Appendix A

Units and Numbers

A.1 Use of SI (Metric Units of Measure in SAE Technical Papers)

The long-term goal for SAE is international communication with minimal effort and confusion. Therefore, the use of SI units in all technical publications and presentations is preferred. The Society will strive toward universal usage of SI units and will encourage their use whenever appropriate.

However, the Society also recognizes that sectors of the mobility market do not yet use SI units because of tradition, regulatory language, or other reasons. Mandating the use of SI units in these cases will impede rather than facilitate technical communication. Therefore, it is the policy to allow non-SI units and dual dimensioning where communication will be enhanced. This shall not be viewed as an avenue to circumvent the long-term goal of 100 percent SI usage.

Instructions on SAE-approved techniques for conversion of units are contained in “SAE Recommended Practices, Rules for SAE Use of SI (METRIC) Units—TSB003.” Copies of TSB003 can be obtained from SAE Headquarters.

Although what follows represents a change to the current policy, it is not a change to the SAE Board of Directors’ Policy since it falls within the scope of the words, “where a conflicting industry practice exists.” Dual (metric/U.S. Customary) units for the following vehicle characteristics may be considered where communication will be enhanced.
A.2 Numbers, Significant Figures, and Rounding

A.2.1 Significant Figures

In all branches of science and technology, numbers are used to express values; i.e., levels or amounts of physical quantities. It is important to state numbers appropriately so that they properly convey the intended information. The number of significant figures contained in a stated number reflects the accuracy to which that quantity is known. For example, suppose the speed of a vehicle is reported as 21 m/s (69 ft/s). Is 21 m/s different from 21.0 m/s? According to the rules of significant figures, yes, but in practice, it may or may not. Could the number 21 m/s imply 20.9 m/s or less or could it imply 21.1 m/s or greater? It could, but such implications or interpretations must be determined from context, not the number 21 itself. Answers to some of these questions are related to the topic of uncertainty (covered in Chapter 1). To properly quantify and communicate a physical measurement or property, it should be stated as a reference value plus and minus an uncertainty. For example, a speed stated as \( v = 21.0 \pm 0.6 \) m/s clearly is meant to be between 20.4 and 21.6 m/s. This is one of the ways of estimating and revealing the uncertainty of results. But the basic rules of using significant figures and rounding must be understood before uncertainty can be expressed. Some of the rules for handling and interpreting the significance of numbers are covered in this Appendix. Note that the terms significant figures and significant digits are used synonymously.

### Table A.1

<table>
<thead>
<tr>
<th>Vehicle characteristic</th>
<th>Metric units</th>
<th>U.S. customary units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume, engine displacement</td>
<td>liters, L, or cubic cm, ( cm^3 )</td>
<td>cubic inches, ( in^3 )</td>
</tr>
<tr>
<td>Liquid volume</td>
<td>liters, L</td>
<td>pints/quarts/gallons</td>
</tr>
<tr>
<td>Engine power</td>
<td>kilowatts, ( kW )</td>
<td>brake horse power, ( bhp )</td>
</tr>
<tr>
<td>Engine torque</td>
<td>Newton-meters, ( N \cdot m )</td>
<td>foot-pounds, ( lb \cdot ft )</td>
</tr>
<tr>
<td>Mass</td>
<td>kilograms, ( kg )</td>
<td>slugs, ( lb \cdot s^2/ft )</td>
</tr>
<tr>
<td>Pressure, stress</td>
<td>kiloPascals, ( kPa )</td>
<td>pounds per square inch, ( psi )</td>
</tr>
<tr>
<td>Temperature</td>
<td>degrees Celsius, ( ^\circ C )</td>
<td>degrees Fahrenheit, ( ^\circ F )</td>
</tr>
<tr>
<td>Area</td>
<td>square cm, ( cm^2 )</td>
<td>square inches, ( in^2 )</td>
</tr>
<tr>
<td>Linear dimensions</td>
<td>millimeters, ( mm ), meters, ( m ), or kilometers, ( km )</td>
<td>inches, ( in ), feet, ( ft ), miles, ( mi )</td>
</tr>
<tr>
<td>Spring rates</td>
<td>Newtons per mm, ( N/mm )</td>
<td>pounds per inch, ( lb/in )</td>
</tr>
<tr>
<td>Speed</td>
<td>kilometers per hour, ( km/h ) or ( kph )</td>
<td>miles per hour, ( mph )</td>
</tr>
<tr>
<td>Fuel economy</td>
<td>kilometers per liter, ( km/L ) or ( kmpl )</td>
<td>miles per gallon, ( mpg )</td>
</tr>
<tr>
<td>Force</td>
<td>Newtons, ( N )</td>
<td>pounds, ( lb )</td>
</tr>
<tr>
<td>Acceleration</td>
<td>kilometers per second per second, ( km/s^2 ), ( g )</td>
<td>feet per second per second, ( ft/s^2 ), ( g )</td>
</tr>
</tbody>
</table>
The number of significant figures in a number is defined in the following way [A.1, A.2]:

1. The leftmost nonzero digit of a number is the most significant digit.
2. If there is no decimal point, the rightmost nonzero digit is the least significant digit.
3. If there is a decimal point, the rightmost digit is the least significant digit, even if it is a zero.
4. All digits, from the least to the most significant, are counted as significant.

