SURFACE VEHICLE RECOMMENDED PRACTICE	**J211™-1**	**AUG2022**
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Instrumentation for Impact Test
Part 1 - Electronic Instrumentation

RATIONALE

In an effort to improve overall accuracy of data collection, SAE J211 is being revised to add additional sensor types, improve the definition of the forces and to recommend that data collection move to 20K samples per a second and 16-bit resolution. Adding a definition for CFC20. Continued ongoing effort to harmonize with ISO 6487.

1. SCOPE

This SAE Recommended Practice outlines a series of performance recommendations, which concern the whole data channel. These recommendations are not subject to any variation and all of them shall be adhered to by any agency conducting tests to this practice. However, the method of demonstrating compliance with the recommendations is flexible and can be adapted to suit the needs of the particular equipment the agency is using.

It is not intended that each recommendation be taken in a literal sense, as necessitating a single test to demonstrate that the recommendation is met. Rather, it is intended that any agency proposing to conduct tests to this practice shall be able to demonstrate that if such a single test could be and were carried out, then their equipment would meet the recommendations. This demonstration shall be undertaken on the basis of reasonable deductions from evidence in their possession, such as the results of partial tests.

In some systems, it may be necessary to divide the whole channel into subsystems, for calibration and checking purposes. The recommendations have been written only for the whole channel, as this is the sole route by which subsystem performances affect the quality of the output. If it is difficult to measure the whole channel performance, which is usually the case, the test agency may treat the channel as two or more convenient subsystems. The whole channel performance could then be demonstrated on the basis of subsystem results, together with a rationale for combining the subsystem results together.

SAE J211-1 of this SAE Recommended Practice covers electronic instrumentation. SAE J211-2 covers photographic instrumentation.

1.1 Purpose

The purpose of this SAE Recommended Practice is to provide guidelines and recommendations for the techniques of measurement used in impact tests. The aim is to achieve uniformity in instrumentation practice and in reporting test results. Use of this SAE Recommended Practice will provide a basis for meaningful comparisons of test results from different sources.

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For more information on this standard, visit
https://www.sae.org/standards/content/J211/1_202208/

1.2 Field of Application

The instrumentation as defined in this SAE Recommended Practice applies in particular to impact tests for road vehicles, including tests of their sub-assemblies, and occupant surrogates.

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 +1 724-776-4970 (outside USA), www.sae.org.

SAE J670 Vehicle Dynamics Terminology

SAE J1727 Calculation Guidelines for Impact Testing

SAE J1733 Sign Convention for Vehicle Crash Testing

SAE J2570 Performance Specifications for Anthropomorphic Test Device Transducers

Chou, C., Lin, Y., and Lim, G., “An Evaluation of Various Viscous Criterion Computational Algorithms,” SAE Technical Paper 930100, 1993, https://doi.org/10.4271/930100.

2.1.2 NHTSA Publications

Available from Department of Transportation, The Office of Crashworthiness Research, 408 7th Street SW, Washington, DC 20590.

NHTSA Version 5 Test Reference Guide: Volume 1 - Vehicle Tests, Volume 2 - Biomechanics, Volume 3 - Components, and Volume 4 - Signal Waveform Generator

3. DEFINITIONS

The definitions in 3.5 to 3.14 apply to the whole data channel, as defined in 3.1.

3.1 DATA CHANNEL

All of the instrumentation from and including a single transducer (or multiple transducers whose outputs are combined in some specified way) up to and including any analysis procedures that may alter the frequency content or the amplitude content or the timing of data. It also includes all cabling and interconnections.

3.2 TRANSDUCER

The first device in a data channel, used to convert a physical quantity to be measured into a second quantity (such as an electrical voltage) which can be processed by the remainder of the channel. For transducer equivalency, see Appendix B.

3.3 FULL SCALE

The maximum usable linear range of a data channel. For ATD transducers, refer to SAE J2570.

3.4 DATA CHANNEL FULL SCALE

That value of a data channel determined by the component of the channel with the lowest full scale level. This is expressed in terms of the measured variable (input). For example, F.S. = 50 G, 1000 N, 1 m/s, etc.

3.5 CHANNEL AMPLITUDE CLASS (CAC)

The designation for a data channel that meets certain amplitude characteristics as specified by this SAE Recommended Practice. The CAC number is numerically equal to the upper limit of the measurement range (that is, equivalent to the data channel full scale).

3.6 CHARACTERISTIC FREQUENCIES (F_H, F_L, F_N)

These frequencies are defined in Figures 1 and 2.

3.7 CHANNEL FREQUENCY CLASS (CFC)

The channel frequency class is designated by a number indicating that the channel frequency response lies within limits specified by Figure 1 for CFCs of 1000 and 600, and by Figure 2 for CFCs of 60 and 180.

NOTE: Figure 1 has not changed in reference to SAE J211 March 1995 except to specify nodal points instead of slopes. This number and the value of the frequency F_H in hertz are numerically equal.

3.8 CALIBRATION VALUE

The value measured and read during the calibration of a data channel (see 4.6).

3.9 SENSITIVITY COEFFICIENT

The slope of the straight line representing the best fit to the calibration values determined by the method of least squares within the channel amplitude class.

3.10 CALIBRATION FACTOR OF A DATA CHANNEL

The arithmetic mean of the sensitivity coefficients evaluated over frequencies which are evenly spaced on a logarithmic scale between F_L and $F_H/2.5$.

3.11 LINEARITY ERROR

The ratio, in percent, of the maximum difference between the calibration value and the corresponding value read on the straight line defined in 3.9 at the upper limit of the channel amplitude class (data channel full scale).

3.12 SENSITIVITY

The ratio of the output signal (in equivalent physical units) to the input signal (physical excitation), when an excitation is applied to the transducer. (Example: 10.24 mV/G/V for a strain gage accelerometer.) For ATD transducers, refer to SAE J2570.

3.13 PHASE DELAY TIME

The phase delay time of a data channel is equal to the phase delay (in radians) of a sinusoidal signal, divided by the angular frequency of that signal (in radians per second).

3.14 ENVIRONMENT

The aggregate, at a given moment, of all external conditions and influences to which the data channel is subjected.

3.15 TRANSVERSE SENSITIVITY (OF A RECTILINEAR TRANSDUCER)

The sensitivity to excitation in a nominal direction perpendicular to its sensitive axis.

NOTE: The transverse sensitivity is usually a function of the nominal direction of the axis chosen. For ATD transducers, refer to SAE J2570.

3.16 TRANSVERSE SENSITIVITY RATIO (OF A RECTILINEAR TRANSDUCER)

The ratio of the transverse sensitivity to its sensitivity along its sensitive axis.

3.17 FAST FOURIER TRANSFORM (FFT)

A mathematical function used to convert data from the time domain to the frequency domain. An FFT filter is a filter which operates in the frequency domain.

3.18 ANTHROPOMORPHIC TEST DEVICE (ATD)

Crash test dummy.

4. DATA CHANNEL PERFORMANCE REQUIREMENTS

4.1 Linearity Error

The absolute value of the linearity error of a data channel at any frequency in the CFC, shall be less than or equal to 2.5% of the value of the CAC, through the whole measurement range. In general a sufficient number of measurements shall be carried out in order to ensure the linearity in the range of interest, that is, between F_L and F_H.

