

Submitted for recognition as an American National Standard

## INJURY CALCULATIONS GUIDELINES

1. **Scope**—This SAE Information Practice describes numerical methods used to process impact test data. Typically used calculations and algorithms are described. For those calculations that are described in other sources, the relevant documents are referenced.

### 2. References

2.1 **Applicable Publications**—The following publications form a part of this specification to the extent specified herein. Unless otherwise specified, the latest issue of SAE publications shall apply.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J211—Instrumentation for Impact Test

SAE J1733—Sign Convention for Vehicle Crash Testing

SAE #880656—A Review and Evaluation of Various IIC Algorithms, by Chou, Howell, and Chang.

SAE #930100—An Evaluation of Various Viscous Criterion Computational Algorithms, by Chou, Lin and Lim.

2.1.2 FEDERAL PUBLICATIONS—Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

FMVSS 201—Code of Federal Regulations, Title 49, Section 571.201—Occupant Protection in Interior Impact

FMVSS 203—Code of Federal Regulations, Title 49, Section 571.203—Impact Protection for the Driver from the Steering Control System

FMVSS 208—Code of Federal Regulations, Title 49, Section 571.208—Occupant Crash Protection

FMVSS 214—Code of Federal Regulations, Title 49, Section 571.214—Side Door Strength

2.1.3 OTHER PUBLICATION

"Anthropomorphic Test Devices," by Mertz, in Accidental Injury, Biomechanics and Prevention, Springer Verlag, 1993.

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**3. Calculations**—The calculations described are typically performed on impact test data. All data should be filtered per SAE J211 prior to executing calculations herein. Some of the calculations are described in the Federal Motor Vehicle Safety Standards (FMVSS). FORTRAN implementations of calculations required by the FMVSS are available from the National Highway Transportation Safety Administration (NHTSA), Washington, D.C., USA, c/o Office of Crashworthiness Research, (202) 366-4850.

**3.1 Integration and Differentiation**—Many numerical methods are available for integration and differentiation, from simple rectangular and trapezoidal rules to much more sophisticated techniques. The simplest way to verify that the method you choose is acceptable is to make sure that your algorithm transposes, i.e., when you integrate and then differentiate, or differentiate and then integrate, that you get back your original data set. Note that any numerical integration routine will yield erroneous results if there is a DC offset in the data set.

**3.2 Relative Velocity and Displacement for Rectilinear Motion**—Relative velocity and relative displacement between two objects can be calculated from the acceleration of the objects using numerical integration. Two procedures exist to determine the relative difference in velocity or displacement between two objects whose accelerations have been measured.

- a. Subtract the two accelerations and integrate the difference to get the relative velocity. Integrate again to get the relative displacement.
- b. Integrate each acceleration to get the velocity of each object, and then subtract the velocities to get relative velocity. To get relative displacement, double-integrate each acceleration to get the distance that each object traveled, then take the difference of the displacements to get relative displacement.

For the relative velocity and displacement calculations to be valid, the acceleration of each object must return to zero at the end of the test. In addition, the axes of the two objects must remain parallel to each other during the test, or the angular difference between the two accelerations must be used in the calculations of the relative velocities and displacements. In general, an Anthropomorphic Test Devices (ATD) head X, chest X, and pelvic X channels do not remain parallel to each other or to the vehicle frame during an impact test.

**3.3 Moment about the Occipital Condyle**—The neck load cells used in ATD measure moments about the X and Y axes. The X and Y axes of the load cell are displaced from the axes of the occipital condyle. Independent of the reported filter class of the force data its filter class must be adjusted to be consistent with the moment data prior to attempting this calculation. To calculate the moments about the occipital condyle, Equations 1 and 2 should be used:

$$M_{ocy} = M_y - (D * F_x) \quad (\text{Eq. 1})$$

$$M_{ocx} = M_y + (D * F_x) \quad (\text{Eq. 2})$$

where:

$M_{ocy}$  = moment Y about the occipital condyle

$M_{ocx}$  = moment X about the occipital condyle

$F_x$  = load cell force output in the X direction in Newtons

$F_y$  = load cell force output in the Y direction in Newtons

$M_y$  = load cell moment output about the Y axis in Newton-meters

$M_x$  = load cell moment output about the X axis in Newton-meters

D = the distance between the axis of the load cell and the axis of the condyle. For the Hybrid III Upper Neck load cell, which is installed through a hole in the base of the skull, the dimension D equals 0.01778 m. For load cells that mount onto the lower surface of the skull base, the dimension D equals 0.008763 m. These dimensions are appropriate for the Hybrid III large adult male, mid-sized adult male, and small adult female. You should verify the D dimension for the ATD and load cell combination that you are using. The sign convention defined in SAE J1733 must be used.