So, for example, 2.610 and 2,498 have four significant digits each, whereas 0.125 and 728,000 have three significant digits. The following numbers each has five significant digits: 1000.0, 1206.5, 12,065,000 and 0.00012065. Unless it is stated to be exact, the speed of 21 m/s has two significant figures. If it is exact, then 21 is equivalent to 21.0000 . . . , with an unlimited number of zeros. Each of the speeds 20.4 and 21.6 has three significant figures.

When numbers are very large or very small, it is convenient to express them in scientific notation. To use scientific notation, a decimal point is placed immediately after the leftmost significant digit and the number is given a suffix of 10 raised to a power \( n \). The value of \( n \) is positive or negative. If the magnitude (disregarding the sign) of the stated number is less than 1, then \( n < 0 \). If the stated number is greater than 10, \( n > 0 \). If the stated number is between 1 and 10, \( n = 0 \). The value of \( n \) is the power of 10 that returns the number in scientific notation to its original value. For example, 0.0000687 becomes \( 6.87 \times 10^{-5} \) and 12,360,000 becomes \( 1.236 \times 10^7 \). Note that the number of significant digits does not change when converting to or from scientific notation.

A.2.2 Rounding of Numbers

After completing calculations or when listing the results of measurements, it usually is necessary to round numbers to a lesser number of significant figures by discarding digits. Three possibilities can arise; these are:

1. **The leftmost discarded digit is less than 5.** When rounding such numbers, the last digit retained should remain unchanged. For example, if 3.46325 is to be rounded to four digits, the digits 2 and 5 would be discarded and 3.463 remains.

2. **The leftmost discarded digit is greater than 5 or it is a 5 followed by at least one digit other than 0.** In such cases, the last figure retained should be increased by one. For example, if rounded to four digits, 8.37652 would become 8.377; if rounded to three digits, it would be 8.38.

3. **The leftmost discarded digit is a 5, followed only by zeros or no other numbers.** Here, the last digit retained should be rounded up if it is an odd number, but no adjustment made if it is an even number. For example, 21.165, when rounded to four significant digits, becomes 21.16. The number 21.155 would likewise round to the same value, 21.16.
A reason for this last rule [A.2] is to avoid systematic errors that otherwise would be introduced into the average of a group of such numbers. Not all computer software follows this rule, however\(^1\), and when rounding for purposes of reporting results of measurements and/or calculations, the even-odd rule is not critical.

### A.2.3 Consistency of Significant Figures When Adding and Subtracting

When adding and subtracting numbers, proper determination of the number of significant figures is stated as a rule [A.1]. The rule is, the answer shall contain no significant digits farther to the right than occurs in the number with the least significant digits. The simplest way of following this rule is first to add or subtract the numbers using all of the stated significant figures\(^2\) followed by rounding of the final answer. For example, consider the addition of the three numbers, 964,532 and 317,880 and 563,000. These have six, five, and three significant figures, respectively. The sum by direct addition is 1,845,412. The answer then is adjusted, or rounded, to conform to the number with the least significant figures (563,000 with three), giving the final result, 1,845,000. This number has no more zero digits to the right of the comma than does 563,000. Now consider the sum of the three numbers, 964,532, -317,880 and -563,000; the direct result is 83,652. As above, this must be made to conform with the significant figures of 563,000 by using the rounding rule and is 84,000.

In the last example, the concept being conveyed is that the number 563,000 is “indefinite” to the right of the “3” digit. It is not known if 563,000 could really mean 562,684 or 563,121 or other values, because 563,000, itself, may have been obtained by rounding. If it had been stated as 563,000.0, then everything would be different (since 563,000.0 would have seven significant figures and 317,880 would then have the least significant digits of the three numbers to be added in the above example).

### A.2.4 Consistency of Significant Figures When Multiplying and Dividing

ASTM SI-10 [A.1] states a rule for multiplying and dividing as the product or quotient shall contain no more significant digits than are contained in the number with the fewest significant digits. For example, consider the product, 125.64 × 829.4 × 1.25, of the three numbers with five, four, and three significant digits, respectively. The answer from straightforward multiplication is 130,257.27. After rounding to three significant figures, the proper end result of the multiplication is 130,000. Note that the answer, 130,000, by itself appears to have only two significant figures. This illustrates that ambiguities sometimes can arise when determining significant figures and that the amount of significant figures of a number may need to be found from context. A way of resolving

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\(^1\) The reader may wish to try such an example in their favorite software.

\(^2\) ASTM SI-10 suggests first rounding each individual number to one significant figure greater than the least before adding or subtracting and then rounding the final answer. Though this may be better, it is not the way most computer software operates. Rounding after summing typically gives the same result.
such ambiguities is to express results of rounding in scientific notation. In this case the result would be $1.30 \times 10^5$.

### A.2.5 Other Forms of Number Manipulation

Not all calculations are done with addition, subtraction, multiplication, and division. There are the taking of roots, logarithms, trigonometric functions, etc. In addition, sometimes strict adherence of rounding rules can produce paradoxical or impractical results (see the following example). So more general rules are needed. In summary, two very general, but some practical rules are recommended:

1. In rounding of numbers and conversion of units, retain a number of significant digits such that accuracy and precision are neither sacrificed nor exaggerated.
2. When making and reporting calculations, continually carry all of the significant figures of a calculating device without rounding intermediate values, and round only the final answer.
3. Unit conversion should precede rounding.
4. Whenever possible, explicitly state the uncertainty of the results of measurements and calculations.

