Small Overlap Frontal Crashworthiness Evaluation Rating Protocol (Version I)

Rating Guidelines for Restraints and Dummy Kinematics, Injury Measures, and Vehicle Structural Performance

Weighting Principles for Overall Rating

October 2012

INSURANCE INSTITUTE FOR HIGHWAY SAFETY
1005 NORTH GLEBE ROAD ARLINGTON, VA 22201
PHONE 703/247-1500 FAX 703/247-1678
http://www.highwaysafety.org

INTRODUCTION

Vehicle performance in the Insurance Institute for Highway Safety's (IIHS) small overlap frontal test is rated based on three categories: restraints and dummy kinematics, dummy injury measures, and vehicle structural performance. Each category is described in detail in this document. The weighting of each individual rating to form an overall rating is located in the *Weighting Principles for Overall Rating* section.

RESTRAINTS AND DUMMY KINEMATICS RATING

The injury measures obtained from a 50th percentile male Hybrid III dummy seated in a standard driver's position are good indicators of the injury risk for a person of about the same size in the same seating position. However, good injury results for the standard dummy and seating position are not sufficient by themselves to indicate low injury risk for drivers of different sizes and/or seating positions in the same crash. For example, the dummy's head moving outside the occupant compartment and/or the steering column moving excessively during the crash indicate the potential for injuries that are not necessarily captured by recorded injury measures on a single dummy.

To provide some assessment of the potential injury risk for drivers of other sizes and/or seating positions, IIHS reviews the kinematics (high-speed video analysis) of the 50th percentile male dummy during the small overlap frontal crash, together with the performance of the restraint system (seat belts, airbags, steering column, seat, and door). The restraints and dummy kinematics rating system is based on demerits, with every vehicle beginning with a good rating. The test is intended to determine if there are reasons to lower the rating. Details of the demerit scheme are described in the definitions below and summarized in Table 1.

Definitions

Frontal Head Protection

- Stable frontal airbag interaction (0 demerits, see Figure 1) means the dummy moves forward into a fully-deployed airbag and then returns directly to the seat during rebound, with the head and body staying within the original extended perimeter of the airbag. If the dummy's head begins to move off the airbag into the gap between the airbag and door, this is not considered stable interaction and is subject to demerits unless there is supplemental protection to assure that the head does not reach hard structure (e.g., a side airbag that extends to cover the A-pillar or an A-pillar airbag that prevents the head from going through the gap or contacting hard structure that might intrude into the gap). Lack of assured head protection from a frontal airbag can result in 1 or 2 demerits:

  – Partial frontal airbag interaction (1 demerit, see Figures 2 and 3) is scored when the head receives significant restraint from the frontal airbag but does not stay within its original extended perimeter and there are no other countermeasures to prevent head contact with hard structures forward of the airbag. Partial interaction also may be scored if the airbag provides little additional frontal protection (e.g., there is little airbag volume between the dummy and interior structures) when the dummy reaches maximum forward excursion.

  – Minimal frontal airbag interaction (2 demerits, see Figures 4 and 5) is scored if the head moves into the gap between the door and frontal airbag with little or no restraint from the airbag and there are no other countermeasures to prevent head contact with hard structures forward of the airbag.

- Excessive lateral steering wheel movement (1 demerit) is scored if the center of the steering wheel moves more than 10 cm laterally. Note that if the steering wheel moves more than 15 cm laterally, an additional demerit is scored for compromised chest protection (see below).

- Two or more hard head contacts with structure (1 demerit) is carried over in concept from IIHS's moderate overlap frontal test and is scored when two distinct head contacts occur registering a resultant head acceleration greater than 70 g. Note that, as in the moderate overlap test, a single hard head contact results in one downgrade of the head injury rating (from good to acceptable, acceptable to marginal, etc.) but no demerit for restraints and dummy kinematics. Also, contact with the B-pillar during rebound is disregarded entirely because of removal of the head restraint prior to testing.

- Late or nondeployment of the frontal airbag (an automatic poor for restraints and dummy kinematics) is scored if the frontal airbag does not deploy or does not deploy in a timely manner. This same demerit is coded in IIHS's moderate overlap frontal test.

Lateral Head Protection

- Side head protection airbag deployment with sufficient forward coverage (0 demerits) means that a side airbag (e.g., roof-mounted curtain, door-mounted curtain, or seat-mounted thorax airbags with head protection) deploys with air chambers that extend forward to at least the orthogonal vertical plane intersecting the center of the steering wheel in its forwardmost telescoping position (if adjustable). Lack of lateral head airbag protection can result in 1 or 2 demerits:

  – Side head protection airbag deployment with limited forward coverage (1 demerit) is scored when the side airbag deploys but does not extend coverage to the orthogonal vertical plane intersecting the center of the steering wheel.

  – No side head-protection airbag deployment (2 demerits) is scored when the airbag does not deploy, deploys too late to provide head protection, or deploys in a manner that does not provide lateral head protection (e.g., allows the dummy's head to move outboard of it).

- Excessive head lateral movement (1 demerit, see Figure 6) is scored if most of the head moves outside of the precrash plane of the driver's side window. This same demerit is coded in IIHS's moderate overlap frontal test.

Frontal Chest Protection

- Excessive vertical steering wheel movement (1 demerit) is scored if the steering wheel center moves more than 10 cm in the vertical direction.

- Excessive lateral steering wheel movement (1 demerit) is scored when the lateral movement of the steering wheel is greater than 15 cm. This demerit is in addition to the demerit scored in the *Frontal Head Protection* section when the lateral steering wheel movement is greater than 10 cm.

Occupant Containment and Miscellaneous

- Excessive occupant forward excursion (1 demerit) is scored if the maximum shoulder belt spool out exceeds the precrash belt position or lap belt slack greater than 100 mm is observed after the crash.

- Occupant burn risk (1 demerit) is scored if the expulsion of hot airbag gases causes burning or melting of dummy body parts or clothing. This same demerit is coded in IIHS's moderate overlap frontal test.