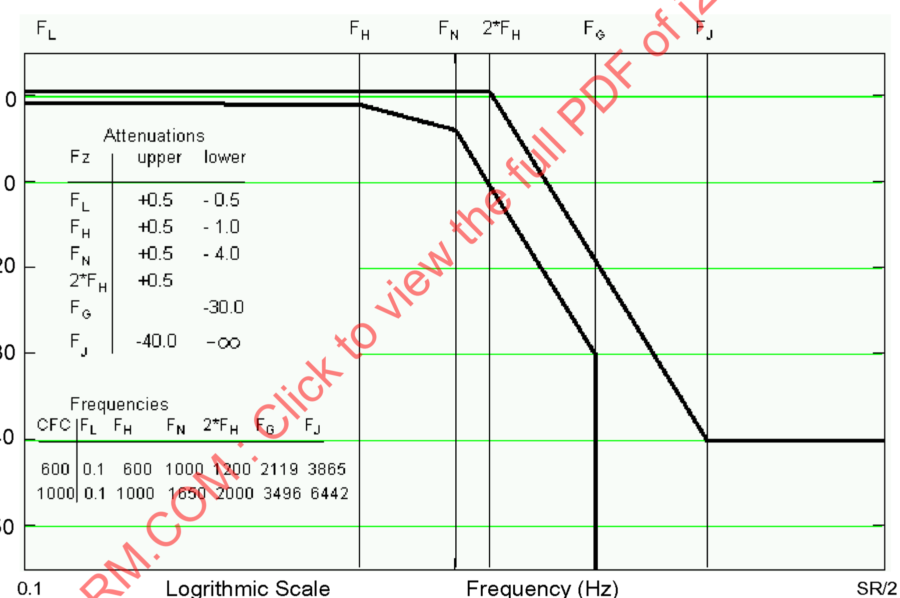

Figure 1 - Data channel dynamic accuracy, class 600 and 1000

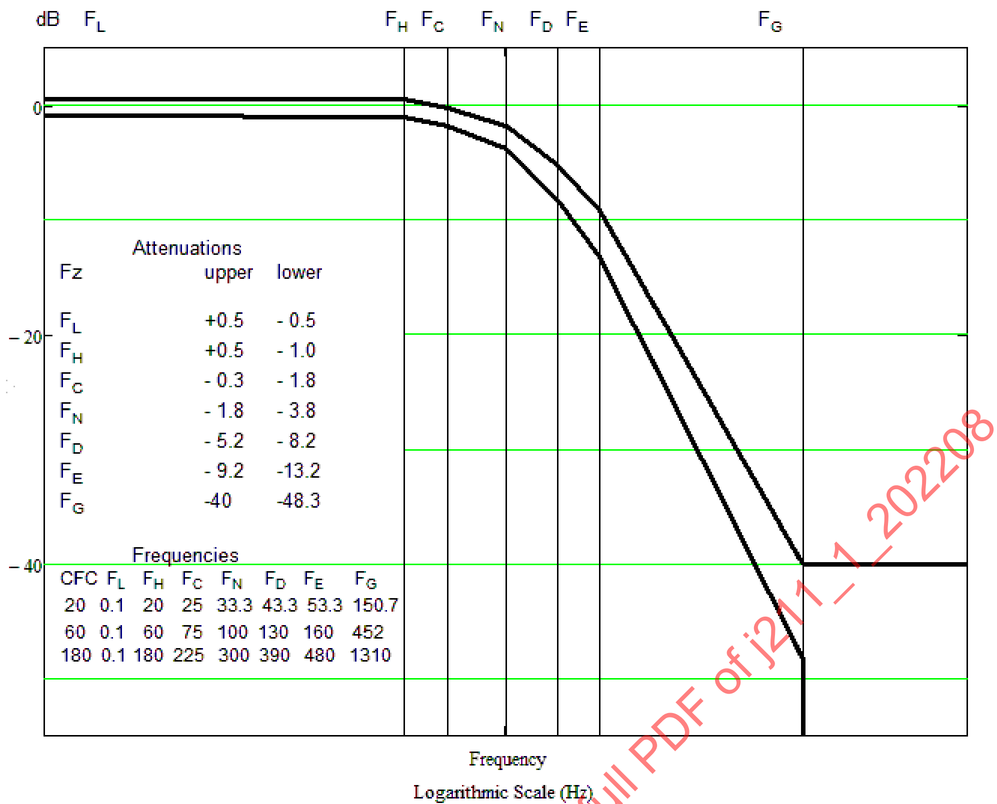

Figure 2 - Data channel dynamic accuracy, class 20, 60, and 180

4.2 Amplitude Against Frequency

The frequency response of a data channel shall lie within the limiting curves given in Figure 1 for CFCs of 1000 or 600. For CFCs of 180, 60, or 20 the frequency response of a data channel shall lie within the limiting curves given in Figure 2. The 0 dB line is defined by the calibration factor.

NOTE: The Figure 2 envelopes have been derived to center the frequency responses of the SAE J211 March 1995 Appendix C CFC 20, 60, and 180 filters in the corridors.

4.3 Phase Delay Time

The phase delay time between the input and the output of a data channel shall be determined, and shall not vary more than $1/(10*F_H)$ seconds between $0.03*F_H$ and F_H. This includes the transducer, that is, the input is the excitation to the transducer.

4.4 Time

4.4.1 Time Base

A time base shall give at least 1/100 second resolution with an error of less than 1/10000 second.

4.4.2 Relative Time Delay

The relative time delay between the signals of two or more data channels regardless of their frequency class, must not exceed 1 ms. Two or more data channels of which the signals are combined shall have the same frequency class and shall not have a relative time delay greater than $1/(10*F_H)$ seconds. This requirement applies to analog signals, as well as digital signals.

4.5 Transducer Transverse Sensitivity Ratio

The transverse sensitivity ratio of all transducers shall be less than 5% in any direction. For ATD transducers, refer to SAE J2570.

4.6 Calibration

Values in this section apply to reference equipment or standards against which a data channel is calibrated; that is, its performance is determined.

4.6.1 General

A data channel shall be calibrated at least once a year against reference equipment traceable to known standards. The methods used to carry out a comparison with reference equipment shall not introduce an error greater than 1% of the CAC. The use of the reference equipment is limited to the range of frequencies for which they have been calibrated. Subsystems of a data channel may be evaluated individually and the results factored into the accuracy of the total data channel. This can be accomplished for example by an electrical signal of known amplitude simulating the output signal of the transducer which allows a check to be made on the gain of the data channel, except the transducer.

4.6.2 Accuracy of Reference Equipment for Calibration

The accuracy of the reference equipment shall be certified or endorsed by an approved metrology service (for example, traceable to the National Institute of Standards and Technology).

4.6.2.1 Static Calibration

4.6.2.1.1 Accelerations

The error shall be less than 1.5% of the channel amplitude class.

4.6.2.1.2 Forces

The error shall be less than 1% of the channel amplitude class.

4.6.2.1.3 Displacements

The error shall be less than 1% of the channel amplitude class.

4.6.2.2 Dynamic Calibration

4.6.2.2.1 Accelerations

The error in the reference accelerations expressed as a percentage of the channel amplitude class shall be less than 1.5% below 400 Hz, less than 2% between 400 Hz and 900 Hz, and less than 2.5% between 900 Hz and the maximum frequency at which the reference acceleration is utilized (see 4.6.4).

Use of a shock calibration device error as a percentage of channel amplitude class shall be less than 1.8%.

4.6.2.2.2 Forces, Moments, and Displacements

Refer to SAE J2570 for load cell specifications titled “Free Air Resonance” for force and moment info.

4.6.2.2.3 Angular Rate

The error in reference angular rate expressed as a percentage of the channel amplitude class shall be less than 0.5%.

4.6.2.3 Time

The error in the reference time shall be less than 1/(10*sample rate).

4.6.3 Sensitivity Coefficient and Linearity Error

The sensitivity coefficient and the linearity error shall be determined by measuring the output signal of the data channel against a well-known input signal, for various values of this signal. (The input signal is referenced to well known physical data, which is, a load or acceleration, but not voltage.)

The calibration of the data channel shall cover the whole range of the amplitude class. (This is between F_L and $F_H/2.5$.)

For bi-directional channels, both the positive and negative values shall be evaluated. If the calibration equipment cannot produce the required input, due to excessively high values of the quantity to be measured, calibrations shall be carried out within the limits of these calibration standards and these limits shall be recorded in the report.

A total data channel shall be calibrated at a frequency or at a spectrum of frequencies with its significant values comprised between F_L and $F_H/2.5$.

4.6.4 Calibration of the Frequency Response

The response curves of phase and amplitude against frequency for the data channel shall be determined by measuring the output signals of the data channel in terms of phase and amplitude against a known input signal, for various values of this signal varying between F_L and ten times the CFC or 3000 Hz, whichever is the lower value.