Suppose a vehicle skids to a stop over a distance of $d = 33.9$ m from an initial speed, $v$, on a pavement with a uniform frictional drag coefficient of $f = 0.7 \pm 0.1$. Use the minimum and maximum values of $f$ and Eq. 1.1 to calculate bounds on the initial speed. Convert the results to U.S. Customary units of ft/s.

**Solution** The lower value of speed for $f = 0.6$:

$$v = \sqrt{2fgd} = \sqrt{2 \times 0.6 \times 9.806650 \times 33.9} = 19.973345...$$

Similarly, the initial speed for $f = 0.8$ is:

$$v = \sqrt{2 \times 0.8 \times 9.806650 \times 33.9} = 23.063233...$$

The frictional drag coefficient and its uncertainty have the fewest number of significant figures of the input values. According to the rules the final results should be rounded to one significant figure. Rounding $19.973345...$ to a single significant digit gives a speed of $v = 20$ m/s. Rounding $23.063235...$ to a single significant digit also gives a speed of $v = 20$ m/s. Both upper and lower bounds result with the same speed, $v = 20$ m/s. Clearly the result is an exaggeration of precision. Consider now another approach.
The variation of \( f = \pm 0.1 \) is another way of saying that because of uncertainty, \( f \) can take on any value between 0.6 to 0.8. From the above discussion of significant figures and rounding, a point of view can be taken that the lower value, 0.6, for example, could be the result of rounding to one significant figure of any number from 0.55+ to 0.65- (such as 0.551, 0.642, etc.). Similarly, the upper value, 0.8, could be viewed as the result of rounding of any number from 0.75+ to 0.85- (such as 0.751, 0.842, etc.). So the full range of values of the frictional drag coefficient corresponding to the stated uncertainty and from the concepts of significant figures is 0.55 ≤ \( f \) ≤ 0.85. At this point the calculations are performed as if all numbers are exact giving a speed range of 19.123022 . . . ≤ \( v \) ≤ 23.773036 . . . m/s. Since rounding to one significant figure here produces an exaggeration of precision (as above), rounding is done to an additional significant figure. Consequently, the final result is stated as: 19 ≤ \( v \) ≤ 24 m/s, or \( v = 19.5 \pm 2.5 \) m/s. Precision no longer is exaggerated. An initial ±14% variation (0.7 ± 0.1) becomes a 12% variation of \( v \) (19.5 ± 2.5) through the use of Eq. 1.1.

Finally, the speed is to be converted to the U.S. Customary units of ft/s. The proper conversion factor is 1 ft = 0.3048 m (this is an exact conversion; see the following unit conversion table). Unit conversions should be done before rounding, so 19.123022 . . . ≤ \( v \) ≤ 23.773036 . . . m/s becomes 62.739573 . . . ≤ \( v \) ≤ 77.995525 . . . ft/s. Rounding again to one significant figure gives the same result, 70 ft, so another significant figure is acceptable, giving 63 ≤ \( v \) ≤ 78 ft/s, or \( v = 70.5 \pm 7.5 \) ft/s.

Another consideration that must be kept in mind when rounding is the use or purpose of the results; for example, if the speed calculated in the last example is to be compared to a speed limit, say 25 m/s. Rounding to a number of significant digits to the right of the decimal point is superfluous. The result 19 ≤ \( v \) ≤ 24 m/s is satisfactory to conclude that the calculated speed is less than the speed limit. Instead, suppose that the calculated speed is a measure of vehicle braking performance and is to be compared to a governmental regulation stated to three significant figures. Rounding to an additional significant figure leads to an exaggeration of accuracy. To compare the speed to such a regulation requires a more accurate value of friction, stated at least to two significant figures.

### A.3 Unit Conversions for Common Units

Factors in **boldface** are exact. When options exist, units in the first column printed in *italics* are preferred by the National Institute for Science and Technology. [A.3]

<table>
<thead>
<tr>
<th>To convert from</th>
<th>To</th>
<th>Multiply by</th>
</tr>
</thead>
<tbody>
<tr>
<td>acre (based on U.S. survey foot)</td>
<td>square meter (m²)</td>
<td>4.046 873</td>
</tr>
<tr>
<td>acre foot (based on U.S. survey foot)</td>
<td>cubic meter (m³)</td>
<td>1.233 489</td>
</tr>
<tr>
<td>ampere hour (A • h)</td>
<td>coulomb (C)</td>
<td>3.6</td>
</tr>
<tr>
<td>atmosphere, standard (atm)</td>
<td>pascal (Pa)</td>
<td>1.013 25</td>
</tr>
</tbody>
</table>