- Seat instability (1 demerit) is scored if the seat orientation and related occupant position is compromised due to floorpan or seat riser deformation. This typically is characterized by 6 cm or more of relative vertical motion between any of the seat attachment points to the floor or other distortions that result in the seatback moving outboard and/or forward. This same demerit is coded in IIHS's moderate overlap frontal test.

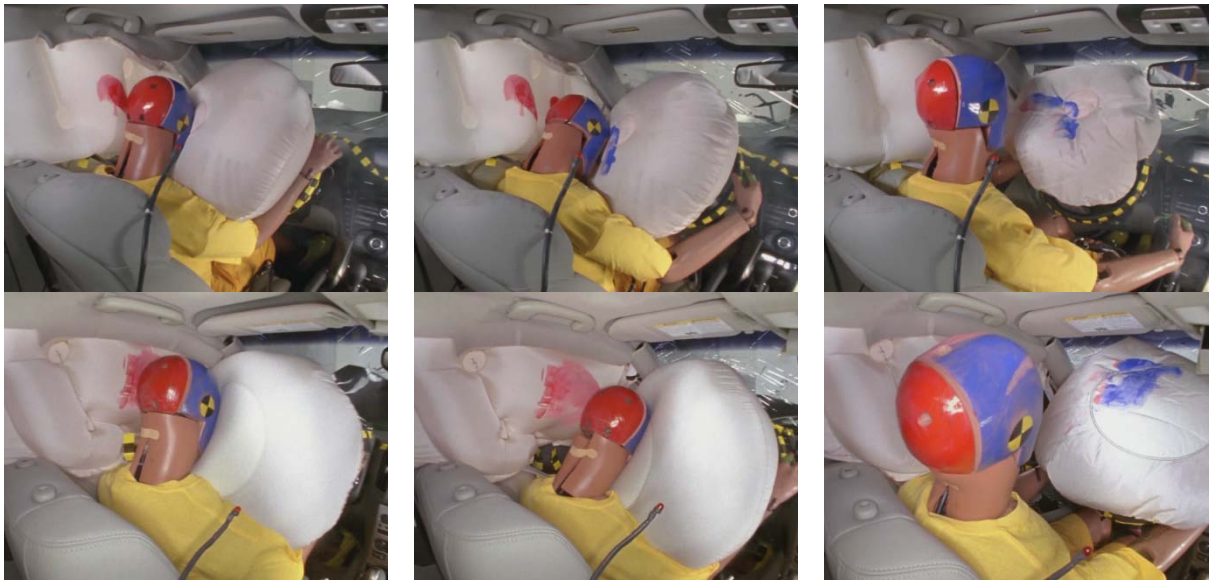
- Seat attachment failure (an automatic poor for restraints and dummy kinematics) is scored if the seat bottom breaks loose or moves significantly in its tracks. This same demerit is coded in IIHS's moderate overlap frontal test.

- Vehicle door opening (an automatic poor for restraints and dummy kinematics) is scored if the door opens or becomes detached. This same demerit is coded in IIHS's moderate overlap frontal test.

Table 1
Demerits for Restraints and Dummy Kinematics

Frontal head protection	
Stable frontal airbag interaction, OR	0 demerits
Partial frontal airbag interaction, OR	1 demerit
Minimal frontal airbag interaction	2 demerits
Excessive lateral steering wheel movement (>10 cm)	1 demerit
Two or more hard head contacts with structure	1 demerit
Late deployment or non deployment of frontal airbag	Automatic poor
Lateral head protection	
Side head protection airbag deployment with sufficient forward coverage, OR	0 demerits
Side head protection airbag deployment with limited forward coverage, OR	1 demerit
No side head protection airbag deployment	2 demerits
Excessive head lateral movement	1 demerit
Frontal chest protection	
Excessive vertical steering wheel movement (>10 cm)	1 demerit
Excessive lateral steering wheel movement (>15 cm)	1 demerit
Occupant containment and miscellaneous	
Excessive occupant forward excursion	1 demerit
Occupant burn risk	1 demerit
Seat instability	1 demerit
Seat attachment failure	Automatic poor
Vehicle door opening	Automatic poor
Overall Restraint and Dummy Kinematics rating	
Good	0-1 demerits
Acceptable	2-3 demerits
Marginal	4-5 demerits
Poor	6+ demerits

Figure 1
Examples of Stable Frontal Airbag Interaction –
2012 Acura TL (CEN1214) top, 2012 Infiniti G25 (CEN1209) bottom



The dummy's movement in these tests was well controlled. The dummy's head loaded the frontal airbag and stayed in contact with the airbag within its original extended perimeter until the dummy rebounded in the rearward direction.

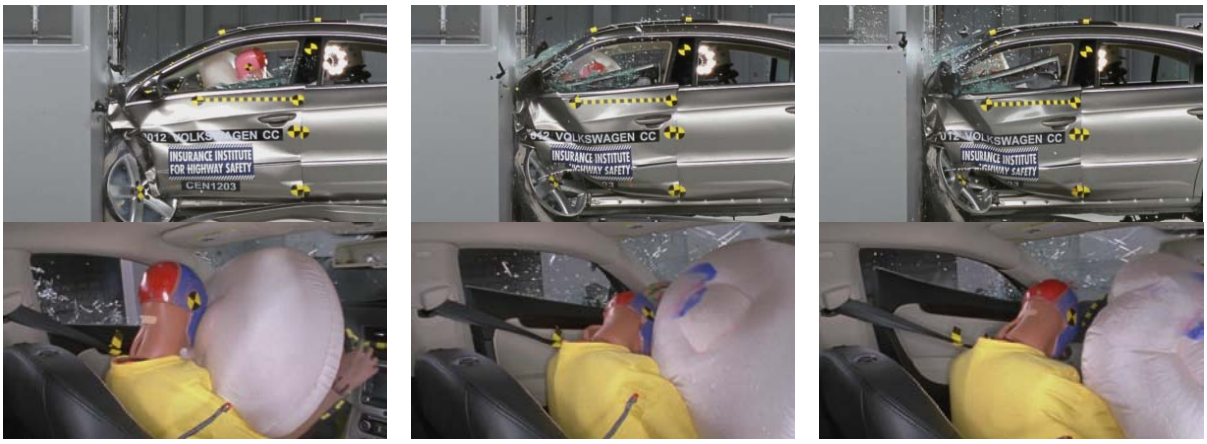
Figure 2
Example of Partial Frontal Airbag Interaction – 2012 Volvo S60 (CEN1207)

The dummy's head contacted the frontal airbag but slid left into a gap providing no support for the head. This gap mainly was due to the narrow, asymmetric frontal airbag. There were no other countermeasures to prevent head contact with hard structures forward of the airbag.

