

SURFACE VEHICLE RECOMMENDED PRACTICE

J1727

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(R) Calculation Guidelines for Impact Testing

RATIONALE

The committee reviewed this Recommended Practice to determine what changes were necessary to include the set of calculations, methods, and indexes that are typically calculated by labs performing impact tests. The major changes are outlined below.

ECE R94 was added to the list of references.

FIA Procedure for the Approval of Safety Structures was added to the list of references.

Resultant

The resultant calculation was added to provide a method for combining sensor signals collected at a single location, where the signals provide measurement along mutually orthogonal axes.

Delta V

The delta V calculation was added to provide a method for calculating the total change in velocity of a point location on an object during an impact test. Verbiage was added to explicitly state that delta V is a point measurement relative to the earth fixed coordinate system. Delta V is not a measurement relative to a vehicle or dummy coordinate system.

Maximum Average Acceleration

The maximum average acceleration calculation was added to provide a method for calculating the acceptance criteria for the energy absorbing structures of a motorsport vehicle during a frontal and a rear crash test.

Impactor Load

Impactor load calculation was added to provide a method for calculating the force on the leading face of an impactor when load cells are installed internal to the impactor.

Impactor G-force

Impactor G-force calculation was added to provide a method for calculating the force on the leading face of an impactor when an impactor is instrumented with an accelerometer.

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V*C

The viscous criteria section was modified to allow filtering of the chest compression data using a CFC 180 filter. ECE R94 and other organizations specify a CFC 180 filter for dummy chest deflection in lieu of the SAE J211-1 specified CFC 600 filter. Due to the sensitivity of the derivative calculation to signal noise, using the CFC 180 filter for V*C has become popular among several organizations and is in common use.

CWVP

The chest wall velocity predictor was added to provide a method for calculating the chest compressive velocity during impulsive and percussive events such as a mine blast.

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1. SCOPE

This SAE Recommended Practice presents a series of standard calculations and numerical methods for processing safety test instrumentation data that has been acquired during impact tests with instruments installed in ATD's (crash test dummies), vehicle structures, and laboratory fixtures. The output data from performing these calculations may have applications that include energy analysis, biomechanical analysis, regulation compliance, or other purposes. However, application of the output data from these calculations is outside the scope of this document. It is the intent of this document to present a basic set of calculations that are applicable to test labs that follow the practices set forth by SAE J211-1, SAE J211-2, SAE J2570, and SAE J1733. For the calculations that are described in other sources, the relevant documents are referenced.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE J211-1	Instrumentation for Impact Test - Part 1: Electronic Instrumentation
SAE J211-2	Instrumentation for Impact Test - Part 2: Photographic Instrumentation
SAE J1733	Sign Convention for Vehicle Crash Testing
SAE J2570	Performance Specifications for Anthropomorphic Test Device Transducers
SAE #880656	A Review and Evaluation of Various HIC 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, Mail Stop: SSOP, Washington, DC 20402-9320.

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 Impact Protection

FMVSS 202a Code of Federal Regulations, Title 49, Section 571.202 - Head Restraints

2.1.3 Other Publications

Accidental Injury, Biomechanics and Prevention, 2nd Ed. Alan Nahum and John Melvin, Springer 2002, Chapter 4 "Anthropomorphic Test Devices", by Harold J. Mertz.

Crash Analysis Criteria, Measured Data Processing Vehicle Safety Workgroup, Algorithm Group.

Sign Convention for Load Cells (SAE-J211), Robert A. Denton Inc.

AEP-55, Procedure for Evaluating the Protection Level of Logistic and Light Armoured Vehicles - Mine Threat, A NATO/PIP Unclassified Publication.

An Evaluation of Existing and Proposed Injury Criteria with Various Dummies to Determine Their Ability to Predict the Levels of Soft Tissue Neck Injury Seen in Real World Accidents; Frank Heitplatz et al, ESV Conference 2003.