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3. Note that there is no implication of the likelihood of any of the values within this range.
<table>
<thead>
<tr>
<th>Unit Description</th>
<th>Base Unit</th>
<th>Conversion Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>atmosphere, standard (atm)</td>
<td>kilopascal (kPa)</td>
<td>1.01325 E+02</td>
</tr>
<tr>
<td>atmosphere, technical (at)</td>
<td>pascal (Pa)</td>
<td>9.80665 E+04</td>
</tr>
<tr>
<td>atmosphere, technical (at)</td>
<td>kilopascal (kPa)</td>
<td>9.80665 E+01</td>
</tr>
<tr>
<td>bar (bar)</td>
<td>pascal (Pa)</td>
<td>1.0 E+05</td>
</tr>
<tr>
<td>bar (bar)</td>
<td>kilopascal (kPa)</td>
<td>1.0 E+02</td>
</tr>
<tr>
<td>barn (b)</td>
<td>square meter (m²)</td>
<td>1.0 E-28</td>
</tr>
<tr>
<td>barrel [for petroleum, 42 gallons (U.S.)] (bbl)</td>
<td>cubic meter (m³)</td>
<td>1.589873 E-01</td>
</tr>
<tr>
<td>barrel [for petroleum, 42 gallons (U.S.)] (bbl)</td>
<td>liter (L)</td>
<td>1.589873 E+02</td>
</tr>
<tr>
<td>British thermal unit (mean) (Btu)</td>
<td>joule (J)</td>
<td>1.05587 E+03</td>
</tr>
<tr>
<td>bushel (U.S.) (bu)</td>
<td>cubic meter (m³)</td>
<td>3.523907 E+02</td>
</tr>
<tr>
<td>bushel (U.S.) (bu)</td>
<td>liter (L)</td>
<td>3.523907 E+01</td>
</tr>
<tr>
<td>calorie (cal) (mean)</td>
<td>joule (J)</td>
<td>4.19002 E+00</td>
</tr>
<tr>
<td>candela per square inch (cd/in²)</td>
<td>candela per square meter (cd/m²)</td>
<td>1.55003 E+03</td>
</tr>
<tr>
<td>carat, metric</td>
<td>kilogram (kg)</td>
<td>2.0 E-04</td>
</tr>
<tr>
<td>centimeter of mercury (0 °C)</td>
<td>pascal (Pa)</td>
<td>1.33322 E+03</td>
</tr>
<tr>
<td>centimeter of water (4 °C)</td>
<td>pascal (Pa)</td>
<td>9.80665 E+01</td>
</tr>
<tr>
<td>centimeter of water, conventional (cm H₂O)</td>
<td>pascal (Pa)</td>
<td>9.80665 E+01</td>
</tr>
<tr>
<td>centipoise (cP)</td>
<td>pascal second (Pa • s)</td>
<td>1.0 E-03</td>
</tr>
<tr>
<td>centistokes (cSt)</td>
<td>meter squared per second (m²/s)</td>
<td>1.0 E-06</td>
</tr>
<tr>
<td>chain (based on U.S. survey foot) (ch)</td>
<td>meter (m)</td>
<td>2.011684 E+01</td>
</tr>
<tr>
<td>circular mil</td>
<td>square meter (m²)</td>
<td>5.067075 E-10</td>
</tr>
<tr>
<td>cord (128 ft³)</td>
<td>cubic meter (m³)</td>
<td>3.624556 E+00</td>
</tr>
<tr>
<td>cubic foot (ft³)</td>
<td>cubic meter (m³)</td>
<td>2.831685 E+02</td>
</tr>
<tr>
<td>cubic inch (in³)</td>
<td>cubic meter (m³)</td>
<td>1.638706 E+05</td>
</tr>
<tr>
<td>cubic mile (mi³)</td>
<td>cubic meter (m³)</td>
<td>4.168182 E+09</td>
</tr>
<tr>
<td>cubic yard (yd³)</td>
<td>cubic meter (m³)</td>
<td>7.645549 E+01</td>
</tr>
<tr>
<td>cup (U.S.)</td>
<td>cubic meter (m³)</td>
<td>2.365882 E-04</td>
</tr>
<tr>
<td>cup (U.S.)</td>
<td>liter (L)</td>
<td>2.365882 E-01</td>
</tr>
<tr>
<td>day (d)</td>
<td>second (s)</td>
<td>8.64 E+04</td>
</tr>
<tr>
<td>day (sidereal)</td>
<td>second (s)</td>
<td>8.616409 E+04</td>
</tr>
<tr>
<td>degree (angle) (°)</td>
<td>radian (rad)</td>
<td>1.745329 E-02</td>
</tr>
<tr>
<td>degree Celsius (temperature) (°C)</td>
<td>kelvin (K)</td>
<td>K = °C + 273.15</td>
</tr>
<tr>
<td>degree Celsius (temperature interval) (°C)</td>
<td>kelvin (K)</td>
<td>1.0 E+00</td>
</tr>
<tr>
<td>degree centigrade (temperature)</td>
<td>degree Celsius (°C)</td>
<td>°C = deg. cent.</td>
</tr>
<tr>
<td>degree centigrade (temperature interval)</td>
<td>degree Celsius (°C)</td>
<td>1.0 E+00</td>
</tr>
<tr>
<td>degree Fahrenheit (temperature) (°F)</td>
<td>degree Celsius (°C)</td>
<td>°F = (°C - 32) / 1.8</td>
</tr>
<tr>
<td>degree Fahrenheit (temperature) (°F)</td>
<td>kelvin (K)</td>
<td>K = (°F + 459.67) / 1.8</td>
</tr>
<tr>
<td>degree Fahrenheit (temperature interval) (°F)</td>
<td>degree Celsius (°C)</td>
<td>5.555556 E-01</td>
</tr>
<tr>
<td>Unit Description</td>
<td>Unit Symbol</td>
<td>Conversion Factor</td>
</tr>
<tr>
<td>------------------</td>
<td>-------------</td>
<td>------------------</td>
</tr>
<tr>
<td>Degree Fahrenheit (temperature interval)</td>
<td>°F</td>
<td>5.555 556 E-01</td>
</tr>
<tr>
<td>Degree Rankine (°R)</td>
<td>kelvin (K)</td>
<td>K = (°R)/1.8</td>
</tr>
<tr>
<td>Degree Rankine (temperature interval)</td>
<td>°R</td>
<td>5.555 556 E-01</td>
</tr>
<tr>
<td>Denier</td>
<td>kilogram per meter (kg/m)</td>
<td>1.111 111 E-07</td>
</tr>
<tr>
<td>Dyne (dyn)</td>
<td>newton (N)</td>
<td>1.0 E-05</td>
</tr>
<tr>
<td>Dyne centimeter (dyn • cm)</td>
<td>newton meter (N • m)</td>
<td>1.0 E-07</td>
</tr>
<tr>
<td>Dyne per square centimeter (dyn/cm²)</td>
<td>pascal (Pa)</td>
<td>1.0 E-01</td>
</tr>
<tr>
<td>Erg (erg)</td>
<td>joule (J)</td>
<td>1.0 E-07</td>
</tr>
<tr>
<td>Erg per second (erg/s)</td>
<td>watt (W)</td>
<td>1.0 E-07</td>
</tr>
<tr>
<td>Fathom (based on U.S. survey foot)</td>
<td>meter (m)</td>
<td>1.828 804 E+00</td>
</tr>
<tr>
<td>Fluid ounce (U.S.) (fl oz)</td>
<td>cubic meter (m³)</td>
<td>2.957 353 E-05</td>
</tr>
<tr>
<td>Fluid ounce (U.S.) (fl oz)</td>
<td>milliliter (mL)</td>
<td>2.957 353 E+01</td>
</tr>
<tr>
<td>Foot (ft)</td>
<td>meter (m)</td>
<td>3.048 E-01</td>
</tr>
<tr>
<td>Foot (U.S. survey) (ft)</td>
<td>meter (m)</td>
<td>3.048 006 E-01</td>
</tr>
<tr>
<td>Footcandle</td>
<td>lux (lx)</td>
<td>1.076 391 E+01</td>
</tr>
<tr>
<td>Footlambert</td>
<td>candela per square meter (cd/m²)</td>
<td>3.426 259 E+00</td>
</tr>
<tr>
<td>Foot of water, conventional (ftH₂O)</td>
<td>pascal (Pa)</td>
<td>2.989 067 E+03</td>
</tr>
<tr>
<td>Foot of water, conventional (ftH₂O)</td>
<td>kilopascal (kPa)</td>
<td>2.989 067 E+00</td>
</tr>
<tr>
<td>Foot per hour (ft/h)</td>
<td>meter per second (m/s)</td>
<td>8.466 667 E-05</td>
</tr>
<tr>
<td>Foot per minute (ft/min)</td>
<td>meter per second (m/s)</td>
<td>5.08 E-03</td>
</tr>
<tr>
<td>Foot per second (ft/s)</td>
<td>meter per second (m/s)</td>
<td>3.048 E-01</td>
</tr>
<tr>
<td>Foot per second squared (ft/s²)²</td>
<td>meter per second squared (m/s²)²</td>
<td>3.048 E-01</td>
</tr>
<tr>
<td>Foot poundal</td>
<td>joule (J)</td>
<td>4.214 011 E-02</td>
</tr>
<tr>
<td>Foot pound-force (ft • lbf)</td>
<td>joule (J)</td>
<td>1.355 818 E+00</td>
</tr>
<tr>
<td>Foot pound-force per hour (ft • lbf/h)</td>
<td>watt (W)</td>
<td>3.766 161 E-04</td>
</tr>
<tr>
<td>Foot pound-force per minute (ft • lbf/min)</td>
<td>watt (W)</td>
<td>2.259 697 E-02</td>
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<tr>
<td>Foot pound-force per second (ft • lbf/s)</td>
<td>watt (W)</td>