4.7 Environmental Effects

4.7.1 Data System Grounding and Sensor Cable Shielding

Electrostatic discharge (ESD), electromagnetic fields (EMF), and radio frequency interference (RFI) commonly encountered in the impact test environment can seriously degrade recorded data quality if proper grounding and shielding techniques are not implemented. ISO and NHTSA have published guidance documents with specific recommendations. These are contained in Appendix D along with more detailed information regarding grounding and cable shielding/routing methods.

4.7.2 Quantifying Environment Effects.

The presence of environmental effects should periodically be checked (that is, electric or magnetic flux, electrostatic discharge, cable velocity, etc.). This can be done for example by recording the output of spare channels equipped with a known input (such as simulated transducers, shorting plug, etc.). If such an output signal is greater than 2% of the expected data peak value, corrective action shall be taken such as relocation or replacement of cables.

5. DATA CHANNEL SELECTION

The selection of a frequency response class is dependent upon many considerations, some of which may be unique to a particular test. The ultimate usage of the data and good engineering judgment will determine what portions of the frequency spectrum are significant or useful. The various classes of frequency response in Figures 1 and 2 are intended to permit appropriate choices for different engineering requirements.

It is important to note that valid comparisons using different frequency response classes may be difficult to make. It is useful to establish specific frequency response classes when comparing test results from different sources. The frequency response classes in Table 1 are recommended for that purpose. These recommendations reflect current practices and equipment. However, it is recognized that other considerations (for example, biomechanics) may impose special instrumentation requirements.

The channel class recommendations for a particular application shall not be considered to imply that all the frequencies passed by that channel are significant for the application. In several cases, such as occupant head accelerations, headform accelerations, and femur force, the recommendation may be higher than necessary, but current biomechanical knowledge will not permit a closer specification. All data are to be gathered at CFC 1000 or higher, for any purpose.

Table 1 - Frequency response classes

Typical Test Measurements	Channel Frequency Class (CFC)[10]
Vehicle structural	
Acceleration	
Total vehicle comparison	60[1]
Collision simulation input	60
Component analysis	600
Integration for velocity or displacement	180
Angular Rate	
Vehicle Control Modules	180
Integration for rotational displacement	180
Barrier face force	60
Belt restraint system loads	60
Anthropomorphic Test Device	
Angular Rate	60
Integration for rotational displacement	180[8]
Differentiation for Angular Acceleration	180[9]
Head	
Accelerations (linear and angular)	1000
Neck	
Forces	1000[2,3,7]
Moments	600[2,3]
Arm	
Forces	600[5]
Moments	600[5]
Accelerations	600[5]
Thorax	
Spine accelerations	180
Rib accelerations	1000[2]
Sternum accelerations	1000[2]
Deflections	600[2,4]
Lumbar	
Forces	600[6]
Moments	600[6]
Pelvis	
Accelerations	1000[2]
Forces	600[6]
Moments	600[6]
Femur/Knee/Tibia/Ankle	
Accelerations	1000
Forces	600
Moments	600[2]
Displacements	180[2]
Sled acceleration	60
Steering column loads	600
Headform acceleration	1000

(1) When overall acceleration of the frame or body in a given direction is desired and a higher frequency response class is used, readability of the data may be improved by averaging outputs of two or more transducers at different locations.
(2) UMTRI-86-32 and ISO/TC22/SC12/WG3 N194.
(3) These classifications are needed to calculate head impact forces based on neck forces and head accelerations when using an ATD.
(4) SAE paper 930100.
(5) SAE paper 2002-01-0806 or ISO/TC22/SC12/WG6 N557.
(6) See Appendix B.
(7) When force channels are multiplied by a moment arm, a CFC 600 filter shall be used.
(8) MVSS202a S5.3.9 Low Speed Rear Impact specifies CFC 600 for head rotation.
(9) SAE Paper 2010-01-1017.
(10) Specific testing protocols may require filters that are different than listed in Table 1.

6. MOUNTING OF TRANSDUCERS

6.1 Transducer Mounting Considerations

Mechanical resonance associated with transducer mounting shall not distort readout data. Transducers shall be mounted on dummies using a support specially provided for this purpose. In cases where properties of non-mechanical test subjects preclude rigid transducer mounting, an analytical or experimental evaluation of mounting effects on the data shall be provided. Acceleration transducers, in particular, shall be mounted in such a way that the initial angle of the actual measurement axis to the corresponding axis of the reference axis system is not greater than 5 degrees unless analytical or experimental assessment of the effect of the mounting on the collected data is made. When multi-axial accelerations at a point are to be measured, each acceleration transducer axis shall pass within 10 mm of that point, and the center of seismic mass of each accelerometer shall be within 30 mm of that point.

6.2 Transducer Resonance

Many transducers have resonant frequencies well above CFC 1000 that may distort recorded data. Care must be exercised to ensure that typical transducer resonance signatures do not cause signal distortion such as unexpected channel saturation, DC offsets, or aliasing. Additional information and recommendations for minimizing effects of transducer resonance are contained in Appendix E.

7. SIGN CONVENTION

In order to compare test results obtained from different crash test facilities, standardized coordinate systems need to be defined for crash test dummies, vehicle structures and laboratory fixtures. In addition, recorded polarities for various transducer outputs need to be defined relative to positive directions of the appropriate coordinate systems. This section describes the standardized sign convention.

7.1 Right-Handed Coordinate System

To assure consistent vector directions of moments and angular velocities and accelerations produced by vector multiplications all coordinate systems used in vehicle testing will be "right-handed."

Right-handed coordinate system consists of an ordered set of three mutually perpendicular axes (x, y, z) which have a common origin and whose positive directions point in the same directions as the ordered set of the thumb, forefinger and middle finger of the right hand when positioned as shown in Figure 3. Note that one can choose the positive x-axis to point in the direction of either the thumb, forefinger or middle finger as shown in the orientations 1, 2, and 3 of Figure 3. However, once this decision is made then the positive directions of the y- and z-axes must be as indicated by corresponding orientation shown in Figure 3.

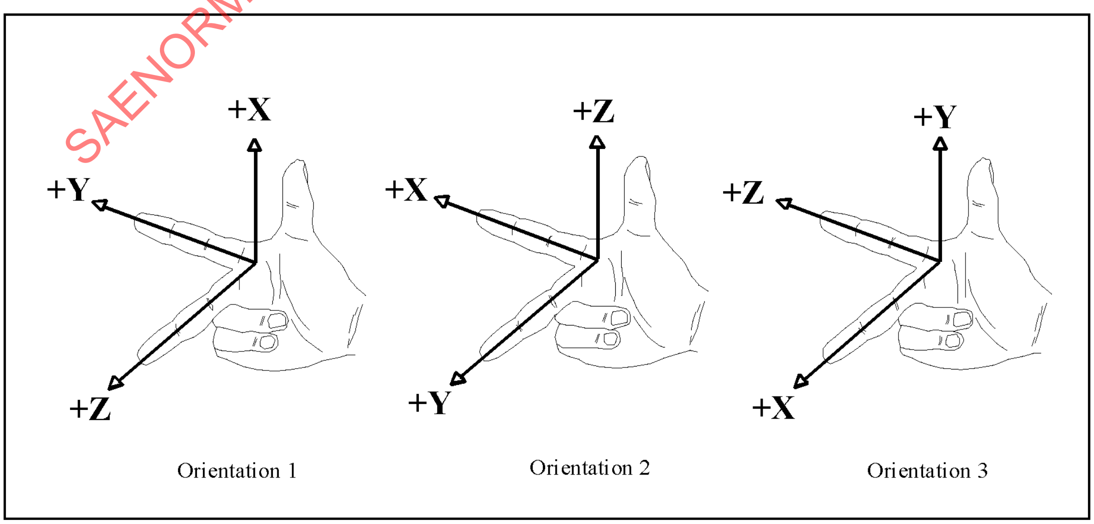

Figure 3 - The three possible orientations of a right-handed coordinate system relative to the thumb, forefinger, and middle finger of the right hand

Positive angular motion and moment directions are determined by the right-handed screw rule. If a positive axis is grasped with the right hand with the thumb extended in the positive direction as shown in Figure 4, then the curl of the fingers indicate the positive direction for angular motions and moments.