Figure 3
Example of Partial Frontal Airbag Interaction – 2012 Mercedes C250 (CEN1211)

The airbag provided significant support to the head early in the crash, but the dummy continued to move laterally outside of the original extended perimeter of the airbag, and there was little airbag volume between the dummy's head and interior structures. The dummy contacted the roof rail during rebound. There were no other countermeasures to prevent head contact with hard structures forward of the airbag.

Figure 4
Example of Minimal Frontal Airbag Interaction – 2012 Volkswagen CC (CEN1203)



The dummy's head barely contacted the frontal airbag before sliding off the left side and undergoing additional forward excursion. There were no other countermeasures to prevent head contact with hard structures forward of the airbag.

Figure 5
Example of Minimal Frontal Airbag Interaction – 2012 Lincoln MKZ (CEN1210)

The dummy's head completely missed the frontal airbag, and there were no other countermeasures to prevent head contact with hard structures forward of the airbag.

Figure 6
Example of Excessive Head Lateral Movement – Lexus IS 250 (CEN1205)

The outboard motion of the dummy, with respect to the vehicle interior, combined with the absence of a side head protection airbag allowed the most of the dummy's head to move outside of the precrash window plane.

INJURY RATING

Injury measures obtained from an instrumented 50th percentile male Hybrid III dummy in the driver seat are used to determine the likelihood that an occupant would have sustained significant injury to various body regions. Twenty-nine different measures are recorded in each of the small overlap crash tests:

- Head acceleration (three directions from head's center of gravity)
- Axial force, anterior-posterior force, lateral-medial force, and anterior-posterior bending moment acting at the connection between the dummy's head and neck
- Thoracic spine acceleration (three directions)
- Sternum compression
- Femur axial force (each leg)
- Tibia-femur displacement (each leg)
- Tibia transverse bending moments (upper and lower, each leg)
- Tibia axial force (each leg)
- Foot acceleration (two directions, each foot)

The 29 measures are grouped into four body regions: head and neck, chest, thigh and hip, and legs and feet. Four injury parameters are used to evaluate protection for the head and neck, three parameters for the chest, one for each thigh and hip, and five parameters for each leg and foot.

Each body region receives an injury protection rating of good, acceptable, marginal, or poor based on the injury parameters for that region. For any body region to receive a good rating, the scores for all injury parameters in that region must indicate good results. If any parameter indicates an acceptable result, then the rating for that body region is acceptable. If any parameter has a marginal result, then the rating for that body region is marginal. Thus the overall injury rating for any body region is the lowest (worst) rating scored for an injury parameter within that region. The thigh/hip and leg/foot ratings are based on the lowest rating scored from either the left or right limb.

Table 2 shows the injury parameter ranges associated with the possible ratings: good, acceptable, marginal, and poor. Injury results that round to the values shown in Table 2 will receive the better of the two ratings they separate. With some exceptions (e.g., chest acceleration), the borders between acceptable and marginal ratings for a given injury parameter correspond to published injury assessment reference values (IARV) for significant injury related to that parameter. Acceptable ratings correspond to measures somewhat below (better than) the IARVs, and good ratings correspond to measures well below the IARVs. Similarly, marginal ratings correspond to measures just above (worse than) the IARVs, and poor ratings correspond to measures well above the IARVs. Information about the origin and associated injury risks for each of the injury measures in the head/neck, chest, and leg/foot are described in the moderate offset frontal test *Guidelines for Rating Injury Measures* (IIHS, 2009). Additional injury criteria for the head and thigh/hip are described below.

Head and Neck

In addition to HIC-15, the maximum vector resultant acceleration of the head is considered. A maximum head acceleration that exceeds 70 g and is caused by contact between the head and a hard surface of the vehicle interior can result in lowering the head injury rating one level (details are provided in Figure 7).

A head/neck rating that is otherwise good will be lowered to acceptable if the neck tension, compression, or shear (X direction) forces fall outside the force duration corridors specified by Mertz (1984). The force duration corridor limits are shown in Figures 8-10.

Thigh and Hip

Thigh and hip injury risk is evaluated on the basis of the knee-thigh-hip (KTH) injury criteria developed by Rupp et al. (2009). The KTH criteria uses a combination of peak compressive force and impulse recorded at each femur to determine the risk of an AIS 2+ knee/distal femur fracture and AIS 3+ hip fracture. A relatively low level of risk of KTH injury is required to obtain a good thigh/hip injury rating because of the greater threat to life and long-term disability associated with fractures to the thigh (due to proximity of femoral artery) and hip.

The KTH impulse is calculated by integrating the femur force from the start of femur compression (the time that force last equals zero prior to the peak compressive force) to the time after the peak force when compressive force first equals 4050 N (Figure 11). A KTH injury risk of 5 percent marks the border between an IIHS rating of good and acceptable. The force impulse corridor limits are shown in Figure 12.