<td>1.355 818 E+00</td>
</tr>
<tr>
<td>Gallon (Gal)</td>
<td>meter per second squared (m/s²)</td>
<td>1.0 E-02</td>
</tr>
<tr>
<td>Gallon [Canadian and U.K. (Imperial)] (gal)</td>
<td>cubic meter (m³)</td>
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</tr>
<tr>
<td>Gallon [Canadian and U.K. (Imperial)] (gal)</td>
<td>liter (L)</td>
<td>4.546 09 E+00</td>
</tr>
<tr>
<td>Gallon (U.S.) (gal)</td>
<td>cubic meter (m³)</td>
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</tr>
<tr>
<td>Gallon (U.S.) (gal)</td>
<td>liter (L)</td>
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</tr>
<tr>
<td>Gallon (U.S.) per day (gal/d)</td>
<td>cubic meter per second (m³/s)</td>
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<tr>
<td>Gallon (U.S.) per day (gal/d)</td>
<td>liter per second (L/s)</td>
<td>4.381 264 E-05</td>
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<tr>
<td>Gallon (U.S.) per horsepower hour [gal/(hp • h)]</td>
<td>cubic meter per joule (m³/J)</td>
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<tr>
<td>Gallon (U.S.) per horsepower hour [gal/(hp • h)]</td>
<td>liter per joule (L/J)</td>
<td>1.410 089 E-06</td>
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4. Standard value of free-fall acceleration is g = 9.80665 m/s².
<table>
<thead>
<tr>
<th>Unit Conversion</th>
<th>Unit of Measurement</th>
<th>Conversion Factor</th>
<th>Notes</th>
</tr>
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<tbody>
<tr>
<td>Gallon (U.S.) per minute (gpm) (gal/min)</td>
<td>Cubic meter per second (m³/s)</td>
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<td>E-05</td>
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<td>Grain (gr)</td>
<td>Kilogram (kg)</td>
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</tr>
<tr>
<td>Grain (gr)</td>
<td>Milligram (mg)</td>
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</tr>
<tr>
<td>Grain per gallon (U.S.) (gr/gal)</td>
<td>Kilogram per cubic meter (kg/m³)</td>
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<td>Milligram per liter (mg/L)</td>
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</tr>
<tr>
<td>Gram-force per square centimeter (gf/cm²)</td>
<td>Pascal (Pa)</td>
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<tr>
<td>Gram per cubic centimeter (g/cm³)</td>
<td>Kilogram per cubic meter (kg/m³)</td>
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<td>Hectare (ha)</td>
<td>Square meter (m²)</td>
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<td>Horsepower (boiler)</td>
<td>Watt (W)</td>
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<td>Horsepower (electric)</td>
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<tr>
<td>Horsepower (water)</td>
<td>Watt (W)</td>
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<td>Hour (h)</td>
<td>Second (s)</td>
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<tr>
<td>Hour (sidereal)</td>
<td>Second (s)</td>
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<td>E+03</td>
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<td>Kilogram (kg)</td>
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<td>Hundredweight (short, 100 lb)</td>
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<td>Meter (m)</td>
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<tr>
<td>Inch (in)</td>
<td>Centimeter (cm)</td>
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<td>Inch of mercury, conventional (in. Hg)</td>
<td>Kilopascal (kPa)</td>
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<td>Kelvin (K)</td>
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<td>t°C = T/K - 273.15</td>
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<tr>
<td>Kilocalorie (mean) (kcal)</td>
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<tr>
<td>Kilogram-force (kgf)</td>
<td>Newton (N)</td>
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<td>E+00</td>
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<td>Newton meter (N • m)</td>
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<td>Kilometer per hour (km/h)</td>
<td>Meter per second (m/s)</td>
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<td>Newton (N)</td>
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<tr>
<td>Kip (1 kip= 1000 lbf)</td>
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<td>Reference Unit</td>
<td>Conversion Factor</td>
<td>Precision</td>
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<td>knot (nautical mile per hour)</td>
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<td>meter (m)</td>
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<td>meter per cubic meter (m³)</td>
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<td>mile per gallon (U.S.) (mpg) (mi/gal)</td>
<td>kilometer per liter (km/L)</td>
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<td>E-01</td>
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<td>mile per gallon (U.S.) (mpg) (mi/gal)</td>
<td>liter per 100 kilometer (L/100km)</td>
<td>divide 235.215 by number of miles per gallon</td>
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<td>meter per second (m/s)</td>
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<td>pascal (Pa)</td>
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<td>E+02</td>
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<tr>
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<td>E+00</td>
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<tr>
<td>minute (angle) (°)</td>
<td>radian (rad)</td>
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<tr>
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<td>second (s)</td>
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<td>minute (sidereal)</td>
<td>second (s)</td>
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</tr>
<tr>
<td>ounce (avoirdupois) (oz)</td>
<td>kilogram (kg)</td>
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</tr>
<tr>
<td>ounce (avoirdupois) (oz)</td>
<td>gram (g)</td>
<td>2.834 952</td>
<td>E+01</td>
</tr>
<tr>
<td>ounce (troy or apothecary) (oz)</td>
<td>kilogram (kg)</td>
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<td>E-02</td>
</tr>
<tr>
<td>ounce (troy or apothecary) (oz)</td>
<td>gram (g)</td>
<td>3.110 348</td>
<td>E+01</td>
</tr>
<tr>
<td>ounce [Canadian and U.K. fluid (Imperial)] (fl oz)</td>
<td>cubic meter (m³)</td>
<td>2.841 306</td>
<td>E-05</td>
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## Units and Numbers