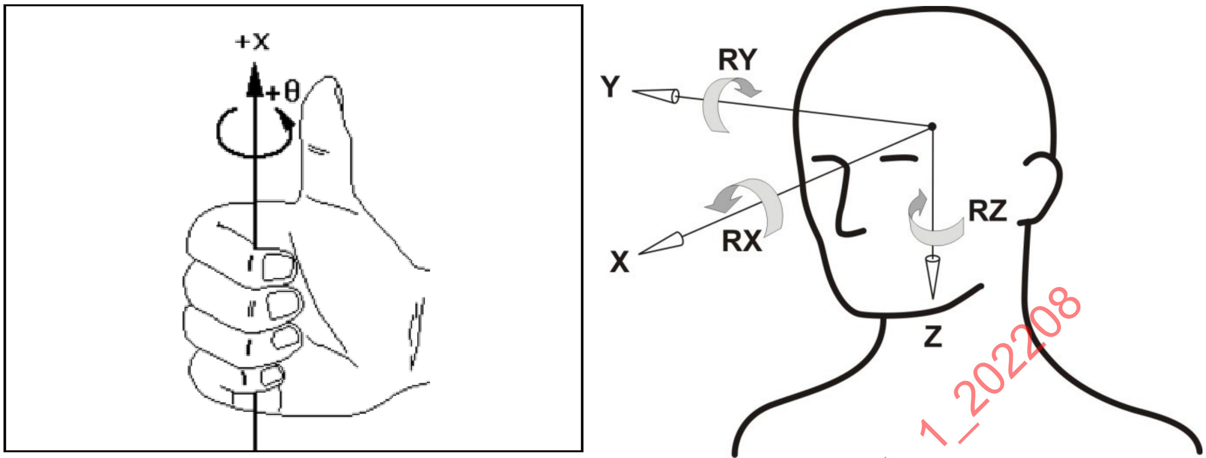

Figure 4 - Right-handed screw rule

A simple method to determine if a (x, y, z) coordinate system is right-handed is to rotate the system 90 degrees about the z-axis using the right-handed screw rule. If the positive x-axis rotates to the position previously occupied by the positive y-axis, then the system is right handed.

7.2 Vehicle and Laboratory Coordinate Systems

For vehicle and laboratory coordinate systems, positive z-axis will be directed downward, positive x-axis will be directed forward relative to the vehicle and positive y-axis will be directed away from the vehicle's left to its right (refer to SAE J670). For structures within the vehicle that have a principle axis of motion such as the steering wheel and column, the vehicle coordinate system may be rotated about the y-axis such that the positive x-axis is directed along the column axis.

7.3 Dummy Coordinate Systems

Coordinate systems can be affixed to any point on the dummy. To determine the orientation of the coordinate axes, the dummy will always be considered as standing erect. For this posture, the positive y-axis will be directed from the dummy's left to its right side, the positive z-axis will be directed downward from head to toe, and the positive x-axis will be directed forward. In anatomical terminology, the positive x-axis is directed from the posterior to the anterior (P-A), the positive y-axis is directed form the left to right (L-R), and the positive z-axis is directed from superior to inferior (S-I). Figure 5 shows examples of this standardized orientation for coordinate systems attached to a few body points. Note that as the dummy is articulated to sit in a vehicle or if the dummy is articulated for a test, the coordinate systems rotate with their respective dummy parts.

7.4 Polarities of Acceleration, Velocity, and Displacement

Positive recorded outputs for these transducers are to be consistent with the positive axes of the coordinate system defined for the specific dummy or vehicle point being measured. For example, a blow to the back of the dummy's head produces an acceleration in the forward direction (+x) which shall be recorded as a positive acceleration. A blow to the top of the head produces a +z acceleration. A blow to the left side of the head produces a +y acceleration.

For displacements, the coordinate systems of interest must be defined. For example, frontal chest compression is the distance that the sternum moves relative to the thoracic spine. In this case, the coordinate system is fixed to the thoracic spine. When the sternum moves closer to the spine, its displacement is rearward relative to the spine which is in the negative x-direction. Hence, the polarity for frontal chest compression is negative. For lateral chest compression, a blow to the left side of the chest produces a positive displacement of the impacted ribs relative to the thoracic spine. However, a blow to the right side of the chest produces a negative rib displacement. The rearward displacement of the tibia relative to the femur that is measured by the knee shear transducer is in the negative x-direction. The polarity for this motion shall be negative.

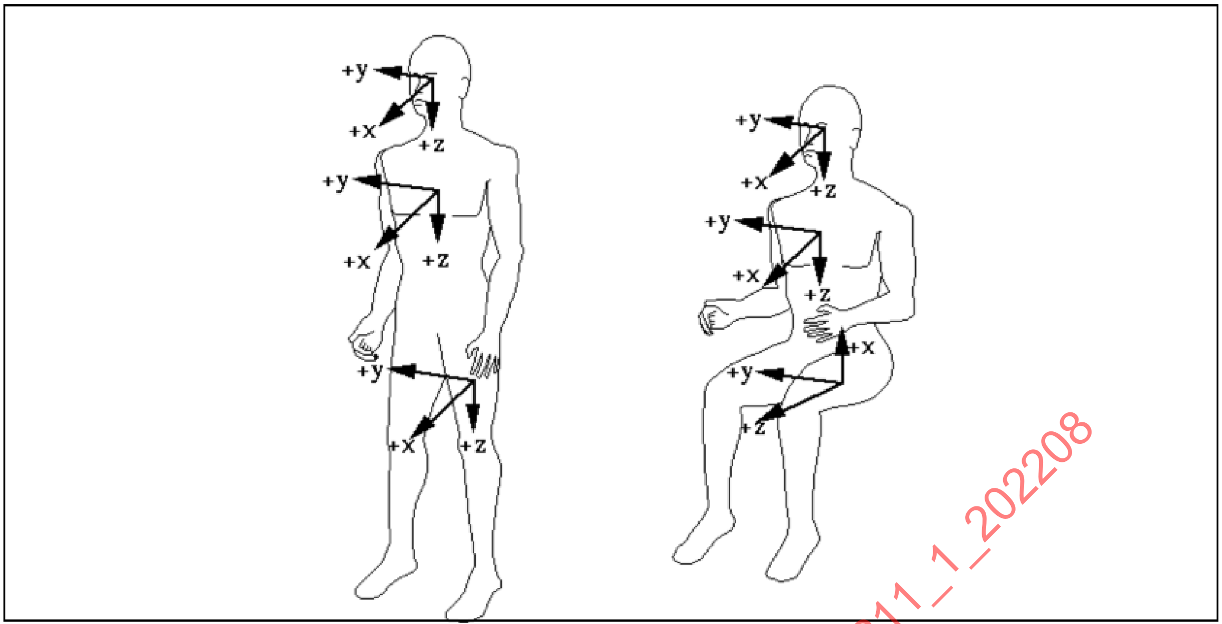

Figure 5 - Orientations of standardized dummy coordinate systems for standing and seated postures

7.5 External versus Internal Load Cells

Two types of load cells are used inside dummies which serve different purposes. The first type measures external loads, the second internal loads. External load cells measure forces applied to a dummy by an object in contact with the outer surface of the dummy. Loads can pass through flesh or other soft parts, but are not transported through skeletal structures into the load cell. It only measures externally applied loads. Internal load cells measure loads carried by skeletal structures between parts of the dummy, or loads transmitted between body segments. Sometimes a load cell measures a combination of loads externally applied loads as well as those transported through structures into the load cell. An example is the WorldSID-50 shoulder load cell (SAE J1733:2018 Figure 39). Where combined loads are measured, they are classified as internal load cells.

7.6 Polarities of Measured External Loads

For load cells that measure loads applied directly to the dummy, their recorded output polarities shall be consistent with the direction of the applied external load referenced to the standardized coordinate system at the point of the load application. For example, load cells that measure shoulder belt loading of the clavicle are designed to measure Fx and Fz applied to the clavicle (SAE J1733:2018 Figure 23). Positive directions for these applied forces would be forward (+x) and downward (+z) relative to the dummy, respectively. For ATDs, a lateral inward load applied to the crest of the left ilium would be positive (+y), while a lateral inward load applied to the crest of the right ilium would be negative (-y).