**3.4 Time-Limited Amplitude Determination**—Measurement of amplitudes not exceeding a given time duration, such as the 3-ms "clip" limits of FMVSS 201, 203, and 208, shall be determined on a continuous basis. This means that you must find the greatest amplitude level of the channel for which the amplitude is continuously above the level for at least the specified time duration. In other words, if the amplitude drops below the given level during an observed time interval, this shall be considered as two separate time periods, not added together. Calculation of amplitude and time duration shall be based on straight-line interpolated values between data sample points.

**3.5 Thoracic Trauma Index (TTI(d))**—The Thoracic Trauma Index calculation is performed on data from side impact tests. For a detailed description see:

Federal Code of Regulations, Title 49, Section 571.214—Side Door Strength

Note that this calculation requires the use of the "FIR 100" finite impulse response filter instead of the filters specified in SAE J211. The Code of Federal Regulations specifies using the FORTRAN program developed by NHTSA, i.e., "FIR 100 Filter Program, Version 1.0, July 16, 1990." The FIR 100 program performs the following operations on the data set:

- a. Filter the data using the SAE J211 Class 180 filter
- b. Subsample the data to 1600 Hz
- c. Remove the bias from the subsampled data
- d. Perform the FIR filter
- e. Oversample the filtered data back to the original sample rate.

**3.6 Head Injury Criterion (HIC)**—The HIC calculation is defined as shown in Equation 3 (see #880656):

$$\sup_{t_1}^{t_2} \left( \frac{1}{t_2 - t_1} \right) \int_{t_1}^{t_2} (a(t))^{2.5} dt \quad (\text{Eq. 3})$$

where:

- a = resultant of acceleration channels
- t<sub>1</sub>, t<sub>2</sub> = start and stop times of the integration, and are selected to give the largest HIC value. The time interval is constrained for injury assessment, see 2.1.3. For FMVSS 208 compliance, t<sub>1</sub> and t<sub>2</sub> are constrained such that (t<sub>2</sub>-t<sub>1</sub>) ≤ 36 ms.

**3.7 Sternal DV over a 4-ms Window**—This calculation is used to compute the change in velocity over a 4-ms window in order to assess injury potential. It is computed using the following steps:

- a. Filter the sternal acceleration-time data at SAE J211 Filter Class 1000.
- b. Integrate the filtered acceleration data to get velocity.
- c. Create a new data set by adding 4 ms to the time of each sternal velocity point. Since this new data set starts at 4 ms and runs 4 ms past the end of the original data set, assign zero velocity to each time point between 0 and 4 ms, and delete the velocity points for the last 4 ms of the new data set.
- d. Create a DV data set by taking the difference point-by-point of the velocity and the time-shifted velocity data.

**3.8 Viscous Criterion (V\*C)**—This calculation is used to evaluate soft tissue injury potential. Several methods of numerical differentiation and subsequent V\*C calculation are reviewed within SAE #930100. Reproducible, uniform results can be achieved using one of the following methods:

3.8.1 METHOD 1

- a. Filter chest compression data (in mm) to SAE J211 Filter Class 600. Filtering at lower classes produces erroneous artifacts within the calculated result which are unrelated to dummy performance. Similarly, multiple filtering passes (i.e., before and after differentiation) must be avoided.
- b. Differentiate compression data to obtain velocity (in meters/second). Method of differentiation should transpose such that integrating yields the original data (see reference No. 2).
- c. Compute V\*C, V\*Cmax (in meters/sec):

$$V^*C = (\text{scale factor}) * (\text{velocity}) * [(\text{compression}) / (\text{chest depth})] \quad (\text{Eq. 4})$$

$$V^*C_{\text{max}} = \text{MAX}(V^*C) \quad (\text{Eq. 5})$$

3.8.2 METHOD 2

- a. Same as Method 1.
- b. Measure the x-component of sternal acceleration and thoracic spine acceleration with the same z-level as the chest compression measurement. Filter the acceleration data with the SAE J211 Class 1000 filter. Integrate the two acceleration signals to get the x-component of the sternal velocity and thoracic spine velocity. Take the difference to get the sternal to thoracic spine relative velocity.
- c. Same as Method 1.

Note—Scale factor and chest depth are defined by dummy type in Table 1.

**TABLE 1—SCALE FACTOR AND CHEST DEPTH**

Dummy Type	Scale Factor	Chest Depth, mm
Hybrid III Mid-Sized Adult Male	1.3	229
Hybrid III Small Adult Female	1.3	187
Hybrid III Large Adult Male	1.3	254
BioSID	1.0	175
EuroSID-1	1.0	140

**3.9 Time-Dependent Loading Criteria**—The load that biological tissue can withstand prior to failure is time dependent. Due to its viscoelasticity, tissue failure increases as the load duration decreases. To comprehend this attribute, time-dependent loading criteria have been proposed for neck tension, neck compression, neck shear, and femur compression for load measurements made with the Hybrid III family of dummies. Injury assessment reference boundaries are presented in 2.1.3. An example graph is included as Figure 1. The ordinate of these graphs is the load level and the abscissa is the maximum continuous duration that a prescribed load level is exceeded.