<table>
<thead>
<tr>
<th>Unit (Canadian and U.K. fluid (Imperial)) (fl oz)</th>
<th>Milliliter (mL) 2.841 306 E+01</th>
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<tbody>
<tr>
<td>Ounce (U.S. fluid (fl oz))</td>
<td>Cubic meter (m³) 2.957 353 E-05</td>
</tr>
<tr>
<td>Ounce (U.S. fluid (fl oz))</td>
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<tr>
<td>Ounce (avoirdupois)-force (ozf)</td>
<td>Newton (N) 2.780 139 E-01</td>
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<tr>
<td>Ounce (avoirdupois)-force inch (ozf • in)</td>
<td>Newton meter (N • m) 7.061 552 E-03</td>
</tr>
<tr>
<td>Ounce (avoirdupois)-force inch (ozf • in)</td>
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<td>Cubic meter (m³) 8.809 768 E-03</td>
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<td>Kilogram (kg) 1.555 174 E-03</td>
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<td>Pennyweight (dwt)</td>
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<td>Meter (m) 4.233 333 E-03</td>
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<tr>
<td>Pica (computer) (1/6 in)</td>
<td>Millimeter (mm) 4.233 333 E+00</td>
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<td>Meter (m) 4.217 518 E-03</td>
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<td>Pica (printer’s)</td>
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</tr>
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<tr>
<td>Point (computer) (1/72 in)</td>
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<td>Point (printer’s)</td>
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</tr>
<tr>
<td>Poise (P)</td>
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<td>Pound (avoirdupois) (lb)</td>
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</tr>
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<td>Pound (troy or apothecary) (lb)</td>
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<tr>
<td>Poundal second per square foot</td>
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<tr>
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<td>Kilogram meter squared (kg • m²) 4.214 011 E-02</td>
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<tr>
<td>Pound-force (lbf)¹</td>
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</tr>
<tr>
<td>Pound-force foot (lbf • ft)</td>
<td>Newton meter (N • m) 1.355 818 E+00</td>
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<tr>
<td>Pound-force foot per inch (lbf • ft/in)</td>
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<td>Pound-force inch per inch (lbf • in/in)</td>
<td>Newton meter per meter (N•m/m) 4.448 222 E+00</td>
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5. If the local value of the acceleration of free fall is taken as the standard value \( g = 9.90665 \text{ m/s}^2 \), then the exact conversion factor is \( 4.448 221 615 260 5 \text{ E}+00 \).
<table>
<thead>
<tr>
<th>Unit</th>
<th>Equivalent Unit</th>
<th>Conversion Factor</th>
<th>Precision</th>
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<tbody>
<tr>
<td>pound-force per foot (lbf/ft)</td>
<td>newton per meter (N/m)</td>
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<td>newton per meter (N/m)</td>
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<tr>
<td>pound-force per pound (lbf/lb) (thrust to mass ratio)</td>
<td>newton per kilogram (N/kg)</td>
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<tr>
<td>pound-force per square foot (lbf/ft²)</td>
<td>pascal (Pa)</td>
<td>4.788 026</td>
<td>E+01</td>
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<td>pound-force per square inch (psi) (lbf/in²)</td>
<td>pascal (Pa)</td>
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<td>E+03</td>
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<td>pound-force per square inch (psi) (lbf/in²)</td>
<td>kilopascal (kPa)</td>
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<td>E+00</td>
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<td>pascal second (Pa • s)</td>
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<td>pound inch squared (lb • in²)</td>
<td>kilogram meter squared (kg •m²)</td>
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<td>E+00</td>
</tr>
<tr>
<td>pound per gallon [Canadian and U.K. (Imperial)] (lb/gal)</td>
<td>kilogram per cubic meter (kg/m³)</td>
<td>9.977 637</td>
<td>E+01</td>
</tr>
<tr>
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<td>kilogram per liter (kg/L)</td>
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<tr>
<td>torr (Torr)</td>
<td>pascal (Pa)</td>
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<td>year (tropical)</td>
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Common Terms and Acronyms in Accident Reconstruction