7.7 Polarities of Measured Internal Loads

Defining recorded output polarities for load cells that measure loads internal to the dummy requires a standardized dummy sectioning scheme and a definition of what sectioned dummy part is to be loaded in the positive direction since internal loads occur in pairs of equal magnitudes but opposite directions. The standardized sectioning scheme is illustrated by the free-body diagram of a cube shown in Figure 6. It is assumed that the load cell of interest is contained within the cube and responds to loads applied to the mounting surfaces of the load cell which correspond to two of the surfaces of the cube. Load cell outputs shall be recorded with positive polarities when normal loads, shear loads, torques, or moments are applied in the positive direction, as defined by the standardized coordinate system, to the load cell mounting surface that would correspond to the right, front, or bottom surfaces of the cube. These loads are represented by solid arrows. For static equilibrium, equal magnitude but opposite (negative) direction loads must be applied to the opposite load cell mounting surface that would correspond to the left, back, or top surfaces of the cube as indicated by the dashed arrows. For example, upper and lower neck (SAE J1733:2018 Figures 11 and 12), lumbar spine (SAE J1733:2018 Figure 17), and upper and lower tibia load cells (SAE J1733:2018 Figure 21) shall have positive recorded outputs when the dummy is sectioned below the load cell in question and positive loads are applied to the bottom mounting surface of the load cell since that mounting surface corresponds to the bottom of the cube which contains the load cell in question. Examples of load cells where horizontal sectioning is used are the WorldSID-50 shoulder, and the THOR-50M acetabulum. In these cases the positive loads are applied to the right side mounting surface of the load cell as shown in SAE J1733:2018 Figures 39 and 48 since that mounting surface of the load cell corresponds to the right surface of the cube in Figure 6. Free-body diagrams showing the load systems that produce the required recorded polarities for specific dummy load cells are given in the appropriate dummy users manual and in SAE J1733.

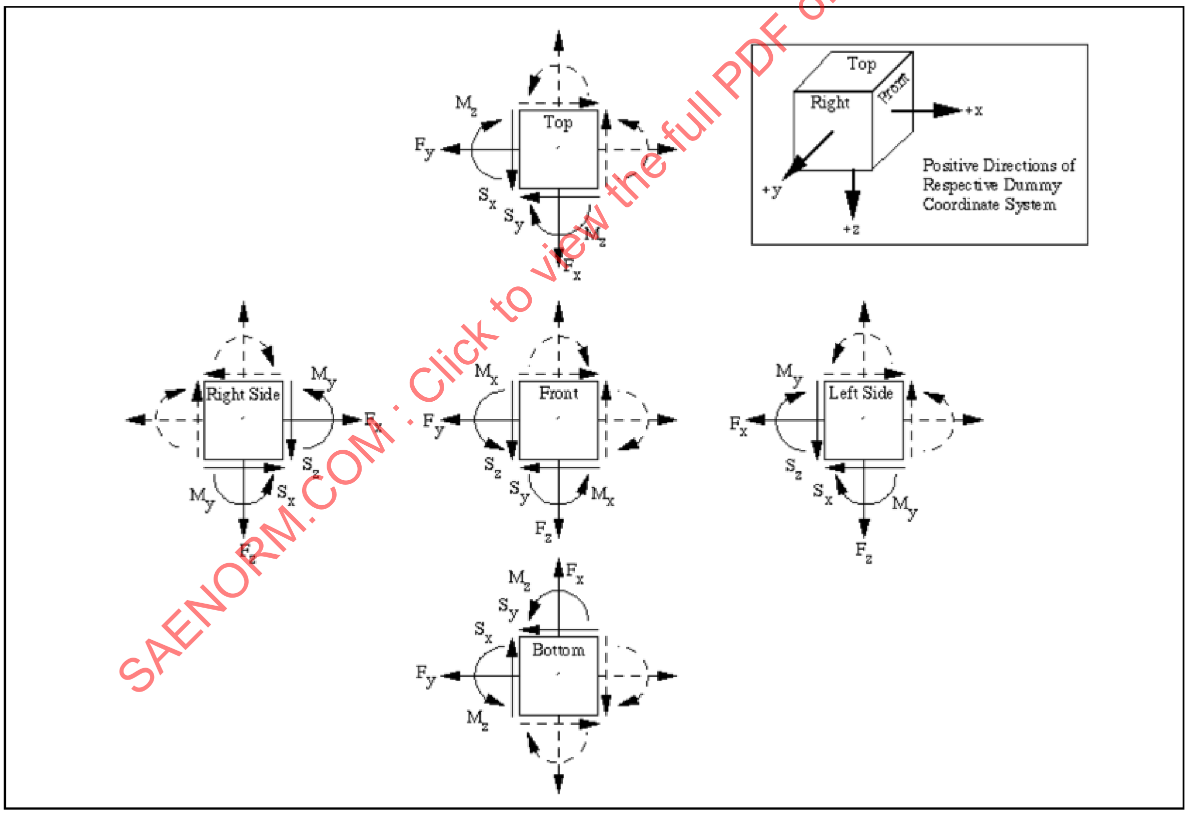

Figure 6 - Directions of loads applied to free-body diagram of the sectioned dummy part containing the load cell of interest (illustrated as a cube) for positive recorded polarities

Notes for Figure 6:

1. Principle axes of load cell are aligned parallel to respective axes of local dummy coordinate system.

2. Bold arrows of normal forces (F), shear forces (S), and moments (M) are shown in positive directions. These positive loads are applied to front, right, and bottom surfaces of the cube. Dotted arrows indicate direction of loads applied to the back, left, and top surfaces for static equilibrium.

7.8 Dummy Manipulations for Checking Polarities of Measured Loads

Table 2 contains descriptions of dummy manipulations and the corresponding polarities for recorded outputs for some of the more common load cells used in dummies. Manipulations for checking polarities of load cells not listed in Table 2 may be found in the user's manual for the specific dummy being used or SAE J1733.

Table 2 - Dummy manipulations for checking recorded load cell polarity relative to sign convention

Load Cell	Measure	Dummy Manipulations	Polarity
Upper	Fx	Head rearward, chest forward	+
And	Fy	Head leftward, chest rightward	+
Lower	Fz	Head upward, chest downward	+
Neck	Mx	Left ear toward left shoulder	+
Loads	My	Chin toward sternum	+
	Mz	Chin toward left shoulder	+
Rib force	Fx	Compression	(-)
Upper	Fx	Chest rearward, Pelvis forward	+
And	Fy	Chest leftward, pelvis rightward	+
Lower	Fz	Chest upward, pelvis downward	+
Lumbar	Mx	Left shoulder toward left hip	+
Spine	My	Sternum toward front of legs	+
	Mz	Right shoulder forward, left shoulder rearward	+
Sacrum load	Fy	Left H-point pad leftward, chest rightward	+
Left iliac load	Fy	Left iliac rightward, chest leftward	+
Right iliac load	Fy	Right iliac rightward, chest leftward	+
Pubic load (side impact)	Fy	Right H-point pad leftward, left pad rightward	(-)
Crotch belt	Fx	Pubic rearward, pelvis forward	(-)
Loads	Fz	Pubic upward, chest downward	(-)
Iliac lap belt	Fx	Upper iliac spine rearward, chest forward	(-)
Loads	My	Upper iliac spine rearward, chest forward	+

Table 2 - Dummy manipulations for checking recorded load cell polarity relative to sign convention (continued)

Load Cell	Measure	Dummy Manipulations	Polarity
Backplate	Fx	Force into back	+
(EuroSID)	Fy	Force into left side	+
	My	Pull back on top of backplate	+
	Mz	Push forward on left edge of backplate, hold thorax in place.	+
		Chest rearward, pelvis forward	
T-12 Spine	Fx	Chest leftward, pelvis rightward	+
(EuroSID)	Fy	Left shoulder to left hip	+
	Mx	Chest forward, hold pelvis	+
	My		+
		Chest rearward, pelvis forward	
Thoracic spine	Fx	Chest upward, pelvis down	+
	Fz	Chest toward knees	+
	My		+
		Left side of abdomen rightward,	
Left side	Fy	chest leftward	+
Abdominal load			
(EuroSID)			
Right side	Fy	Right side of abdomen leftward,	(-)
Abdominal load		chest rightward	
(EuroSID)			
Femur loads	Fx	Knee upward, upper femur downward	+
(dummy in	Fy	Knee rightward, upper femur leftward	+
Seated position,	Fz	Knee forward, pelvis rearward	+
Femurs	Mx	Knee leftward, hold upper femur in place	+
Horizontal)	My	Knee upward, hold upper femur in place	+
	Mz	Tibia leftward, hold pelvis in place	+
Knee clevis	Fz	Tibia downward, femur upward	+
Upper tibia	Fx	Ankle forward, knee rearward	+
Loads	Fy	Ankle rightward, knee leftward	+
	Fz	Tibia downward, femur upward	+
	Mx	Ankle leftward, hold knee in place	+
	My	Ankle forward, bottom of knee clevis rearward	+
Lower tibia	Fx	Ankle forward, knee rearward	+
Loads	Fy	Ankle rightward, knee leftward	+
	Fz	Ankle downward, knee upward	+
	Mx	Ankle leftward, hold knee in place	+
	My	Ankle forward, bottom of knee clevis rearward	+

8. DIGITAL DATA PROCESSING

This section establishes guidelines for digital data processing equipment used by crash testing agencies.

