



Never Stand Still

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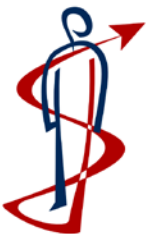
Flail-Space Model – A Review of the Lateral Impact Velocity for Thoracic Injuries

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- Michie (1981) reported on injury risk criterion for vehicle passengers.
- Vehicle deceleration limited to:
 - 5 g for longitudinal impacts.
 - 3 g for lateral impacts.
- Michie (1981) performed a literature review and expressed that this was conservative.



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- Michie (1981) introduced the flail-space model.
- Flail-space model:
 - Assessed potential injury risk to an unrestrained occupant.
 - Applied when vehicle road safety barrier crash test is conducted and an ATD is not used.
 - Obtain accelerations from accelerometer mounted at vehicle's Centre of Gravity (CG).



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- Flail-space model was founded on the hypothesis that occupant injury kinematics occurs in two phases.
 - First phase:
 - Vehicle impacts an object and decelerates.
 - Impact is longitudinal (frontal) or lateral (side).
 - In longitudinal impacts, occupants are assumed to traverse 0.6 m.
 - In lateral impacts, occupants are assumed to traverse 0.3 m.



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- Second phase:
 - Occupant is assumed to remain in contact with vehicle interior.
 - Occupant experiences a “ridedown” deceleration.
- Seatbelt wearing rates was approximately 20% at the time of flail-space model introduction (Michie, 1981).



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- Flail-space model occupant injury risk thresholds

	Preferred Value	Maximum Value
Longitudinal and Lateral Occupant Impact Velocity	9 m s ⁻¹	12 m s ⁻¹
Longitudinal and Lateral Occupant Ridedown Acceleration Limits	15 g	20 g



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- Manual for Assessment of Safety Hardware (MASH) continues to use the same flail-space model values.

Occupant Impact Velocity Limits

	Preferred	Maximum
Longitudinal and Lateral	3.0 ft/s (9.1 m s ⁻¹)	40 ft/s (12.2 m s ⁻¹)



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- Gabauer and Gabler (2006) assessed occupant longitudinal impact velocity.
- Obtained vehicle kinematics from 211 real-world crashes.
- Performed logistic regression analysis.
- Produced injury risk curves for belted and unbelted occupants.



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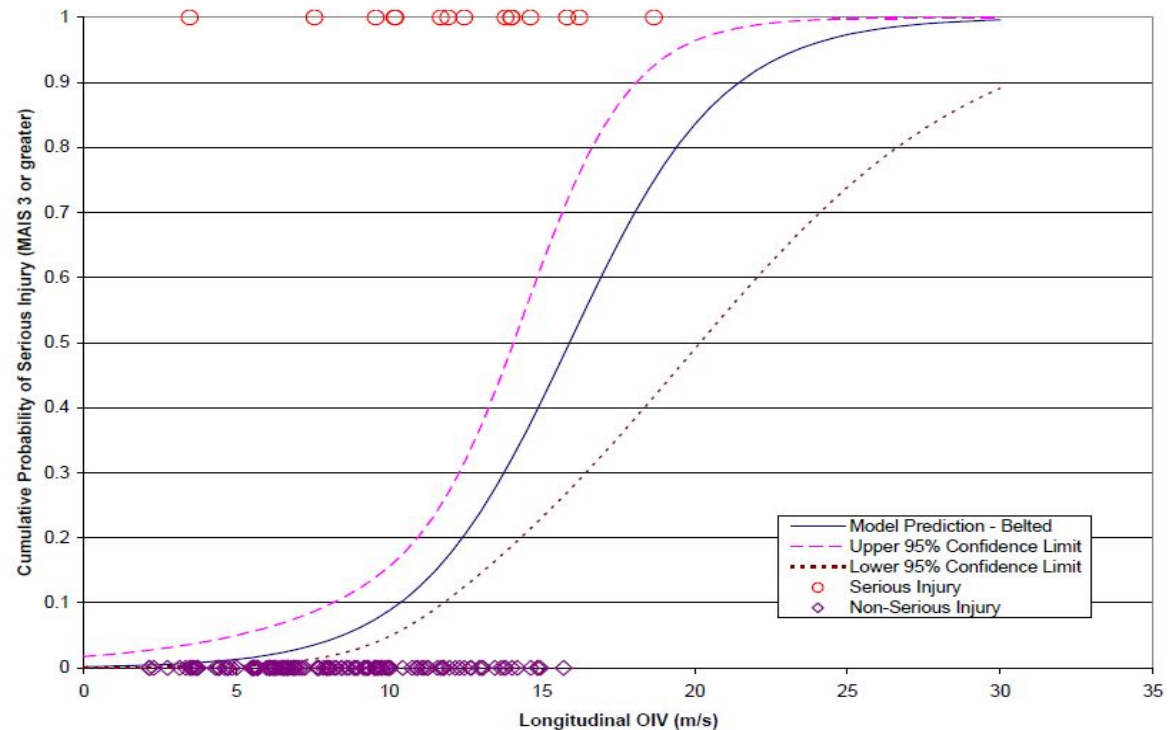
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- Probability of serious occupant injury – Belted and airbag restrained occupants (Gabauer and Gabler, 2006).



