Abdomen and Pelvis Force.

5.2. Effect on Occupant Thorax Velocity and Intrusion Characteristics

In addition to the peak values attained, it is insightful to examine the changes in velocity and intrusion characteristics of the occupant thorax in response to the variations applied in simulation.

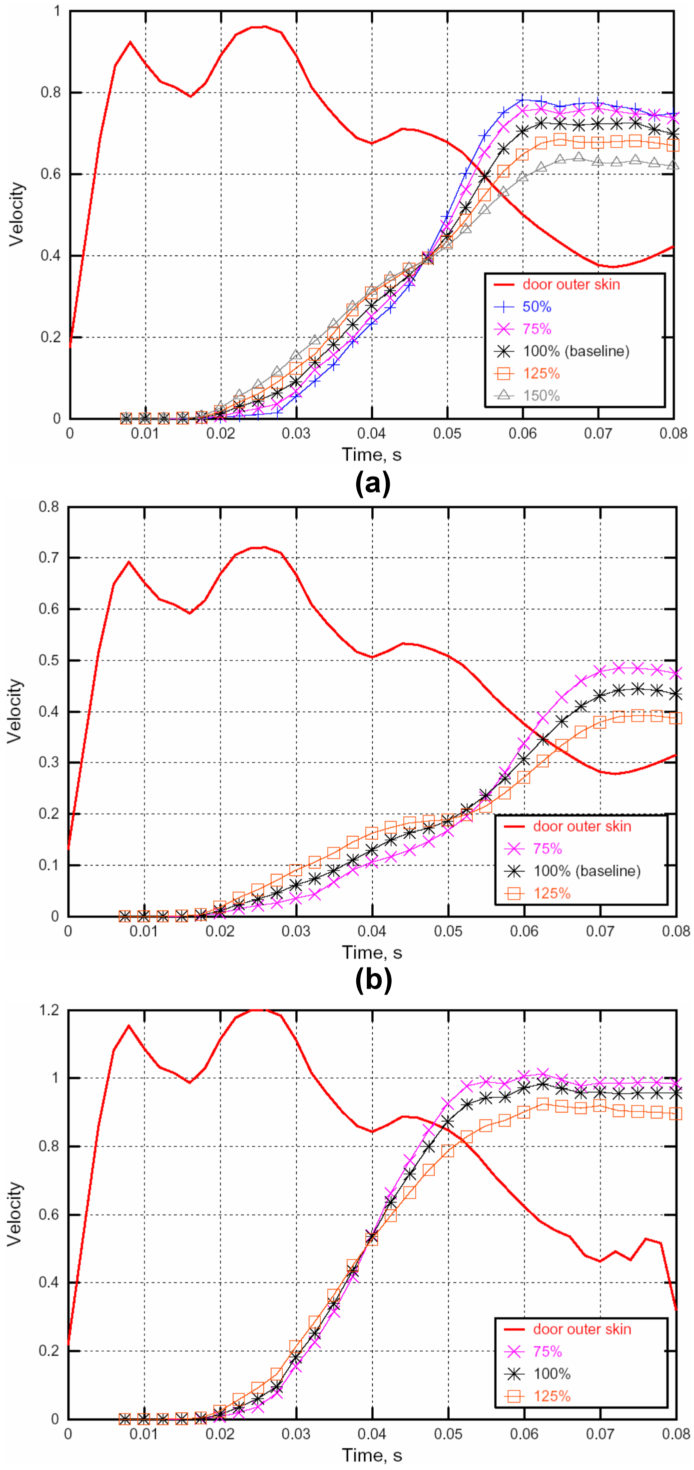
Fig. 5.5(a) shows that, as expected, the stiffer airbags cause a quicker rise in thorax velocity of the dummy. However, the dummy is, as a result, moved further away from the door. The airbag is effectively increasing the working space and the dummy reaches the same velocity as the door at a later and lower velocity than with the softer bags. This phenomenon is seen to hold true for both less severe events, Fig. 5.5(b) and more severe events, Fig. 5.5(c).

This result appears to be contrary to the commonly held perception that by bringing the dummy to the vehicle velocity at a later and lower velocity better values of injury criteria can be achieved, as we saw in Section 5.1 that the softer bags yielded the lowest rib intrusions.