Table 2
Injury Parameter Cutoff Values Associated with Possible Injury Protection Ratings

Body Region	Parameter	IARV	Good – Acceptable	Acceptable – Marginal	Marginal – Poor
Head and neck	HIC-15	700	560	700	840
	N_{ij}	1.00	0.80	1.00	1.20
	Neck axial tension (kN)*	3.3	2.6	3.3	4.0
	Neck compression (kN)*	4.0	3.2	4.0	4.8
Chest	Thoracic spine acceleration (3 ms clip, g)	60	60	75	90
	Sternum deflection (mm)	–50	–50	–60	–75
	Sternum deflection rate (m/s)	–8.2	–6.6	–8.2	–9.8
	Viscous criterion (m/s)	1.0	0.8	1.0	1.2
Thigh and hip	Knee-thigh-hip injury risk		5%	15%	25%
Leg and foot	Tibia-femur displacement (mm)	–15	–12	–15	–18
	Tibia index (upper, lower)	1.00	0.80	1.00	1.20
	Tibia axial force (kN)	–8.0	–4.0	–6.0	–8.0
	Foot acceleration (g)	150	150	200	260

*Neck axial force duration corridors are shown in Figures 8 and 9.

Figure 7
Flowchart: Influence of Multiple Impacts on Head/Neck Injury Rating

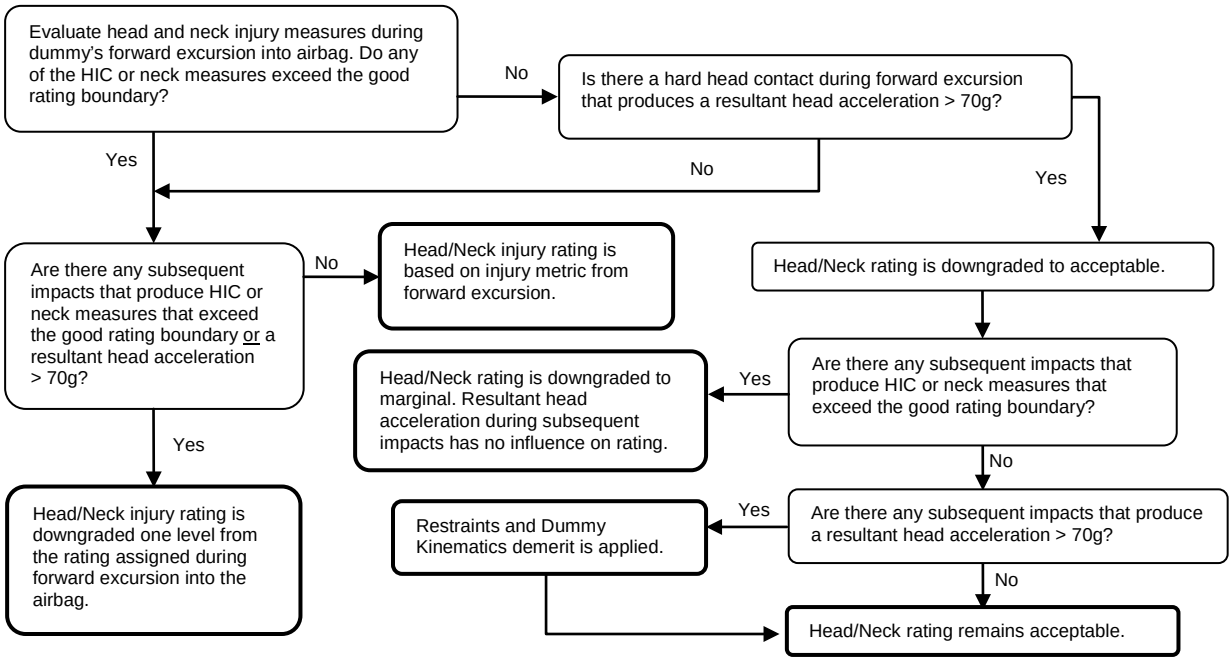


Figure 8
Force Duration Corridor for Neck Tension Force

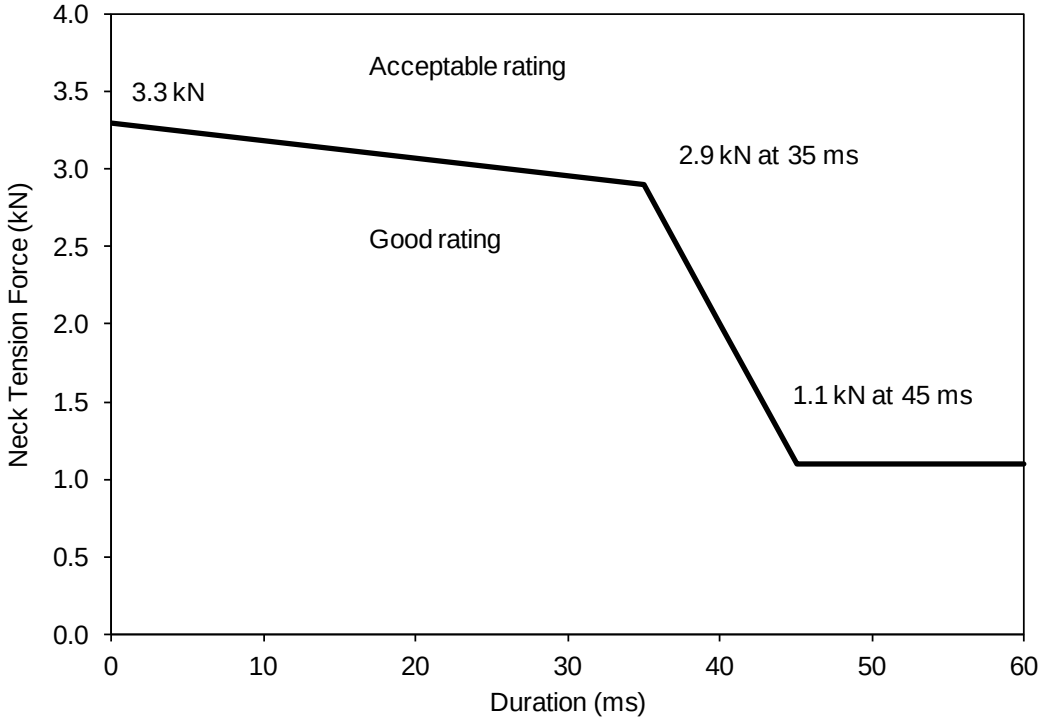


Figure 9
Force Duration Corridor for Neck Compression Force

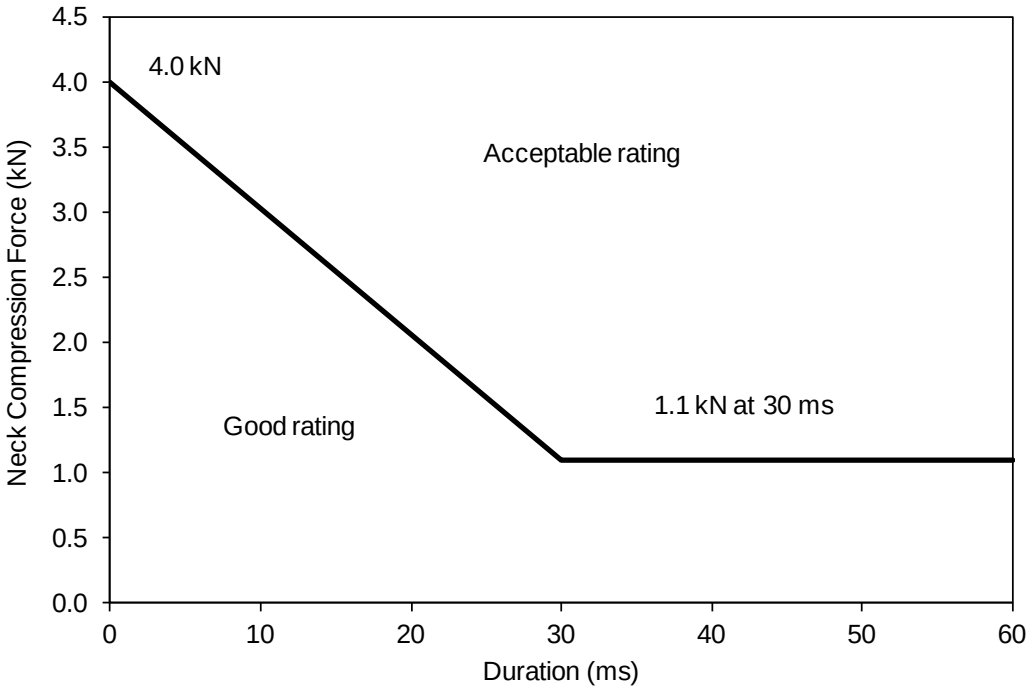


Figure 10
Force Duration Corridor for Neck Shear Force

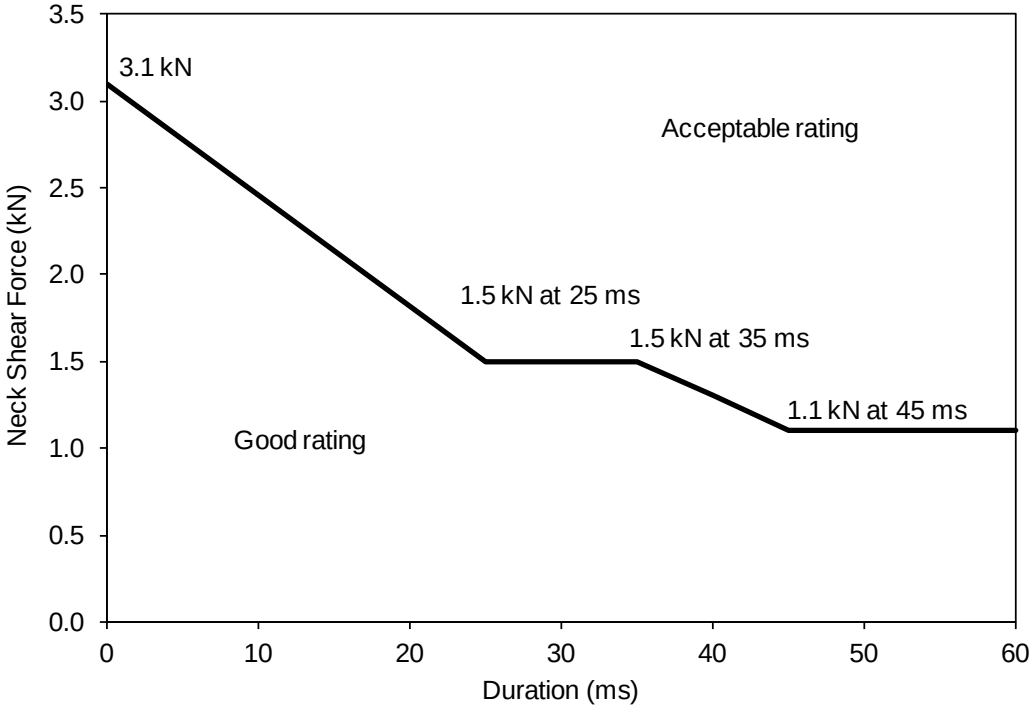


Figure 11
Integration Limits for Calcualtion of Femur Impulse for Hybrid III 50th Dummy