A Sled Test Procedure Proposal to Evaluate the Risk of Neck Injury in Low Speed Rear Impacts Using a New Neck Injury Criterion (NIC); Paper No. 98-S7-O-07; Ola Bostrom, Yngve Haland, Rikard Fredriksson, Autoliv Research Sweden, Mats Y Svensson Hugo Mellander, Chalmers University of Technology Sweden, 16th ESV Conference; June 1-4, 1998 Windsor Canada.

Biomechanical and Scaling Bases for Frontal and Side Impact Injury Assessment Reference Values; Harold J. Mertz, Annette L. Irwin, Priya Prasad, Stapp Car Crash Journal 2003-22-0009, October 2003.

ECE R94, Uniform Provisions Concerning the Approval of Vehicles with Regards to the Protection of the Occupants in the Event of a Frontal Collision.

Federation Internationale de l'Automobile, Procedure for the Approval of Safety Structures.

3. PRE-CALCULATION CORRECTIONS AND CONVERSIONS

3.1 Scale Correction/Conversion to Engineering Units

Data must be scale corrected to convert the acquired data from bit counts, the standard output unit of an analog to digital (A/D) converter, to physical engineering units. Modern data acquisition systems (DAS) perform this scale correction/conversion automatically by accounting for the transducer sensitivity, channel excitation, channel gain, A/D conversion factor, A/D range, channel full scale physical engineering unit range and any required scale correction factors determined prior to the acquisition of test data.

3.2 Polarity Correction

Polarity of channel data must follow the sign conventions established by SAE J211-1 and SAE J1733. Failure to strictly follow the aforementioned polarity conventions will cause incorrect calculation results. Channel data that is acquired with reverse polarity must be inverted prior to performing calculations that include these channels. Inverting of channel polarity is accomplished by multiplying channel data by -1 .

$$\text{Ch}(A_{\text{SAE}}) = -1 \times \text{Ch}(A_{\text{NOT}(\text{SAE})})$$

where:

$\text{Ch}(A_{\text{NOT}(\text{SAE})})$ denotes acquired channel data that does not follow SAE polarity convention

$\text{Ch}(A_{\text{SAE}})$ denotes channel data that follows SAE polarity convention, i.e., the inverse of $\text{Ch}(A_{\text{NOT}(\text{SAE})})$

3.3 Bias Correction

Channel data must be bias corrected to account for any DC offset in the acquired signals. Simply relying on hardware systems to balance such data prior to a test event is not recommended. In addition to performing a hardware balance, many data acquisition systems include software routines that bias correct channel data. Bias correction may also be done during data post-processing. Typical bias correction methods include, but are not limited to, the following:

3.3.1 Average Data in a Section of the Test Data File

Average data over a time range in the data stream of the test data file, during which the actual physical values are at a known constant reference value (e.g. zero or 1 g acceleration, zero or non-zero load, zero or non-zero displacement). Typically, the time range selected is prior to the event (t_0), and is referred to as pre-trigger data. However, there are cases where other time ranges are more appropriate.

3.3.2 Average Data to Account for a Pre-Load

This method is useful when the unit under test must undergo an unknown pre-load. Average data over a time range in the data stream of a pre-test data file, prior to applying any pre-load, and during which the actual physical values are at a known constant reference value, e.g. zero or 1 g acceleration, zero load, zero displacement. The DAS must not be re-balanced after recording this pre-test data file that is used to determine bias correction factors that account for electrical offsets. Acquire a second pre-test data file with the unit under test in the pre-loaded condition. The time between acquiring the first and second pre-test data files should be as close as possible to reduce any temperature drift or other drift phenomena. The DAS may be rebalanced after collecting the second pre-test data file. Process the second pre-test file using the bias correction factors from the first pre-test file and determine the value of the pre-load. The pre-load value determined from this processing is the known constant reference value that is used with the above method in 3.3.1 and the actual test data file. Other similar methods are also acceptable provided that all electrical offsets and all pre-loads are accounted for.