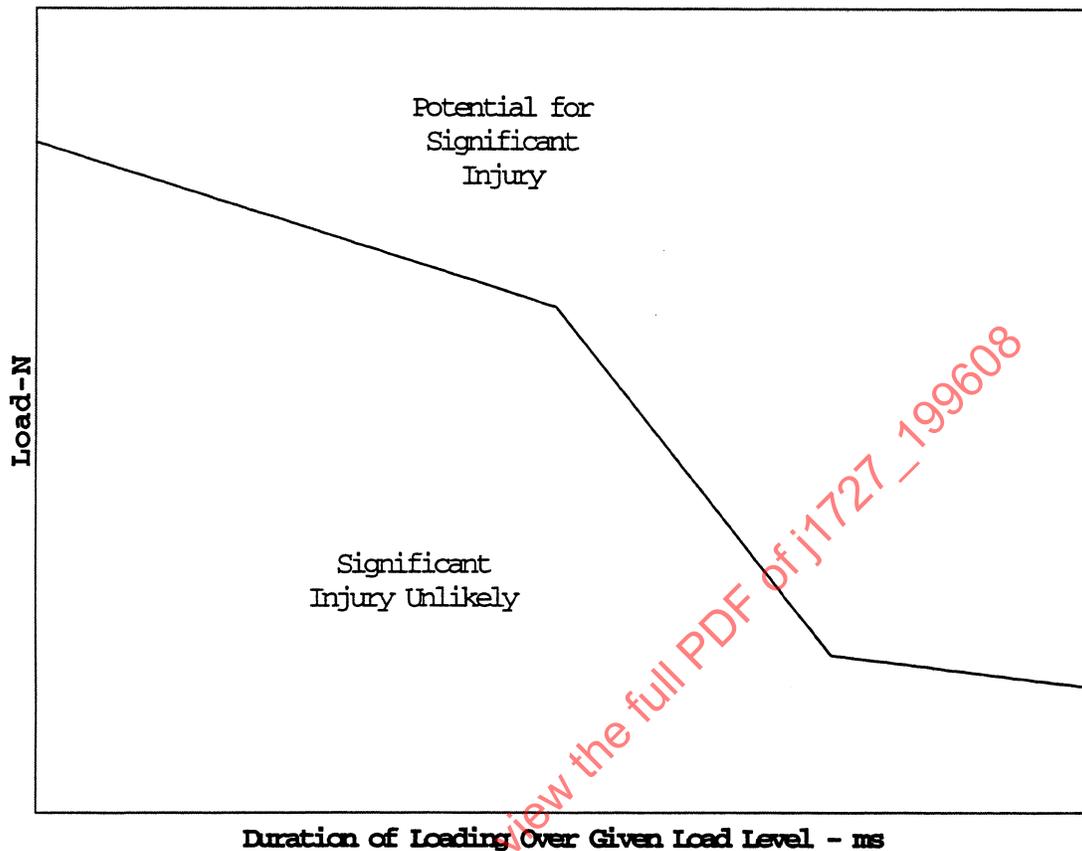


FIGURE 1—GENERIC TIME-DEPENDENT INJURY ASSESSMENT REFERENCE BOUNDARY CURVE

The method used to determine the load and corresponding duration data points needed to plot the time-dependent load criterion curve relative to its injury assessment reference boundary is as follows:

- a. Determine the maximum value of the criterion load and assign a duration of zero to it. This point is plotted on the ordinate of the criterion graph.
- b. Divide the maximum value by 100. Create a matrix of two columns and 101 rows. In the first column store the load levels starting with the peak value. Each subsequent load value will be equal to the previous load value minus 1/100 of the peak value. The load value in the last row will be zero.
- c. For each load in the first column, determine the maximum continuous time interval that the measure load exceeds the prescribed load level. Use linear interpolation to determine time interval and round to nearest millisecond. Store these values in the second column of the matrix created in (b).
- d. Each row of the matrix now defines a load-and-duration point. Plot these points on the criterion graph with its injury assessment reference boundary. Plot only those points whose durations are less than 60 ms.
- e. For each load-and-duration point, compute the ratio of the value of the time-dependent load criterion curve divided by the value of the injury assessment boundary and multiply by 100. The greatest value of these calculations is the injury assessment reference value for the loading curve.
- f. Print the injury assessment reference value that was calculated in (e) along with its corresponding duration on the graph.