8.1 Pre-sample Filtering

Since crash test data may have high-frequency components above the channel class F_H, pre-sample filtering shall be used to keep these components from causing aliasing errors in the sampling process. Before recording, analog anti-aliasing filtering, at a level corresponding to CFC 1000 or higher, shall take place. Overall data acquisition system pre-sample filtering must be such that the total system response shall comply with 3.7. The maximum error induced by aliasing at the F_H frequency shall not exceed 0.1% of the CAC (more than 60 dB of attenuation at sample rate - F_H Hertz).

8.2 Sampling Rate

The minimum acceptable sampling rate is a function of many variables, particularly sophistication of the reconstruction method used in the processing software. For those installations utilizing only simple reconstruction software, the sample rate shall be a minimum of 20 times the F_H or a minimum sampling rate of no less than 20000 samples per second per channel.

8.3 Resolution

Digital word lengths of at least 16 bits (including sign) shall be used to be assured of reasonable accuracy in processing. The least significant bit shall correspond to no greater than 0.2% of the CAC.

8.4 Data Processing

Processing software is typically used to scale and filter data, determine zero levels, perform mathematical operations, and prepare data plot formats.

8.4.1 Digital Filtering

Phaseless filters are to be used for post-test filtering. Phaseless filters will cause time uncertainty in turn causing problems in comparing data to film, and comparing data to data if the class filters are different. Filtering shall precede all non-linear operations, such as calculation of resultant vectors and injury indices. Any phaseless filtering algorithm can be used for CFC filtering as long as the total system response conforms to the data channel performance requirements as given in Section 4 (the SAE J211-1 March 1995 Appendix C filter algorithm continues to meet this requirement for CFC-60 and CFC-180). An FFT filtering system is available in Appendix C. Compliance to these corridors can be determined by measuring the attenuation of a known analog input. Alternatively a sum of the data acquisition system, transducer calibration pass/fail corridors, and the phase-less filter response can be compared to the CFC corridor. The type of digital filter used shall be reported. The user is cautioned to examine the unfiltered data for signal overloads, since the filtering process can mask certain overload conditions.

8.4.2 Scaling

A check of the channel gain accuracy shall be applied to each analog input before every test, rather than relying on the set gain values. Corrective measures shall be required when the results of this check are outside of the requirements of 4.6.1.

8.4.3 Zeroing

The zero level of each data channel shall be corrected post-test. This correction shall bring the normalized value of a stable pre-test section of data to the proper initial value for the transducer.

8.4.4 Injury Index Calculations

Injury index calculations shall use all sampled data points. Details on various injury index calculations can be found in SAE J1727.

9. TIMING MARKS

Timing marks are essential in data analysis and correlation of high-speed film to other data channels. Timing frequency error shall be less than 1% of the chosen or designated frequency. Timing synchronization shall be within ±1 ms.

10. TIME OF CONTACT SYNCHRONIZATION

Time of initial contact shall be recorded within 0.4 ms of the closing of a switch actuated by the impact. It shall also be recorded in film data using a visual indicator such as strobe lights or timing mark channels. When a switch is not applicable, Time of Contact may be established through post-test correction or re-setting the T0 mark to coincide with first sample to exceed a predetermined value (for example, 0.5 G) when processed with an appropriate phaseless CFC filter. The established time zero (if different from the initial time of contact) shall be reflected in all digital systems, with no more than 0.4 ms difference between any two systems, and noted in all analog data. Non-analysis cameras shall be exempt.

11. PRESENTATION OF RESULTS

In reporting results of tests, the following information shall be provided with data tabulations, time history traces, etc.:

a. The data channel designations.

b. Description of designated reference points and locations of vehicle accelerations.

c. Transducer mounting analysis, if required by Section 6.

d. Type of digital filter used.

e. Method of combining sub-systems for calibration.

f. Inertial coordinate system definition.

The results shall be presented on A4 (210 x 297 mm) size paper (ISO 216) or 8.5 x 11 inch paper. Results presented as diagrams shall have axes scaled with one measurement unit corresponding to a suitable multiple of the chosen unit (for example 1, 2, 5, 10, 20 mm). SI units shall be used, except for vehicle velocity where kilometers per hour may be used and for accelerations due to an impact where g may be used (with g = 9.80665 m/s/s).

12. STANDARDIZATION OF DIGITAL DATA

For purposes of digital data exchange it is recommended that the ISO or NHTSA format for data exchange be followed. The ISO multimedia data exchange format is defined by the technical specification ISO/TS 13499: 2003. This publication is available through an order to ISO/CS (International Standards Organization) or the National ISO Member ANSI. The documentation for the NHTSA format is available through the Office of Crashworthiness Research (NHTSA). The title of the documentation is NHTSA Version 5 Test Reference Guides.

13. NOTES

13.1 Revision Indicator

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY SAE SAFETY TEST INSTRUMENTATION STANDARDS COMMITTEE

APPENDIX A - SPECIFIC MEASUREMENTS

A.1 IMPACT VELOCITY

This can be calculated by measuring the time required to traverse a known distance prior to impact. Determination of impact velocity shall be with an error of less than 1% of the actual velocity.

A.2 TEST SPECIMEN CRUSH

A.2.1 Residual Crush

Residual crush is specified by one or more single-valued data points, with respect to designated reference points. Determination of residual crush shall be with an error of less than 5% of the actual crush.

A.2.2 Dynamic Crush

Maximum dynamic crush is a measurement of the maximum deformation of the test specimen during the impact. This is also measured with respect to one or more designated reference points. Contingent on the size of the specimen and the magnitude of the expected dynamic crush, the following are possible measurement methods:

a. High-speed motion picture photography.

b. Double integration of acceleration data.

c. Use of a specific displacement transducer.

The error shall be less than 5% of the actual crush.

A.3 STEERING COLUMN DISPLACEMENT

Displacements relative to designated reference points on the vehicle can be measured by various techniques. The coordinate system in which displacement is measured shall be indicated. Determination of steering column displacement shall be accurate to ±0.5 inch (±1.27 cm).

APPENDIX B - TRANSDUCER EQUIVALENCY

Transducer selection is a primary concern in the process of selecting a data channel configuration. Furthermore, the variety of transducers, within a transducer category, i.e., acceleration, pressure, force, displacement, etc., is ever widening, yielding concern regarding equivalence and/or correlation of various transducer performances for any specific application. As the transducer forms an integral part of the data channel, the error contribution of transducer related factors shall be included when considering overall data channel performance requirements as outlined in Section 4.

The purpose of SAE J211 is to recommend techniques of measurement used in impact tests which will provide a basis for meaningful comparison of test results from different sources. This is the goal of establishing equivalency of performance for various transducer types. Such a goal, considered relative to a transducer category, requires thorough knowledge of the measurement objective and its environment. It is not necessarily limited by technological constraints of transducer fabrication or design but is unmistakably linked to both the transient and steady responses under impact loading conditions.

Both steady-state and transient transducer responses depend on the combined performance of the transducer characteristics or specifications. Interaction of transducer characteristics can precipitate significant differences in both steady-state and transient responses between transducers with similar specifications. The user must ascertain combined performance to establish equivalence.