3.3.3 Average Data in Real-Time

Average data over a series of real-time measured data points during which the actual physical values are at a known constant reference value, e.g. zero or 1 g acceleration, zero or non-zero load, zero or non-zero displacement.

The bias correction factor is obtained by subtracting the calculated average value from the known constant reference value. Acquired channel data is then bias corrected by adding the bias correction factor to all acquired data points. In order to calculate the bias correction factor, it is recommended to average a series of measured data points over a time range, compared to measuring one single data point.

$$AVG_{i1-i2}(Ch(A)) = 1/(i2 - i1 + 1) * Sum(A[i1-i2])$$

$$CF_{BIAS} = CH(A)_{REF} - AVG_{i1-i2}(Ch(A))$$

$$CH(A)_{BiasCorrected} = Ch(A) + CF_{BIAS}$$

where:

A = single measurement value from channel A

CH(A)_{BiasCorrected} = bias corrected channel data

Ch(A) = channel data, prior to bias correction

CF_{BIAS} = bias correction factor

CH(A)_{REF} = known constant reference value of channel A during the index range i1 to i2

AVG_{i1-i2}(Ch(A)) = average of channel A, over the index range from i1 to i2

Sum(A[i1-i2]) = summation of all channel A values, over the index range from i1 to i2

i1 = starting index for calculating the average

i2 = ending index for calculating the average

4. FILTERING

Channel data must be filtered per SAE J211-1 prior to performing any of the following calculations on the channel data. In cases of performing moment calculations that include lever arms and force channel data, the force channel data is to be filtered in accordance with the SAE J211-1 specification for the moment channel data. In cases where filters other than the CFC filters from SAE J211-1 are used, the filtering algorithm may induce a DC offset error. In these cases, additional bias correction should be performed after filtering.

5. GENERAL COMPUTATIONS

5.1 Integration and Differentiation

Many numerical methods are available for integration and differentiation, including simple rectangular and trapezoidal rules to much more sophisticated techniques. Following the aforementioned SAE recommended practices ensures bandwidths are sufficiently wide and properly located along the spectrum scale to ensure accurate results are obtained with the following methods. Shown below are recommended methods for differentiation and integration.

5.1.1 Integration

The trapezoidal method is recommended for integration.

$$F[x] = \text{Integral}\{Y[x] \, dx\}, \text{ from } x_0 \text{ to } x_f$$

$$F[x_0] = 0, i = 0$$

$$F[x_i] = F[x_{i-1}] + (Y[x_i] + Y[x_{i-1}])/2 * (x_i - x_{i-1}), i > 0, i \leq f$$

where:

F[x] = the resulting integral

Y[x] = the channel to integrate

x = the channel to integrate with respect to

i = the index location, the row number in the column/row matrix of channel data

x₀ = the lower limit of integration, provides the first index location for calculating the integral

x_f = the upper limit of integration, provides the last index location for calculating the integral

* NOTE: Any numerical integration routine will compound a DC offset in the data set; signals must be appropriately bias corrected prior to integrating.

5.1.2 Differentiating with Respect to a Channel with Equidistant Samples

It is recommended to use the following method when differentiating with respect to a channel that has equidistant samples. This is often the case when differentiating with respect to time.

$$Y'[x] = dY[x]/dx$$

$$dY[x_i]/dx = (8*(Y[x_i + \Delta x] - Y[x_i - \Delta x]) - (Y[x_i + 2\Delta x] - Y[x_i - 2\Delta x]))/12\Delta x$$

where:

$Y'[x]$ = the resulting derivative
 $dY[x_i]/dx$ = the derivative of Y, with respect to x, at index location i
 Y = the channel to be differentiated
 x = the channel to differentiate with respect to
 i = the index location, the row number in the column/row matrix of channel data
 Δx = the equidistant step width of the x channel

5.1.3 Differentiating with Respect to a Channel with Non-equidistant Samples

It is recommended to use the following method when differentiating with respect to a channel that does not have equidistant samples. This is often the case when differentiating with respect to any channel other than time.

