FRONTAL INJURY RISK CRITERION

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ABSTRACT
A new injury risk criterion for restrained car occupants based on the collision response of the vehicle is presented. It is proposed that the total risk to a restrained occupant is due to the specific power of the impact and the intrusion/collapse of the occupant compartment. Risk functions for AIS2+ and AIS3+ injuries and for fatalities are validated using real world data.

Keywords: Frontal impacts, injury criteria, inertial injuries, intrusion

***ΔV* HAS CONVENTIONALLY** been used to measure impact severity and as a basis of injury risk (Evans, 1994). However, Ydenius (2002) found that mean vehicle acceleration is a better predictor of injury risk than ΔV, and it has been shown both theoretically and empirically that injuries are correlated with the specific power of an impact ($\bar{a}.\Delta V$), (Di Lorenzo, 1976; Newman et al; 2000; Neal-Sturgess, 2002). Walfisch et al (1985) showed that in frontal impacts the average specific power experienced by the vehicle correlated well with thoracic injuries of belted occupants while Kramer and Appel (1990) proposed specific power as an injury risk criterion. However, in addition to the tolerance to inertial loading, it is well known that intrusion into the occupant compartment strongly influences injury. Augenstein et al (2005) reported that the proportion of intrusion induced injuries increases with collision severity. Therefore a frontal injury risk criterion must account for both inertial and intrusion induced injuries.

NEW FRONTAL INJURY RISK CRITERION

It is proposed that occupant risk due to inertial loading is essentially independent from intrusion based risk, and therefore the aggregate injury risk (*IR*) can be formulated using a square root of the sum of the squares approach as follows:

$$IR = \left(A\left(\frac{\bar{a}.\Delta V - (\bar{a}.\Delta V)_{\min}}{\bar{a}.\Delta V_{\max} - (\bar{a}.\Delta V)_{\min}} \right)^{2n} + B\left(\frac{d/L - (d/L)_{\min}}{(d/L)_{\max} - (d/L)_{\min}} \right)^{2m} \right)^{1/2} , \qquad (1)$$

where $\bar{a}$ and ΔV are the mean acceleration and velocity change, d is the crush depth and L is vehicle length. The term $(\bar{a}.\Delta V)_{min}$ is the threshold below which no inertial injury occurs, while $(\bar{a}.\Delta V)_{max}$ is the threshold above which inertial injury always occurs. The terms $(d/L)_{min}$ and $(d/L)_{max}$ have equivalent meaning for intrusion injuries. The constants *A*, *B*, *m* and *n* are used to scale the contributions of the two injury modalities. In principle the various parameter values can be determined for individual vehicle and restraint configurations. For comparison purposes the $(\bar{a}.\Delta V)_{min,max}$, $(d/L)_{min,max}$ and structural stiffness values, etc. have been derived from real world collision data for belted drivers and for cars pre-2003 (Wood et al, 2003, 2004, 2005a, Jungmichel, 2005, Folksam, 2004, Evans, 1994) and structural behavioural characteristics (Abramowicz, 1986, Jones and Birch, 1990, Schneider, 2004, Johnson and Mamalis, 1978, Wood et al, 1993, 1996, Wood and Mooney, 1997, Prasad and Smorgonsky, 1995, Buzeman Jewkes, 2003, Mizuno et al, 2004), see table 1. The constants in equation 1 change with the severity of injury under consideration (AIS2+, AIS3+, etc).

Table 1. Risk Parameters

Injury Level	N	$\bar{a}.\Delta V_{min}$ (m^2s^{-3})	$\bar{a}.\ \Delta V_{max}$ (m^2s^{-3})	m	d/L_{min}	d/L_{max}
AIS2+	1	0	2912	2	0.24	0.75
AIS3+	1	196.2	9968	2	0.24	0.75
Fatality	1.77	196.2	9968	2	0.24	0.75
where: A=1 for $\bar{a}.\Delta V > 0$ (AIS2+), $\bar{a}.\Delta V > 196.2$ (AIS3+, Fatalities); B=1 for $d/L > 0.24$ (All)						

VALIDATION

Swedish 'real-world' AIS3+ risk data for belted drivers in frontal impacts was previously reported (Wood et al, 2005b). Figure 1 compares this real world data with scatter plot, 50%ile and ± 1 standard deviation data obtained using the new frontal injury risk criterion combined with the structural behaviour of the pre-2003 car population (Wood et al 2003, 2004, 2005a).