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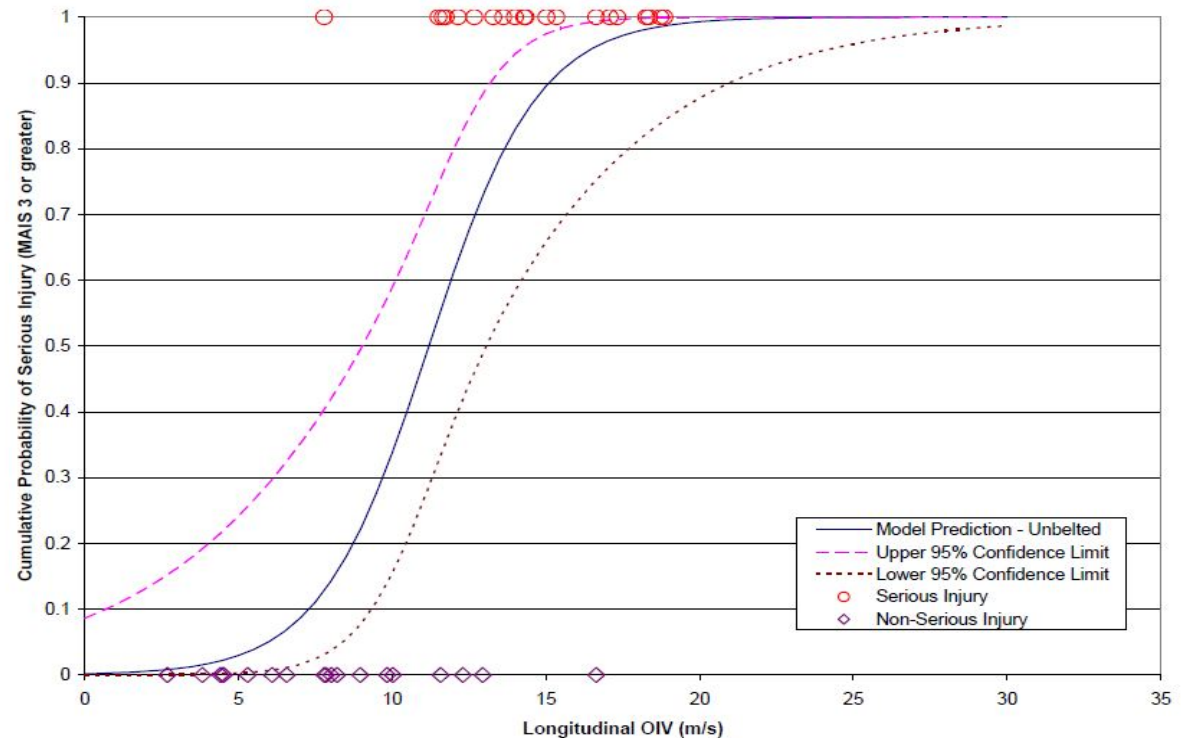
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- Probability of serious occupant injury – Unbelted and airbag restrained occupants (Gabauer and Gabler, 2006).



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- Summary of injury probability based on MASH Values (Gabauer and Gabler, 2006).

	Occupant Impact Velocity Threshold (m s ⁻¹)	Probability of Serious Injury (%)
Belted + Airbag Occupants	9	6
	12	18
Unbelted + Airbag Occupants	9	23
	12	61



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- Lateral impact velocity has not yet been assessed.



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- Evaluate flail-space's model for lateral occupant impact velocity.