Potential sources of transducer errors are related to data channel compatibility (i.e., transducer may adversely interact with the remainder of the data channel upstream of the anti-aliasing filter), e.g., resonance/damping influences. Other sources of errors are related to environmental compatibility, i.e., non-measurement influences and interactions, which encompass temperature drift, magnetic and electric fields effects, etc., and transducer size, weight, seismic mass location, transverse sensitivity, gage creep, etc. As such, the user must ascertain data channel and environmental compatibility when establishing equivalence.

To establish equivalence, it is the user's responsibility to perform the tests necessary to ensure that the transducers under consideration yield similar results for the application of interest, within the error tolerances recommended by SAE J211 for the whole data channel.

If feasible, to verify equivalence, transducers may be used back-to-back and/or side-by-side in actual test conditions for a given measurement application. A statistically significant number of tests shall be performed to validate the results. This method also may be used if there are no calibration methods to validate the dynamic response of the transducer type in question.

SAE J2570 addresses issues of transducer equivalency. The purpose of the report is to establish guidelines in comparison and selection of various transducer types.

APPENDIX C - VERIFYING THE DATA ACQUISITION SYSTEM PERFORMANCE

To verify compliance with SAE J211 total system response requirements, four sources of attenuation/distortion must be summed and compared to an acceptable limit. The limit is provided by the SAE J211 CFC system corridors, the sources of distortion include the data acquisition system, the transducer, the post-test filter algorithm, and other sources such as noise induced into the cabling. In these routines, an allowance of 0.1 db is provided as a default for all cables between the transducer and the data acquisition system (CBL and CBU). The testing agency shall verify their cables meet this value or modify CBL and CBU if necessary. The total distortion from the data acquisition system and transducer are bounded by their individual calibration pass/fail corridors. Although exact values could be used, the pass/fail corridors provide a worst case scenario for system response. A CFC compliant filter must provide sufficient attenuation to keep the sum of all attenuation/distortion within the SAE J211 CFC system corridor.

In general these routines shall not need to be modified. However, if modification to the routines is necessary they shall be made using good engineering judgment, and aimed at meeting the SAE J211 goal of improving compatibility between test sites. For example, if a data acquisition system has a low frequency anti-aliasing filter it may fall below the lower CFC-1000 boundary. In such a case, the post-test filter would be required to add gain at specific frequencies (which the routines currently do not allow), to keep the system within the SAE J211 CFC corridor. Such a change would require a careful consideration of the affects on noise and distortion, and verification that none of the SAE J211 parameters are violated.

These routines use the fast Fourier transform (FFT) defined by the FFT(v) function from MathCad 8, described as:

Real Fourier transform. This transform has the form (non-optimized):

$$TD_j = \frac{1}{L}\sum_k D_k * e^{-ijk\,2\pi/L} \quad \text{(Eq. C1)}$$

where:

L = the power of two length of data vector (D)

TD = the transformed data vector

i = the imaginary unit (k and j have initial values of zero)

The length of the TD vector from this function will be 0.5*L+1. Some commercial fast Fourier transform functions will result in TD being the same length as L. Within these, the second half of TD vector will be a reflection of the first half. The use of such a FFT function will require some modifications to the routines supplied herein.

Definitions:

CBL The cable boundary lower, the negative lower limit of the attenuation due to sources other than the data acquisition system, transducer, and filter algorithm, such as cabling (default to a max of -0.1).

CBU The cable boundary upper, the positive upper limit of the attenuation due to sources other than the data acquisition system, transducer, and filter algorithm, such as cabling (default to a min of 0.1).

COR A 7 by 16 matrix which defines the nodal points of the CFC corridors.

DAS The data acquisition system. This describes a set of parameters used to collect a data channel for the purpose of designing a custom filter for that channel.

DFZ The delta value for the reference frequency vector, equal to SR/L.

DLA A vector of the attenuations of the nodes in the data acquisition systems lower pass/fail boundary.

DLF A vector of the frequencies of the nodes in the data acquisition systems lower pass/fail boundary.

DUA A vector of the attenuations of the nodes in the data acquisition systems upper pass/fail boundary.

DUF A vector of the frequencies of the nodes in the data acquisition systems upper pass/fail boundary.

FM A matrix containing the FZ vector and each of the CFC filter vectors (as the ratio of attenuation).

FV A vector which provides the custom filter's ratio of attenuation at each of the FZ frequencies (one column from the FM matrix).

FZ A vector of equally spaced reference frequencies, with a delta value of DFZ (corresponding to the FFT transformed data vector).

FZH The greatest FFT reference frequency value, equal to half the DAS sample rate (SR).

L Length of the data vector, with padding (a power of two, at least 15% longer than LDO).

LDO The length of the raw data vector.

LF The length of the frequency domain data vector (the FFT transformed data vector).

SR Data acquisition system sample rate in samples per second.

TLA A vector of the attenuations of the nodes of the transducers lower pass/fail boundary.

TLF A vector of the frequencies of the nodes of the transducers lower pass/fail boundary.

TUA A vector of the attenuations of the nodes of the transducers upper pass/fail boundary.

TUF A vector of the frequencies of the nodes of the transducers upper pass/fail boundary.

Procedure to develop the frequency response curves, in decibels versus frequency, for the each of the post-test filters, referenced to the FZ frequencies.

Create the COR matrix using the following values (four columns per filter corridor).

0.1	0.5	0.1	-0.5	0.1	0.5	0.1	-0.5	0.1	0.5	0.1	-0.5	0.1	0.5	0.1	-0.5
60	0.5	60	-1	180	0.5	180	-1	600	0.5	600	-1	1000	0.5	1000	-1
75	-0.3	75	-1.8	225	-0.3	225	-1.8	1200	0.5	1000	-4	2000	0.5	1650	-4
100	-1.8	100	-3.8	300	-1.8	300	-3.8	3865	-40	2119	-30	6442	-40	3496	-30
130	-5.2	130	-8.2	390	-5.2	390	-8.2	FZH	-40	2120	-9000	FZH	-40	3497	-9000
160	-9.2	160	-13.2	480	-9.2	480	-13.2	0	0	0	0	0	0	0	0
452	-40	452	-48.3	1310	-40	1310	-48.3	0	0	0	0	0	0	0	0
FZH	-40	453	-9000	FZH	-40	1311	-9000	0	0	0	0	0	0	0	0

FZH is the greatest FFT reference frequency value, equal to the DAS sample rate (SR) divided by 2. To add additional filters there are two expected elements, which must be followed:

1. The frequency of the second nodal point is the CFC frequency.

2. If the lower boundary drops to minus infinity, set the attenuation to, at most -8000, the routines will recognize this and treat it as minus infinity.

Use the CORs routine to expand the SAE J211 corridors, referenced to the FZ frequencies. SCS = CORs(DFZ,LF,COR), to generate an expanded SAE J211 corridor matrix using the CORs matrix. The first column is the FZ vector. The following eight columns will provide the upper and lower expanded boundaries of the CFC corridors, in the order they appear in the CORs matrix. Using the same format, create vectors for the data acquisition system and transducer pass/fail nodes.

Example: An accelerometer with a +2% to -2% to 2000 Hz and +5% to -5% to 4000 Hz transducer pass/fail corridor would be as follows:

	0.1		20*log(1.02)		0.1		20*log(0.98)
TUF =	2000	TUA =	20*log(1.02)	TLF=	2000	TLA=	20*log(0.98)
	2001		20*log(1.05)		2001		20*log(0.95)
	4000		20*log(1.05)		4000		20*log(0.95)

Use the FILL routine to expand the four boundary vectors, referencing them to the FZ frequencies.

DU = FILL(DFZ,LF,DUF,DUA), a vector of the upper DAS pass/fail boundary, referenced to FZ.
DL = FILL(DFZ,LF,DLF,DLA), a vector of the lower DAS pass/fail boundary, referenced to FZ.
TU = FILL(DFZ,LF,TUF,TUA), a vector of the upper transducer pass/fail boundary, referenced to FZ.
TL = FILL(DFZ,LF,TLF,TLA), a vector of the lower transducer pass/fail boundary, referenced to FZ.