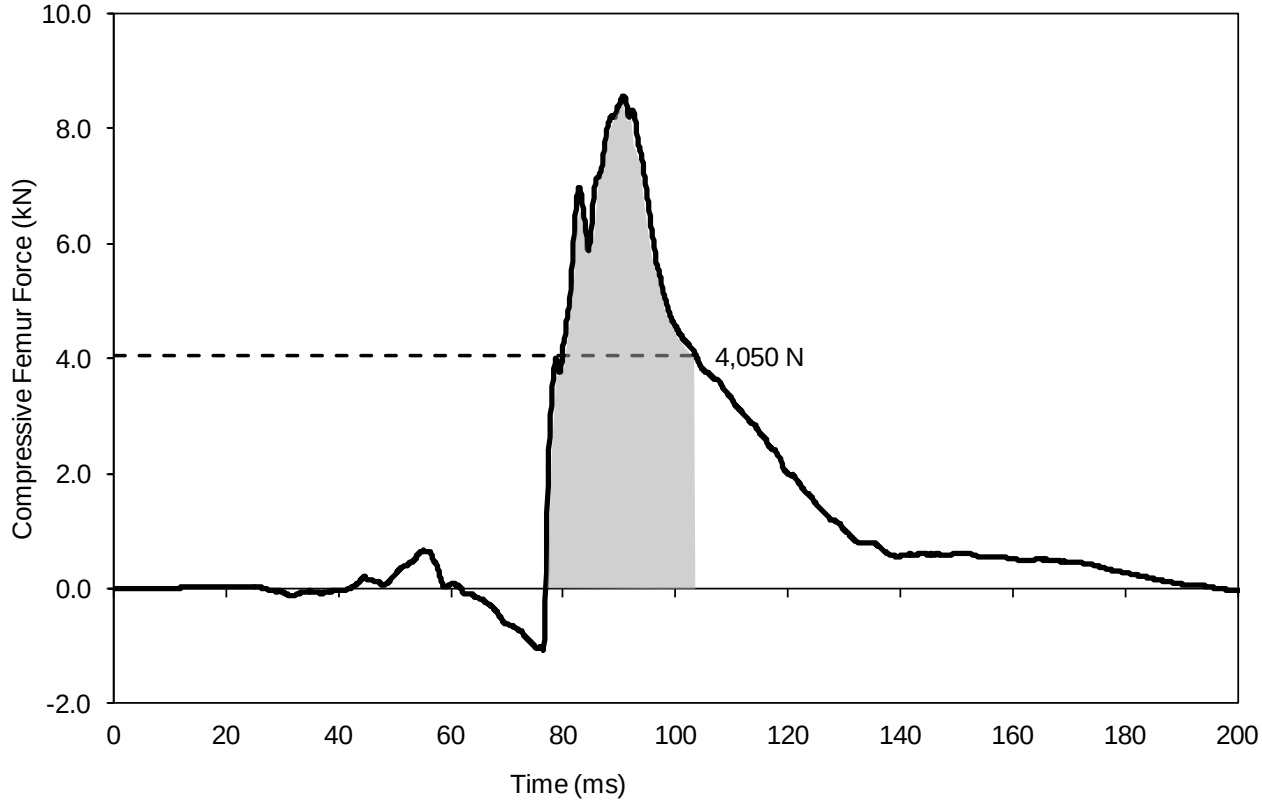
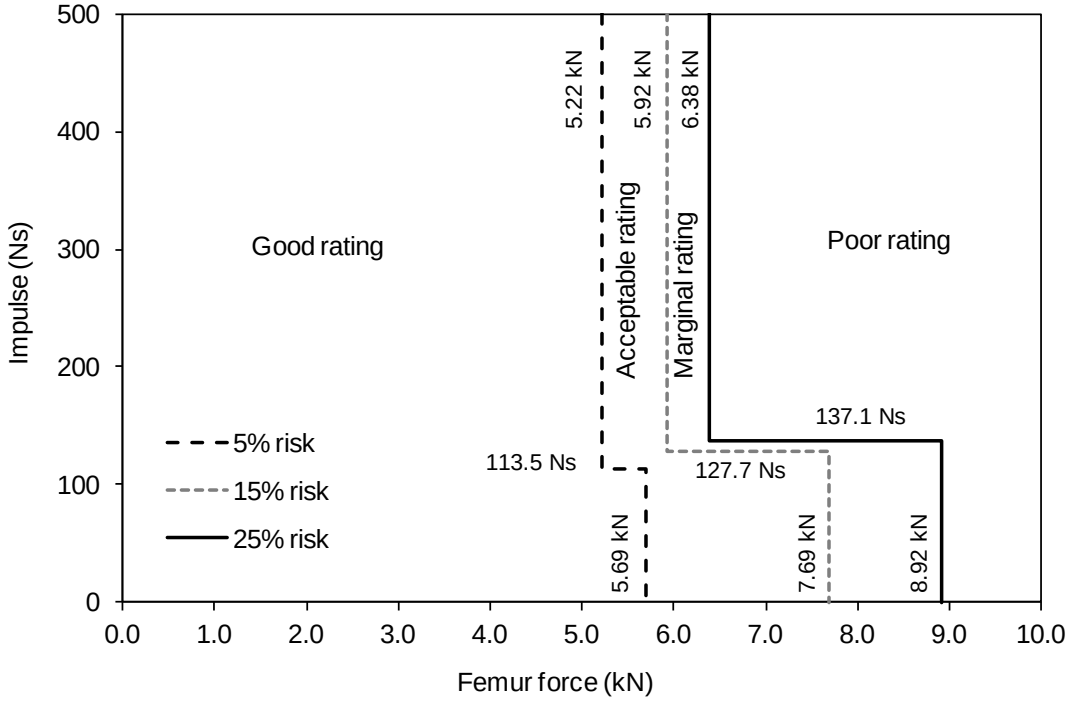


Figure 12
Force and Impulse Corridor Limits for Knee-Thigh-Hip Injury Risk



VEHICLE STRUCTURAL RATING

Injury measures recorded on a 50th percentile male Hybrid III driver dummy are used as one indicator of crashworthiness performance. These measures are not the only indicators, however, because although high dummy injury measures recorded in the small overlap test mean some people in similar real-world crashes would sustain significant injuries, the converse is not true. Low dummy injury measures do not necessarily mean there is no risk of significant injury to people in similar crashes. This is because the forces experienced by people of different sizes from the test dummy, or who adjust their seats in different positions, can be quite different, especially when there is significant collapse of or intrusion into the occupant compartment. Major deformation of or intrusion into the compartment is a good predictor of injury risk for people in similar crashes, even when dummy injury measures are low. For this reason, IIHS evaluates the structural integrity of the occupant compartment, or safety cage, during the small overlap test and uses this as an important additional indicator of crashworthiness performance. Specific measurements of intrusion into the occupant compartment are used to assess this aspect of performance.