Looking to the corresponding rib intrusion characteristics, Fig. 5.6, it can be seen that at the point in time when the dummy thorax velocity approaches that of the intruding structure, between 47 and 57 ms in Fig. 5.5(a), the ribs in the simulations with the stiffer bags are starting to relax, Fig. 5.6(a).

In contrast, at approximately the same time, the thorax velocity in the softest bags is forced to accelerate to a higher intruding surface velocity in a shorter amount of time. This is a result of there being an effectively smaller amount of working space due to the softer action of the airbag in the earlier stages. Sudden peaks are then caused in the rib intrusions, as the dummy ‘strikes-through’ the airbag, and the stiffness of the coupling suddenly changes from that of the relatively soft bag to that of the relatively stiff door trim.

It is perhaps helpful to note that the intrusion of the ribs is a result of a difference in velocity between the rib and the rigid spine part of the thorax. In Fig. 5.7(a), the velocity curves are illustrated for the baseline simulation.

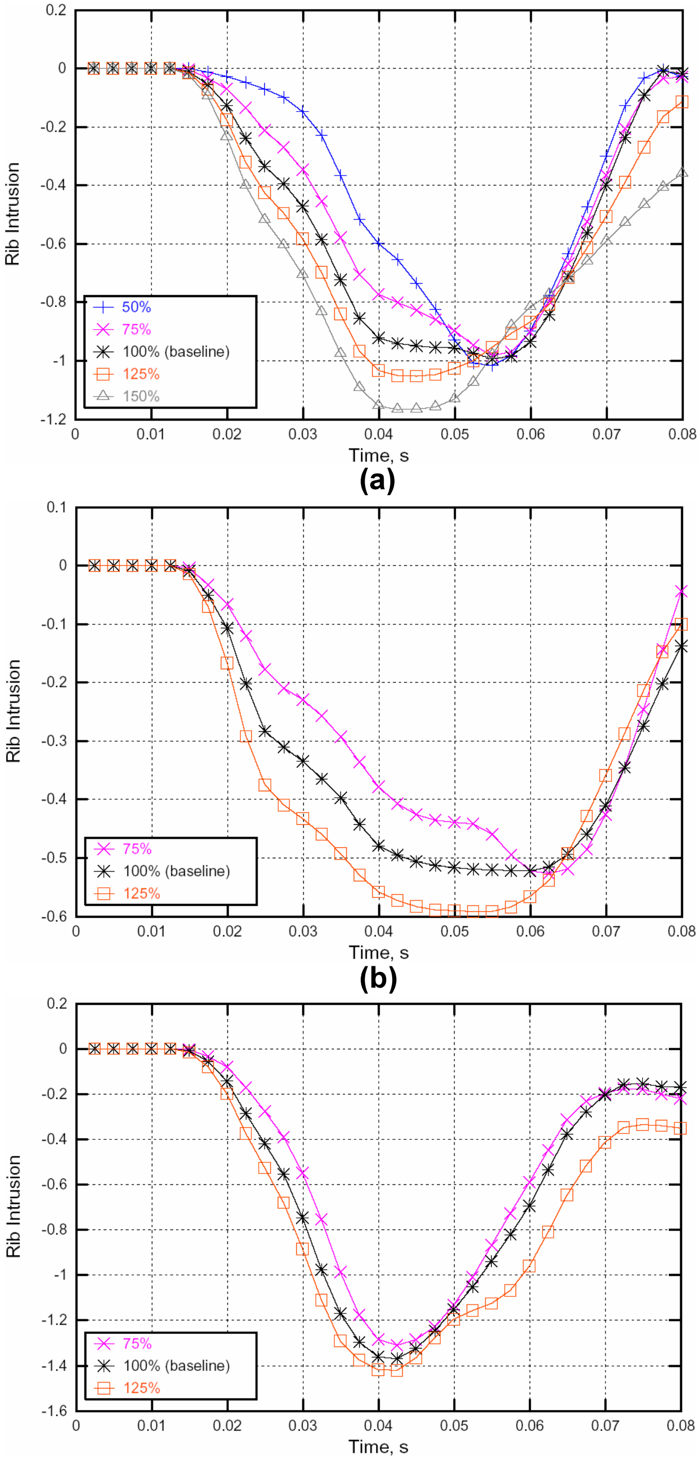


(a)

(b)

(c)

Fig. 5.5: Effect of Airbag Pressure Variation on Occupant Velocity Characteristic for Baseline Event (a), 75% Severity (b) and 125% Severity (c).