$$Y'[x] = dY[x]/dx$$

$$dY[x_i]/dx = \Delta Y[x_i]/\Delta x_i$$

$$\Delta Y[x_i] = Y[x_{i+1}] - Y[x_i]$$

$$\Delta x_i = x_{i+1} - x_i$$

where:

$Y'[x]$ = the resulting derivative
 $dY[x_i]/dx$ = the derivative of Y, with respect to x, at index location i
 Y = the channel to be differentiated
 x = the channel to differentiate with respect to
 i = the index location, the row number in the column/row matrix of channel data
 $\Delta Y[x_i]$ = the step width of the Y channel, at index location i
 Δx_i = the step width of the x channel, at index location i

5.2 Velocity, Relative Velocity, Displacement, and Relative Displacement for Rectilinear Motion

Velocity, relative velocity, displacement, and relative displacement of objects can be calculated from the acceleration of the objects using numerical integration along with known initial conditions. For the 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 otherwise the motion is not rectilinear. In general, 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. In the case of pendulum testing, provided that the stroke of the pendulum during the impact is sufficiently short, approximating the pendulum's tangential motion as rectilinear motion is a valid practice. The methods to calculate the velocity, relative velocity, displacement, and relative displacement of test objects are shown below. Two methods are shown to determine the relative difference in velocity or displacement between two objects whose accelerations have been measured.

5.2.1 Rectilinear Motion Method 1

In order to calculate the relative velocity and relative displacement between two objects, first subtract the two accelerations. Integrate the difference to get the relative velocity. Integrate again to get the relative displacement.

$$v_{rel} = [\text{Integral}\{(a_2 - a_1) dt\}, \text{ from } t_0 \text{ to } t_f] + v_{rel}(0)$$

$$d_{rel} = [\text{Integral}\{v_{rel} dt\}, \text{ from } t_0 \text{ to } t_f] + d_{rel}(0)$$

where:

v_{rel} = relative velocity
 $v_{rel}(0)$ = relative velocity at t_0
 a_1 = acceleration of object number 1
 a_2 = acceleration of object number 2
 d_{rel} = relative displacement
 $d_{rel}(0)$ = relative displacement at t_0
 t_0 = time zero, i.e. the time of impact
 t_f = final time of evaluation

* Although the initial conditions at t_0 will often be zero, this should not be assumed.

5.2.2 Rectilinear Motion Method 2

Integrate the acceleration to calculate the velocity of each object. Subtract the velocities to calculate relative velocity. Integrate the velocity to calculate the displacement of each object. Subtract the displacements to calculate relative displacement.

$$v_1 = [\text{Integral}\{a_1 dt\}, \text{ from } t_0 \text{ to } t_f] + v_1(0)$$

$$v_2 = [\text{Integral}\{a_2 dt\}, \text{ from } t_0 \text{ to } t_f] + v_2(0)$$

$$v_{rel} = v_2 - v_1$$

$$d_1 = [\text{Integral}\{v_1 dt\}, \text{ from } t_0 \text{ to } t_f] + d_1(0)$$

$$d_2 = [\text{Integral}\{v_2 dt\}, \text{ from } t_0 \text{ to } t_f] + d_2(0)$$

$$d_{rel} = d_2 - d_1$$

where:

v_1 = velocity of object 1
 $v_1(0)$ = velocity of object 1 at t_0
 v_2 = velocity of object 2
 $v_2(0)$ = velocity of object 2 at t_0
 v_{rel} = relative velocity
 d_1 = displacement of object 1
 $d_1(0)$ = displacement of object 1 at t_0
 d_2 = displacement of object 2
 $d_2(0)$ = displacement of object 2 at t_0
 d_{rel} = relative displacement
 t_0 = time zero, i.e. the time of impact
 t_f = final time of evaluation

* Although the initial conditions at t_0 will often be zero, this should not be assumed.