The terms defined here are for the convenience of the readers, both those learning accident reconstruction as well as those already familiar with the field. Not all terms included in the list are used in this book.

**18-wheeler**: A tractor, semitrailer with a total of 18 wheels; see tractor, semitrailer.

**A, B, C, D, pillars and posts**: The vertical pillars and posts of a light vehicle forming the major vertical structural members of the body; see Fig. B1. Pillars typically are at window height; posts are below window height. From front to rear, the A post/pillar is the most forward member, the B post/pillar is the second most forward vertical member, etc.

![Figure B1. Pillars and posts.](image)
AACN: Automatic Advanced Crash Notification, General Motors term for ACN (see also ACN).

AADT: Average Annual Daily Traffic.

AASHTO: American Association of State Highway and Transportation Officials.


ABS: Antilock Braking System.

ACAT: Advanced Collision Avoidance Technology.

ACC: Adaptive Cruise Control.

acceleration: Change in linear or angular velocity or speed with respect to time.

accelerometer: An electromechanical sensing device with an output signal proportional to acceleration.

accident investigation: The process of observation, acquisition, and documentation of physical evidence and other information regarding an accident or crash.

accident reconstruction: A procedure carried out with the specific purpose of estimating in both a qualitative and quantitative manner how an accident occurred using engineering, scientific, and mathematical principles and based on evidence obtained through accident investigation.

accident scene: A place where a traffic accident occurs, both during and immediately following the accident, and before vehicles and participants have departed; see accident site.

accident site: A place where a traffic accident occurred, after vehicles and participants have departed the scene; see accident scene.

accident, vehicle: An event in which one or more vehicles undergo unexpected action(s), usually involving contact with another vehicle or other object, producing injury, death, and/or property damage; an accident is an unstabilized situation which includes at least one harmful event; see crash.

ACM: Airbag Control Module (Chrysler), control module for airbags and related restraint systems, see RCM and SDM.

ACN: Automatic Crash Notification System.

acoustic levels: see sound levels.

ADA: Americans with Disabilities Act.

ADR: Accident data recorder; see EDR.
AE: Algorithm Enable


aggressivity: The inertial and structural properties and characteristics of a vehicle that relate to the severity of injuries to occupants in the other vehicle in a crash.

agricultural commodity trailer: Trailer designed to transport bulk commodities from harvest sites to process or storage sites.

air bag: A device in the interior of a vehicle that inflates and acts between an occupant and an interior vehicle surface to prevent injury in a crash; see supplemental restraint system.

angular acceleration: The time rate of change of angular velocity.

angular velocity: The time rate of change of rotational displacement.

animation: The process by which the movement of objects is illustrated.


approach speed: Speed of a vehicle just prior to the first significant event such as contact in an accident; see closing speed.

aquaplaning: See hydroplaning.

area of impact: Area encompassed by the interface between colliding objects projected onto the road; see point of impact.

articulated vehicle: A vehicle comprised of two or more distinct, interconnected bodies such as a tractor, semitrailer.

asphalt: See bituminous pavement.