(a)

(b)

(c)

Fig. 5.6: Effect of Airbag Pressure Variation on Occupant Rib Intrusion Characteristic for Baseline Event (a), 75% Severity (b) and 125% Severity (c).

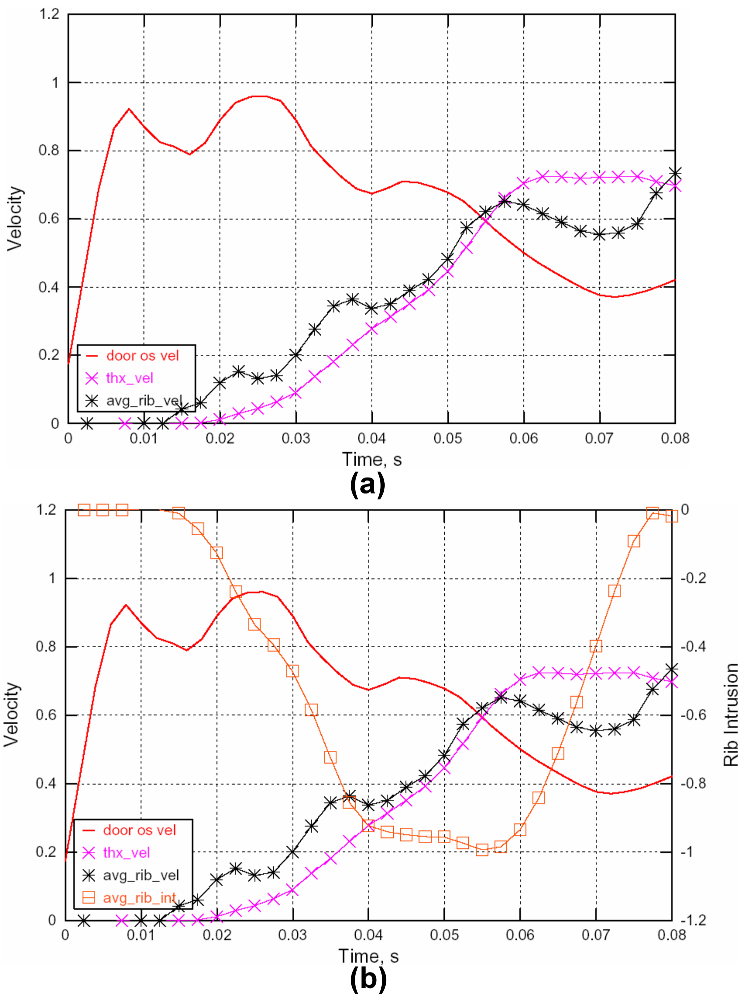
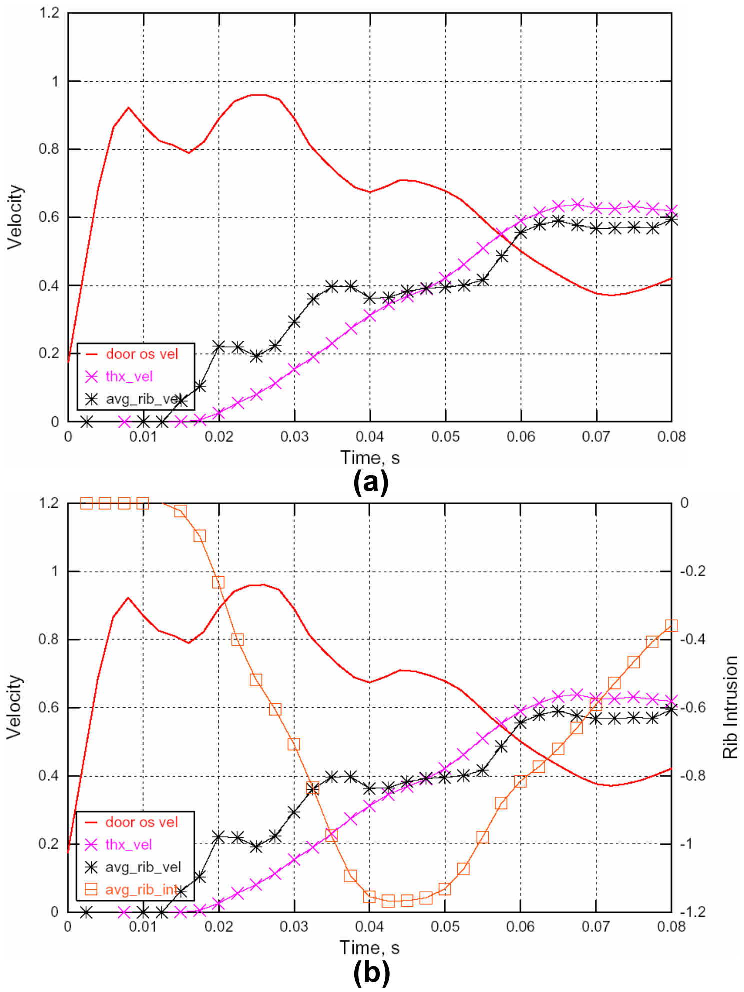