CBL and CBU are values that represent possible distortion due to cabling. Set these CBU = 0.1 and CBL = -0.1 as a default. If other sources of distortion are suspected, increase the CBL and CBU values to account for the distortion.

Repeat for all combinations of CFC, transducer, and DAS pass/fail corridors, which appear in the processed data.

The CENTERM routine can be used to generate filter response curves, which center the data acquisition system pass/fail corridor in the SAE J211 system corridor. These shall be the target response for all filter routines.

One possible method of filtering:

The CENTERM routine can be used to derive the CFC filters directly, when filtering in the frequency domain. To apply this method the data must be converted into the frequency domain using a Fourier transform, multiplied by an attenuation ratio (the filter vector), and converted back to the time domain. This method allows the CFC filter vectors to be calculated once and stored. The filter does not need to be re-calculated each time it is used, as time based filters are. For this method follow the procedure below.

Choose a value for L if a longer than the minimum value is desired (L is equal to 2^n, where 2^n this is at least 15% longer than the raw data length).

Use the PREPARE routine to convert the data to the frequency domain. The FFT(x) and IFFT(x) elements are a fast Fourier transform, and its inverse (the FFT(x) function will provide a complex vector as a result). Multiple each element of the frequency domain data vector by the corresponding element of the filter vector (one column from the FM matrix).

Use the REMOVE routine to convert the frequency domain and filtered vector to the time domain.

The FILTER routine can be used to apply these four steps.

The TC_COR routine is provided for your convenience. It calculates a maximum transducer pass/fail corridor, considering all of the FM filters and SAE J211 corridors, when only the DAS pass/fail corridor and CBU and CBL values are provided.

For more insight into frequency domain data processing see the SAE paper # 2002-01-0796 (the routines in SAE J211 represent an upgraded to the routines in this paper).

CENTERM(COR,LF,DU,DL,DFZ): a function to make a matrix of the customized FFT filters that centers the data acquisition system pass/fail corridor in the SAE J211 CFC corridors. Beyond the lower CFC boundary drop off frequency (DOI) DB attempts to continue the total system response at -24 db per octave. This function does not allow the filter to add any gain. To generate a plot showing the total system response, see the TSR routine.

COR A matrix containing CFC filter nodal information.
DFZ The delta frequency of the FZ vector (equal to SR/L)
DL The lower data acquisition pass/fail boundary
DU The upper data acquisition pass/fail boundary
LF The length of the transformed data vector, supplied by the FFT process.

```
SCS = call CORs(DFZ,LF,COR)          Call the CORs subroutine to generate the system response corridors.
for r = 0 to LF - 1
    if DL(r) >= -7000                CD = defines the center of the data acquisition system pass/fail corridor.
    then CD(r) = 0.5*(DU(r)+ DL(r))  beyond the CFC corridor drop off it continues at the previous slope.
    else CD(r) = CD(r - 2) + (CD(r - 1) - CD(r - 2))*log(r/(r - 2))/log((r -1)/(r - 2))
    endif
    FM(r,0) = SCS(r,0)               Set the first column of FM equal to the FZ vector (SCS first column).
next r
for c = 2 to cols(SCS) - 1 step 2    For loop in c by 2's from 2 thru the columns in the SCS matrix
    CC = int(COR(1,c*2 - 2)/DFZ)     CC = the index of FZ vector corresponding to the CFC frequency
    CN = int(0.7*CC)                 CN = the index of FZ at 70% of the CC frequency.
    DOI = LF - 1                     Initialize DOI
    while SCS(DOI,c) < -60           find the index of where the lower CFC boundary drops below -60 db
        DOI = DOI - 1
    Wend
    for r = 0 to CN
        if CD(r) < 0
            then DB(r) = 0           Do not allow DB(r) filter to add gain.
            else DB(r) = -1*CD(r)    Have the system provide no attenuation below 90% of FH.
        endif
    next r
    for r = CC + 1 to DOI            For loop in r (row) from CC plus one to DOI
        DB(r) = 0.5*(SCS(r,c - 1) + SCS(r,c) ) - CD(r)    DB = attenuation needed to center CD in the SAE J211 corridor
                                     between CC+1 and DOI frequency indexes.
        MF = SCS(r,c) + 0.2 - DL(r)  MF = the maximum allowable amount of attenuation at this frequency.
        if DB(r) < MF then DB(r) = MF    Do not allow DB(r) filter to be less then MF
        if DB(r) > 0 then DB(r) = 0  Do not allow DB(r) filter to add gain
    next r
    for r = CN+1 to CC               DB = attenuation needed to center CD in the SAE J211 corridor.
        DB(r) = DB(CN) + (DB(CC + 1) - DB(CN))*log(r/CN )/log((CC + 1)/CN )
        If DB(r) > 0 then DB(r) = 0  Do not allow DB(r) filter to add gain
    next r
    MTU = SCS(DOI,c - 1) - DB(DOI) - DU(DOI)    MTU = the gap between DU and the upper CFC corridor boundary at
                                     the DOI frequency, used as a minimum gap size.
    if MTU > 2 then MTU = 2          Limit MTU (the minimum gap size) to a maximum of 2 db.
    for r = DOI + 1 to LF - 1        For loop from the DU drop off frequency to FZH.
        DB(r) = DB(DOI) + CD(DOI) - CD(r) - 24*log(r/DOI)/log ( 2 )    Cause the upper data acquisition system pass/fail
                                     boundary plus DB to continue at -24 db per octave.
        if r > 2*CN then
            MF = SCS(r,c - 1) - MTU - DU(r)    MF = the maximum allowable amount of attenuation at this frequency to
                                     meet MTU. This keeps the upper transducer pass/fail corridor open.
            if DB(r) > MF then DB(r) = MF    Do not allow the transducer upper boundary to be less than MF.
        endif
        if DB(r) > 0 then DB(r) = 0  Do not allow DB(r) filter to add gain
```

next r	
for r = 0 to LF - 1	Convert the filter vector, DB into the ratio of attenuation and stores it.
FM(r,c*0.5)= 10^(0.05*DB(r))	as a column in the filter matrix, FM
next r	
next c	
(return the FM matrix)	

CORs(DFZ,LF,COR): a function to expand the SAE J211 CFC corridors defined by the COR matrix.

COR A matrix defining the nodal points of the SAE J211 CFC corridors.
DFZ Delta FZ the step size in the FZ vector (DFZ = SR/L).
LF The length of the frequency domain data vector.

CO = cols(COR)*0.5 - 1	CO = the number of CFC boundaries (upper and lower), minus one =(the "cols()" function returns the number of columns in the COR matrix).
ROW = rows(COR) - 1	ROW = the number of rows in the COR matrix, minus one (the "rows()" function returns the number of rows in the COR matrix).
for c = 0 to CO	Loop through each of the boundary corridors
F = 0	Clear the frequency vector.
A = 0	Clear the Amplitude vector.
E = 0	Clear the expanded boundary vector.
for r = 0 to ROW	
F(r) = COR(r,c*2)	copy the F vector from the COR matrix
A(r) = COR(r,c*2 + 1)	copy the A vector from the COR matrix
next r	
E = call FILL(DFZ,LF,F,A)	use the FILL routine to generate the expanded boundary vector
for r = 0 to LF - 1	
S(r,c + 1) = E(r)	copy the E vector into the S matrix
next r	
next c	
for r = 0 to LF - 1	
S(r,0) = r*DFZ	make the first column of S equal to the FZ vector.
next r	
(return the S matrix)	

FILL(DFZ,LF,F,A): a function Used to expand a table of nodal points into a vector, with a length of LF and referenced to the FZ frequencies. If the attenuation of the last nodal point drops to minus infinity, set the value to at most -10000. If the boundary becomes horizontal, at least two nodes must be defined.

A A vector of the node attenuation's (corresponding to the F vector frequencies)
DFZ Delta FZ the step size in the FZ vector (□FZ = SR/L).
F A vector of node frequencies (in order from lowest to highest frequency)
LF The length of the frequency domain data vector.

LA = length(A) - 1	LA is the index of the last element of the A and F vectors
while $F_{LA} = 0$	While loop to reduce the length of F to remove any trailing zeros from the node vectors.