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- 1970s and later lateral impact cadaver tests data sought.
- Search was performed with:
 - Science Direct
 - Compendex
 - PubMed
 - SAE International



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- Keywords used in search:
 - Side impact
 - Thorax
 - Thoracic
 - Injury
 - Injury criteria
 - Sled
 - Cadaver
 - Post Mortem Human Surrogate (PMHS)



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- Filters applied:
 - Studies associated cadaver impact velocity to thoracic AIS level.
 - Test method:
 - Included: Heidelberg sled test, dual sled test and pendulum tests.
 - Excluded: Limited stroke impactor and drop tests.
 - Impact wall type:
 - Included: Rigid and padded surfaces.
 - Excluded: None.



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- Filters applied:
 - Impact wall interface:
 - Included: Padded flat wall, rigid flat wall, pendulum and padded thoracic offset wall.
 - Excluded: All other types of wall offsets.
 - Arm location:
 - Included: Side of thorax, anteriorly located and above head.
 - Excluded: None.



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- Test duplication checked.
- Total of 131 test cases identified and used:

	Number of Tests	Test Method	Impact Wall Interface
Cavanaugh et al. (1993)	10	Sled	Rigid and padded
Kallieris & Mattern (1986)	42	Sled	Rigid and padded
Kuppa et al. (2000)	6	Sled	Rigid and padded
Kuppa et al. (2004)	25	Sled	Rigid and padded
Marcus et al. (1983)	11	Sled	Rigid and padded
Melvin et al. (1976)	7	Sled	Rigid and padded
Pintar et al. (1997)	5	Sled	Rigid and padded
Robbins et al. (1979)	9	Sled and pendulum	Rigid and padded
Viano et al. (1989)	16	Pendulum	(Not applicable)



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- Multiple variable logistic regression performed.
- Association between independent variables and thoracic AIS 3+ and AIS 4+ injury sought.
- Dependent variable:
 - First model: Thoracic AIS 3+ injury (dichotomously coded)
 - Second model: Thoracic AIS 4+ injury (dichotomously coded)



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■ Five independent variables:

- Impact velocity

	Minimum	Maximum	Mean
Impact Velocity (m s⁻¹)	3.62	11.94	8.0

- Cadaver age

	Minimum	Maximum	Mean
Cadaver Age (Years)	17	86	52

- Cadaver mass

	Minimum	Maximum	Mean
Cadaver mass (kg)	40.8	107.0	68.1



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- Test method

	Frequency
Sled Test	109
Pendulum Test	22

- Impact interface

	Frequency
Padded Wall	53
Unpadded Wall	78



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- Other variables considered: acceleration, gender and height.
- Independent variables evaluated for their significance for both AIS 3+ and AIS 4+ models.
- Significance was evaluated with Maximum Likelihood Estimate (MLE) p-value test.
- Significance level selected based on MLE p-value of <0.05 .



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- Single variable logistic regression performed to assess association between:
 - Thoracic impact velocity and AIS 3+ thoracic injury.
 - Thoracic impact velocity and AIS 4+ thoracic injury.
- Hosmer and Lemeshow (2008) Goodness-of-Fit used to check the fit.
- Receiver Operator Characteristic (ROC) area under the curve used to determine model's predictive power.



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- Multiple variable logistic regression for AIS 3+ model:

	MLE Estimate	Standard Error	95% CI	MLE p-value
Cadaver Mass	-0.001	0.017	0.959, 1.023	0.5595
Impact Wall Interface	0.820	0.295	1.682, 16.476	0.0054
Test Method	0.0598	0.3917	0.198, 4.777	0.8786
Impact Velocity	0.9626	0.2056	1.777, 3.778	<0.0001
Cadaver Age	0.061	0.0160	1.031, 1.097	0.0001



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- Multiple variable logistic regression for AIS 4+ model:

	MLE Estimate	Standard Error	95% CI	Maximum Likelihood Estimate p-value
Cadaver Mass	-0.01	0.0161	0.963, 1.024	0.6717
Impact Wall Interface	0.829	0.292	1.960, 20.482	0.0045
Test Method	0.0816	0.403	0.518, 17.754	0.8394
Impact Velocity	1.373	0.2512	2.460, 6.769	<0.0001
Cadaver Age	0.0794	0.0185	1.045, 1.125	< 0.0001