Measurements of Safety Cage Deformation

The measurements used by IIHS represent the residual movement (precrash/postcrash difference) of interior structures in front of the driver dummy. The movement of seven points on the vehicle interior plus three points along the door frame are the foundations of IIHS's structural ratings. The points are separated into two regions: the lower occupant compartment and the upper occupant compartment. The lower occupant compartment includes the lower hinge pillar, footrest, left toepan, brake pedal, parking brake pedal, and rocker panel measurements. The upper occupant compartment includes the steering column, upper hinge pillar, upper dash, and left instrument panel (knee bolster). The precrash and postcrash locations of these points are measured with respect to a coordinate system originating on the driver door striker. The measured movement of all points is adjusted to reflect movement with respect to the driver seat, which is represented by the location of of the driver seat rear attachments to the vehicle

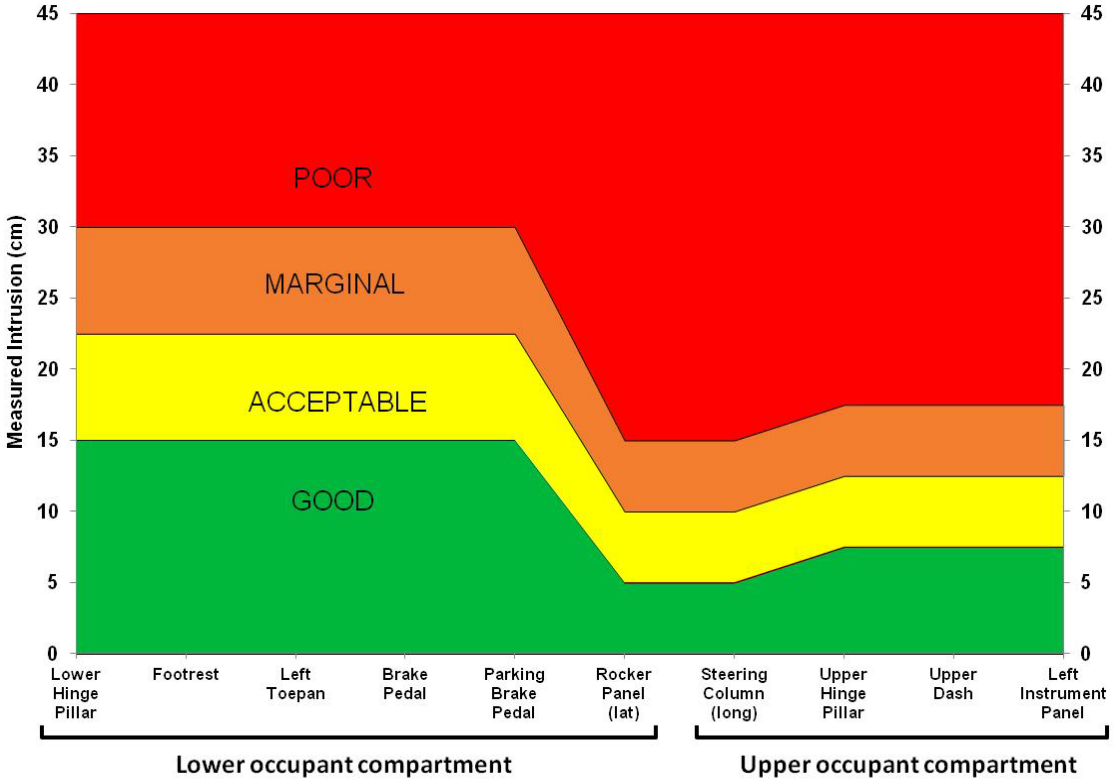
floor. This adjustment accounts only for movement in the longitudinal direction. Thus, longitudinal movement of the driver seat with respect to the reference coordinate system is not reflected in evaluations of vehicle structure. A further adjustment may be made to the brake or parking brake pedal intrusion in the event of pedals that "break away" or otherwise deform to limit intrusion. If a pedal breaks away, or deforms, under reasonable force, the measured intrusion is taken from the deformed position.

Evaluation of Intrusion Measurements

The initial structural rating is based on comparison of intrusion measurements with rating guidelines (Figure 13). This rating may then be modified (downgraded) on the basis of additional observations about the structural integrity of the safety cage.

The X-Y-Z vector resultant movements of the lower hinge pillar, footrest, left toepan, brake pedal, parking brake pedal, upper hinge pillar, upper dash, and instrument panel, are used for comparison with the rating guidelines. For all points, if the X movement is forward (away from the driver seat), then only the Y-Z vector resultant movement is used. For the upper hinge pillar, lower hinge pillar, rocker panel, and parking brake pedal locations, if the Y movement is leftward (outboard), then only the X-Z vector resultant movement is used. Only the inboard movement (Y) of the rocker panel is compared with the guidelines. Only the rearward movement (X) of the steering column is compared with the guidelines. The upper hinge pillar rating is the maximum of three locations on the upper hinge pillar. The lower hinge pillar rating is the maximum of three locations on the lower hinge pillar. The rocker panel rating is the average of three locations on the rocker. Figure 13 shows the ranges for these measurements and associated structural ratings.

Figure 13
Guidelines for Rating Occupant Compartment Intrusion



The lower occupant compartment and the upper occupant compartment each receive a subrating. Lower or upper intrusion measures all falling in the area labeled good will receive a good structural subrating if no additional observations lead to a downgraded rating. Similarly, vehicles with all intrusion measures falling into one of the other three zones shown in Figure 13 will receive an acceptable, marginal, or poor subrating. When intrusion measurements fall in different rating bands, the subrating generally reflects the band with the most measures. However, the subrating will not be more than one rating level better than the worst measurement. For example, a vehicle with a poor measurement for the left instrument panel would not score better than marginal for upper occupant compartment structure, even if all other upper occupant compartment measured values were good. Where there are ties, with half the measurements in one band and half in another, the subrating will be that of the worse band. Intrusion measurements falling on a boundary value will be considered to fall in the band that represents the better rating.