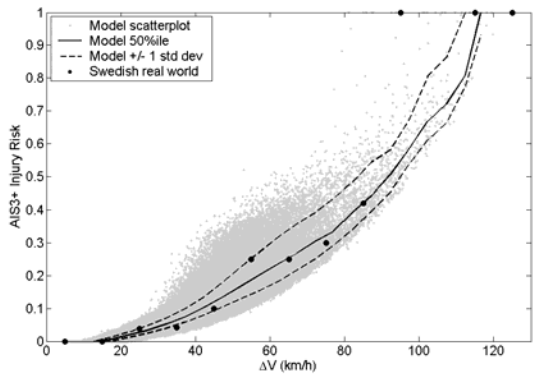

Fig. 1 – Model versus Swedish data

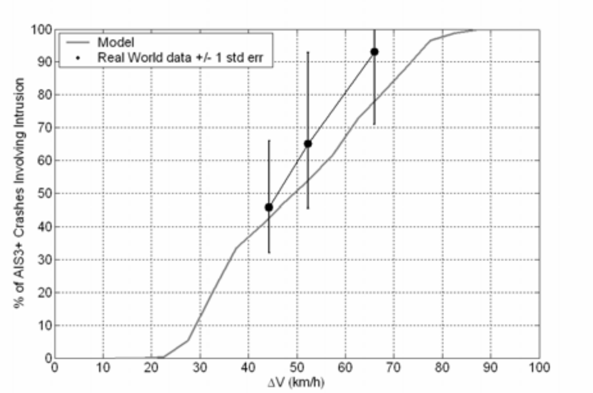

Fig 2 - Augenstein data for intrusion injuries

The U.K. car fleet mass distribution and collision closing velocity distribution were characterised from data in Thomas and Frampton (2002). Table 2 compares the prediction of quartile (25%ile and 75%ile) and median (50%ile) ΔV values (km/h) for AIS2+, AIS3+ and fatalities for belted drivers in frontal collisions from the frontal injury risk criterion, with various U.K. studies (Harms, 1993, Lenard and Welsh, 2001, Thomas and Frampton, 2002). There is a close match between the model and the real world data in both cases.

Augenstein et al (2005) reported the proportion of AIS3+ injuries for belted drivers due to intrusion. Figure 2 compares this data for intrusion injuries with the model prediction for the proportion of AIS3+ injury accidents where intrusion is present. The trend of predicted intrusion with ΔV is similar to the Augenstein data albeit somewhat lower. However, statistical comparisons (t-tests) shows no statistical difference, at the 0.05 level, between the real-world data and the model predictions.

Table 2. ΔV (km/h) for model versus U.K. studies

	Overall Crashes		AIS2+		AIS3+		Fatality	
	Model	Real World	Model	Real World	Model	Real World	Model	Real World
25%ile	19	19-25	31	25-37	38	36-44	45	43-45
50%ile	28	23-34	43	35-49	48	46-53	53	53-60
75%ile	41	34-47	54	44-59	58	55-66	63	61-75

DISCUSSION

Injuries to restrained occupants in frontal collisions can be due to inertial loading via the restraints, contact loading with the vehicle interior and crushing injuries due to collapse of the vehicle structure. As collision severity increases, the number of contact and intrusion based injuries increases. At very high levels of vehicle deformation, occupant survival chances are poor. A compliant vehicle structure lowers the acceleration of the occupant compartment during a collision but there will be earlier intrusion, and this poses a clear design conflict for occupant protection. The transition between dominant injury modalities (inertial, contact and crushing) has important implications for occupant safety.

In the light of the findings of Ydenius (2002), Wood et al (2005b) proposed an injury risk function based on vehicle acceleration,

$$P_i(\bar{a}) = (\bar{a}/\bar{a}_{critical})^n, \qquad (2)$$

where $\bar{a}_{\text{critical}}$ is the lower limit of $\bar{a}$ for which risk equals 1.0. The empirical constants $\bar{a}_{\text{critical}}$ and n were derived by regression of real world injury risk data; (Wood et al., 2005b, 2005c). This acceleration based risk function showed very good comparison with real world injury risk data (Wood et al, 2005b,c). However this approach does not account for intrusion and therefore predicts that reducing $\bar{a}$ will always reduce occupant risk, irrespective of collision severity.

The new frontal injury risk criterion presented in equation 1 provides a means to address the shortcomings of a risk function based solely on acceleration, because it includes the effects of intrusion in higher severity impacts. The inertial injury term dominates at lower severities, while the intrusion term contributes significantly at high severities. An analysis of the US NASS data shows that 50% of fatalities in frontal collisions occur with ΔV's below 52 km/h (Evans, 1994), and as figure 2 indicates, a large proportion of belted occupants are injured/killed in frontal impacts through inertial loading via the restraint system. Therefore, the effect of intrusion injuries on overall population risk remains less than inertial loading injuries, because most accidents have little or no intrusion. However, the new model presented here provides a means to estimate the effects of reducing vehicle compliance on higher severity impacts and overall population risk.

CONCLUSIONS

The new frontal injury risk criterion presented in this paper explicitly accounts for the different sources of occupant risk in frontal collisions. Application of the model in combination with vehicle collision characteristics derived from on board collision recorders shows a good comparison with the available real-world injury risk data. The model can be applied to individual car types and restraint configurations thereby accounting for specific structural stiffness and intrusion characteristics and changes in same over time.

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