Fig. 5.7: Comparison of Door Outer Skin, Thorax and Average Rib Velocity in Baseline Simulation (a) and with respect to Average Rib Intrusion (b).

It can be seen that the point of intersection of the thorax velocity curve and the rib velocity curve is at approximately 57ms, and occurs approx. 3ms after both the rib and thorax have reached the intruding surface velocity. When viewed with respect to the average rib intrusion characteristic, Fig. 5.7(b), it can be seen that this point of intersection corresponds to the ultimate peak of the rib intrusion. The thorax rib velocity then falls below that of the thorax and the rib begins to relax. Again, this ultimate peak is not the peak of a smooth loading and unloading curve, rather the peak of a sudden increase in intrusion as the dummy strikes through the bag.



(a)

(b)

Fig . 5.8: Comparison of Door Outer Skin, Thorax and Average Rib Velocity in Simulation with 125% Airbag Pressure (a) and with respect to Avg. Rib Intrusion (b).

This indicates that if the point of intersection of the rib and thorax velocity characteristics, i.e. the peak of rib intrusion, occurs after the thorax and ribs have reached the intruding surface velocity, the coupling has been too soft and strike through will occur.

However, should the intersection of the thorax and ribs velocities occur before they attain the intruding surface velocity as in the simulation with a 125% pressure airbag, Fig. 5.8(a), the peak of rib intrusion also occurs before the dummy has reached the velocity of vehicle. There is a smooth transition from loading of the rib to unloading and no strike through occurs. However, the airbag is now too stiff and more intrusion of the rib has occurred than is actually necessary to bring the dummy to the vehicle velocity.