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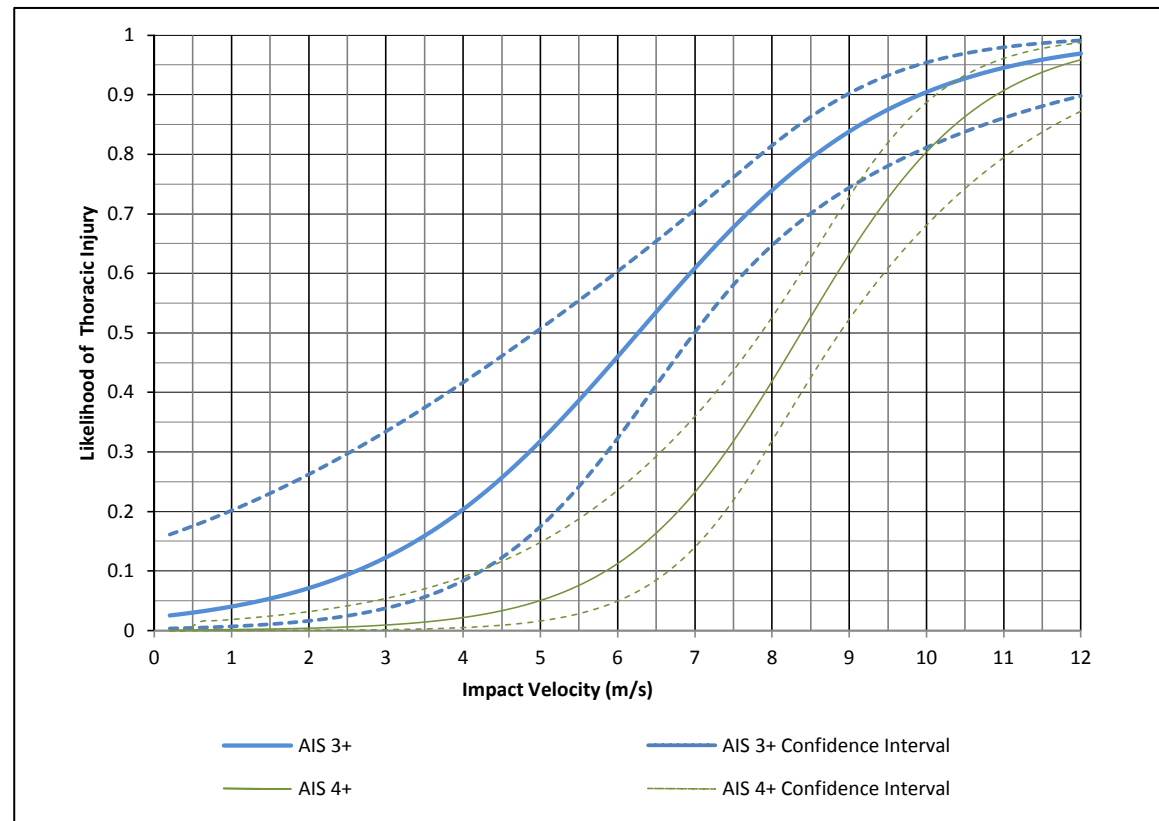
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- Single variable logistic regression AIS 3+ and AIS 4+ model:



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- Hosmer and Lemeshow (2008) Goodness-of-Fit & ROC Area Under the Curve results:

	Hosmer and Lemeshow Goodness-of-fit Test	Degrees of Freedom	Receiver Operator Characteristic Area Under the Curve
AIS 3+ Model	8.9204	8	0.8459
AIS 4+ Model	4.7927	8	0.7795



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- The current flail-space occupant impact values are high.

	Occupant Impact Velocity	Probability of AIS 3+ Injury	Probability of AIS 4+ Injury
Preferred	9 m s ⁻¹	84%	67%
Maximum	12 m s ⁻¹	97%	97%



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- Proposed lateral impact velocity obtained by:
 - Setting sensitivity of 90% of AIS 3+ injury in the ROC classification table.
 - 90% sensitivity corresponds to a thoracic impact velocity of 6.4 m s^{-1} .



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- Proposed flail-space occupant impact values:

Occupant Impact Velocity	Probability of AIS 3+ Injury	Probability of AIS 4+ Injury
6.4 m s ⁻¹	53%	18%



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- Limitations:
 - 6.4 m s^{-1} was obtained from thorax impacts only.
 - Acceleration threshold has not been evaluated.
 - Cadaver arm location.
 - Cadaver age.
 - Pooling of data from multiple studies.



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