The overall structural rating is the worse rating of the lower and upper occupant compartment subratings, if no additional observations lead to a downgraded rating. For example, a vehicle with a lower occupant compartment subrating of acceptable and an upper occupant compartment subrating of marginal will receive an overall structural rating of marginal.

Qualitative Observations Leading to Downgraded Structure Rating

Some patterns of deformation are less desirable regardless of intrusion measurements. For example, a footwell that collapses in a way that traps the dummy's feet represents a greater injury risk than a footwell with similar intrusion measurements that does not trap the dummy's feet. Another example of a potentially modifying observation involves intrusion into the safety cage of some component or structure not captured by the ten measurement points (e.g., complete tearing of hinge pillar). If a modifying observation is made, then the overall structural rating will be lowered one level from the rating suggested by the intrusion measurements (e.g., from acceptable to marginal).

Fuel and High-Voltage System Integrity Leading to Downgraded Rating

If a significant fuel leak or compromise of a high-voltage system (i.e., electric drivetrain) is observed during a test, both the structural and overall ratings may be downgraded to poor. Significant fuel leaks are those that exceed the leak rate allowed following tests conducted to assess fuel system integrity under U.S. Federal Motor Vehicle Safety Standard (FMVSS) 301.

High-voltage systems must meet the electrolyte spillage, battery retention, and electrical isolation requirements in FMVSS 305 to avoid downgrade. The following summarizes these requirements:

- **Electrolyte spillage:** No more than 5 liters of electrolyte from propulsion batteries shall spill outside the passenger compartment and no visible trace of electrolyte shall spill into the passenger compartment.

- **Electric energy storage/conversion system retention:** Electric energy storage/conversion devices shall remain attached to the vehicle by at least one component anchorage, bracket, or any structure that transfers loads from the device to the vehicle structure, and electric energy storage/conversion devices located outside the occupant compartment shall not enter the occupant compartment.

- **Electrical isolation:** After the test, one of the following requirements must be met:

  – Electrical isolation between the high-voltage source and vehicle chassis must be greater than or equal to 500 ohms/volt for all high-voltage sources without continuous monitoring of electrical

isolation. The isolation must be greater than or equal to 100 ohms/volt for all DC high-voltage sources with continuous monitoring of electrical isolation; or

– The voltages from high-voltage sources measured according to the procedure specified in FMVSS 305 must be less than or equal to 30 VAC for AC components, or 60 VDC for DC components.

WEIGHTING PRINCIPLES FOR OVERALL RATING

Components

The weighting scheme is comprised of ratings for the following components: vehicle structure, occupant head/neck, chest, thigh/hip, and leg/foot injury measures, and restraints and dummy kinematics.

General Principles of Weighting System

The rating system is based on demerits, with every vehicle beginning with a good overall rating. The test is intended to determine if there are reasons to lower the rating. The demerit scheme that matches these principles is given in Table 3.

Table 3
Weighting of Individual Components
IIHS Crashworthiness Evaluation –Small Overlap Frontal Crash Test

	Rating			
Component	**Good**	**Acceptable**	**Marginal**	**Poor**
Vehicle structure	0	2	6	10
Head and neck	0	2	10	20
Chest	0	2	10	20
Thigh and hip	0	2	6	10
Leg and foot	0	1	2	4
Restraints and dummy kinematics	0	2	6	10
Overall rating cutoffs	**0-3**	**4-9**	**10-19**	**20+**

Ratings for head/neck and chest are based on risk of life-threatening injuries. A poor rating in either area is a serious demerit that cannot be overcome.

Small overlap frontal testing is intended to assess structural performance. Marginal or poor structural performance counts very heavily, though not as heavily as head/neck or chest injury measures.

Injuries to the thigh and hip are based on the risk of potentially life-threatening injuries. Marginal or poor ratings in these injury areas count heavily, though not as heavily as head/neck or chest injury measures.

Injuries to the legs typically are not life threatening. Marginal and poor ratings in these injury areas typically result in fewer demerits.

Restraints and dummy kinematics receives the same weight as structure. It is intended to evaluate the robustness of the restraint system and risks that are not captured by dummy injury measures or structural performance assessments. Additionally, it raises concerns about serious risk of injury to other size occupants or occupants seated differently.

REFERENCES

Insurance Institute for Highway Safety. 2009. Frontal Moderate Overlap Crashworthiness Evaluation Guidelines for Rating Injury Measures. Arlington, VA.

Mertz, H.J. 1984. Injury assessment values used to evaluate Hybrid III response measurements. Comment to the National Highway Traffic Safety Administration concerning Federal Motor Vehicle Safety Standard 208, Occupant Crash Protection. Enclosure 2 of Attachment 1 of Part III of General Motors Submission USG 2284; Docket Document No. 74-14-N32-1666B, March 24, 1984. Washington, DC: U.S. Department of Transportation.

Rupp, J.D.; Reed, M.P.; Miller, C.S.; Madura, N.H.; Klinich, K.D.; Kuppa, S.M.; and Schneider, L.W. 2009. Development of new criteria for assessing the risk of knee-thigh-hip injury in frontal impacts using Hybrid III femur force measurements. *Proceedings of the 21st International Technical Conference on the Enhanced Safety of Vehicles (Paper 09-0306).* Washington, DC: National Highway Traffic Safety Administration.

APPENDIX A

Document Revision History

Version I, October 2012

- Modified the list of possible demerits for Restraints & Dummy Kinematics by removing a demerit for "No side thorax airbag protection" and renaming the "Frontal and lateral chest protection" category to "Frontal chest protection."
- The flowchart describing impacts on head/neck injury rating (Figure 7) was revised to reflect the weighting of demerits for Restraints & Dummy Kinematics.