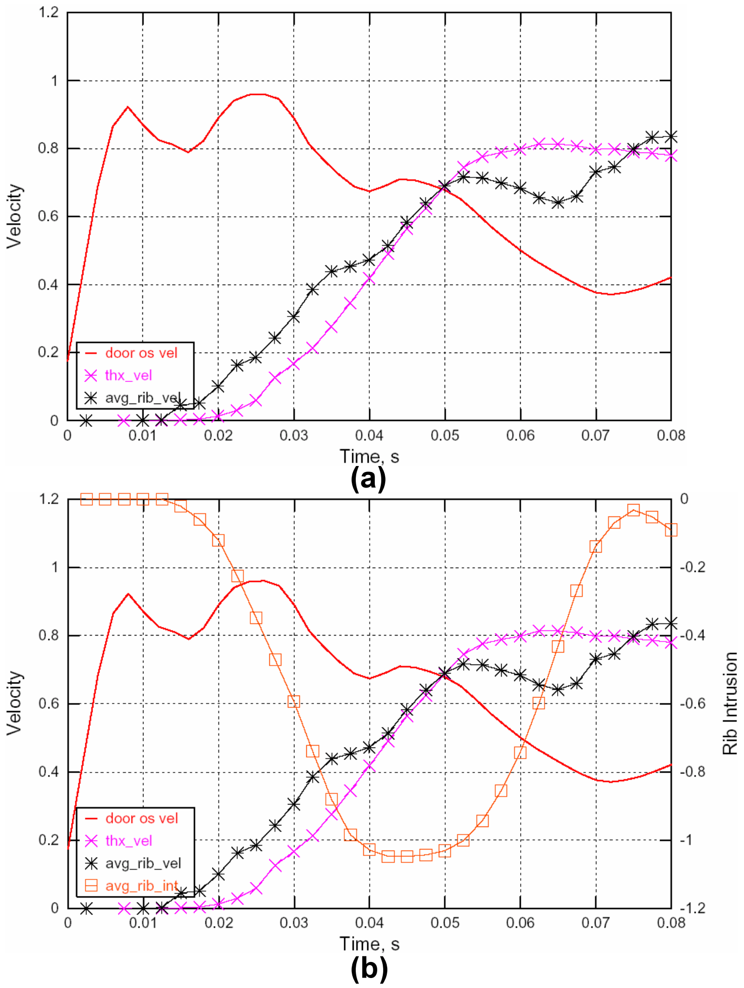


Fig. 5.9: Comparison of Door Outer Skin, Thorax and Avg. Rib Vel. in Sim. with Offset Dummy Position and 75% Airbag Pressure (a) and with respect to Avg. Rib Int. (b).

It can therefore be said that the optimum case is that the intersection of the dummy ribs and thorax velocity curves, i.e. the peak of rib intrusion, should coincide with the point at which they cross the intruding surface velocity curve. In this case, no strike though will occur and only the amount of rib intrusion necessary to bring the dummy to the vehicle velocity in the given working space will have been applied, Fig. 5.9.

The question then turns again to which point on the intrusion surface velocity curve it is best to have the peak or intersection. Fig. 5.9(a) and (b), depict the velocities and intrusions for the simulation with the dummy offset towards the door and a 75% pressure airbag. In this case it can be seen that the intersection and peak occur at, or just before, the dummy reaches the vehicle velocity, and as such this is the optimum airbag stiffness for this configuration in terms of strike through and appropriate rib intrusion.

However, in contrast to the baseline, Fig. 5.7, the point at which the dummy reaches the vehicle velocity is approximately 5ms earlier and 10% higher on the vehicle velocity curve. The corresponding rib intrusion in the offset configuration, Fig. 5.9(a) is slightly higher.

It is worthwhile to note that if the airbag pressure in the baseline simulation were optimum (slightly stiffer), we could expect its intersection to occur slightly earlier and thus achieve a marginally lower peak rib intrusion, somewhere between the first plateau and the strike through peak in Fig. 5.7(b). This would give a more significant difference between the offset case and the ‘optimised’ baseline.

Thus, given that the peak rib intrusion can be arranged to occur at the point at which the dummy reaches the velocity of the intruding structure, if this point can be made later and lower on the intruding structure velocity curve, reductions in the rib intrusions can be achieved.

5.3. Potential Further Variations

The obvious variation omitted from this study is the time at which the coupling of the dummy to the structure actually begins. It was not possible to make this variation within this study without introducing an airbag of different geometry, and thus volume and working pressure. This step would have added to the complication of the study and number of simulations to be discussed significantly and is therefore left to a later study.

6. Conclusions

An overview of occupant protection in side impact has been presented and a number of the associated problems discussed.

An investigation into occupant/vehicle coupling regimes in side impact events has been presented with particular attention to the Euro NCAP Side Impact Barrier loadcase. Results from simulations involving the variation of thorax airbag stiffness have been presented and discussed in the context of predicted thorax intrusion, T12 section force and the combined abdomen and pelvic force.

The concept of upper/lower body balance in loading has been highlighted and the role of the T12 section force as an indicator of this balance confirmed. It has been observed that in the offset of the occupant from the intruding structure, which is a key difference between large and small vehicle configurations, there exists a critical offset for a given event severity about which the upper/lower body balance pivots.

Furthermore, the effects of the above variations in the case of small and large vehicles have been examined through simulations involving the scaling of the crash event severity, variation of the occupant position relative to the intruding surface and variation of the available working space in which the airbag can act.

Finally, the effect of such variations on the occupant thorax velocity and intrusion characteristics has been illustrated. It has been found that for a given configuration, the optimum rib intrusion is achieved only when the peak rib intrusion is arranged to coincide with the point at which the occupant velocity reaches that of the intruding structure. It was observed that the conventional wisdom of bringing the occupant to the vehicle velocity later and lower on the intruding structure velocity curve only holds true if the above criterion is satisfied.

7. References

1. European New Car Assessment Programme (EuroNCAP), Side Impact Testing Protocol, Version 4.0, January 2003.

2. European New Car Assessment Programme (EuroNCAP), Pole Side Impact Testing Protocol, Version 4.0, January 2003.

3. PAMCRASH Notes Manual, PAM SYSTEM INTERNATIONAL, March 2000.