BAC: Blood Alcohol Concentration.

backlite header: The structural body member which connects the upper portions of the rearmost driver and passenger pillars and forms the top edge of the backlite (back window) [B.1].

backlite: The rear or back window which spans from the driver’s to passenger’s side of the vehicle [B.1].

barrier equivalent velocity (BEV): The forward speed and corresponding kinetic energy with which a vehicle contacts a flat fixed rigid barrier at 90° with no rebound; see also equivalent energy speed (EES).
**Appendix B**

**BAS**: Brake Assist System

**BCM**: Body Control Module.

**BEV**: Barrier Equivalent Velocity, or Battery Electric Vehicle.

**bicycle model**: A two-wheeled vehicle used conceptually in vehicle dynamics studies to represent a four-wheeled vehicle where the side-to-side extent of the vehicle is neglected for simplicity.

**bituminous pavement**: A pavement comprising an upper layer or layers of aggregate with a bituminous binder (asphalt, coal tars, natural tars, etc.) and surface treatments such as chip seals, slurry seals, sand seals, and cape seals.

**black box**: See event data recorder.

**blacktop**: See bituminous pavement.

**BMP**: BitMaP, digital photograph file format.

**bobtail**: A term used to refer to a truck tractor being driven without a semitrailer.

**brake slip**: See wheel slip.

**braking distance**: The distance taken to bring a vehicle to rest during brake application in straight forward motion; see stopping distance.

**braking force, peak**: The largest force that can be developed during brake application as wheel slip is varied over the range of free-rolling slip to locked-wheel slip.

**braking force**: The force over the contact surface between a tire and a road in the direction of heading of the braked wheel that develops as a result of brake application.

**BTO**: Brake Throttle Override.

**BTS**: Bureau of Transportation Statistics.

**BTSI**: Brake Transmission Shift Interlock.

**Btu**: British thermal unit.

**bus**: A vehicle designed to transport more than 15 passengers, including the driver.

**CAA**: Clean Air Act.

**CAD**: Computer Aided Design (often referring to drafting software).

**CAFE**: Corporate Average Fuel Economy.

**CAN**: Controller Area Network, a type of communication bus (see also GMLAN).
CCD: Charge Coupled Device (such as the sensor in a digital camera).

CCM: Cruise Control Module.

CDR: Crash Data Retrieval System; a system used to image crash data from certain light vehicles.

center of gravity (cg): That point of a body through which the resultant force of gravity (weight) acts irrespective of the orientation of the body.

center of impact: See impact center.

center of mass: See center of gravity.

central impact: An impact in which the contact impulse passes through the center of gravity; see oblique impact.

CDL: Commercial Driver’s License


change in momentum: The difference of the momentum (product of mass and velocity) of a mass from one time to another; the difference of the momentum of a mass between the beginning and end of contact with another mass; the difference in the momentum of a system of bodies; see also conservation of momentum.

change of velocity: The difference between velocity vectors at two points in time; see also ΔV, delta-V.

CHB: Crash Imminent Braking.

CHOP: a broad shallow gouge in a road surface, beginning with an even, regular, deeper side and terminating in scratches and striations on the opposite shallower side; a depression in pavement made by a strong, sharp metal edge moving under heavy pressure [B.2], more commonly occurring at an impact event as opposed to post-impact trajectory.

clearance lamp: Light used on the front or rear of a motor vehicle to indicate overall width or height.

closing speed: The magnitude of the relative velocity between two vehicles at a given point in time as they approach each other; the relative velocity between two vehicles as they approach each other at the beginning of a accident; normal component of the closing velocity; see approach speed.

closing velocity: The magnitude of the relative velocity between two vehicles at a given point in time as they approach each other; the magnitude of the relative velocity between two vehicles at the beginning of a crash; the vector difference between the velocity of the vehicle and the vehicle/object struck immediately before impact.
CMV: Commercial Motor Vehicle.

CO: Carbon monoxide.

CO2 (CO2): Carbon dioxide.

coefficient of friction: A number representing the resistance to sliding of two flat surfaces in contact; defined as the ratio of the resistance force to the normal force between the surfaces; see frictional drag factor.

coefficient of restitution: The ratio of the relative normal velocity at the time of separation to the relative normal velocity at the time of initial contact between the point area of contact of two colliding bodies.

coefficient of rolling resistance: The ratio of the force of resistance to rolling with zero slip to the vertical load of a wheel or vehicle; see rolling resistance.

collision deformation classification (CDC): A classification of the extent of deformation to an automobile, utility vehicle, pickup, and van from a crash [B.3].

collision: Sudden contact of a vehicle with an object or another vehicle, usually resulting in visible damage; see impact, crash.

common contact point: See impact center

common velocity conditions: Two independent conditions applicable to a collision where at the time of separation the relative normal velocity component is zero (no restitution) and the relative tangential component of velocity is zero (sliding has ended).

compatibility, vehicle: Disparities in structural crashworthiness of different sized vehicles due to varying structural geometries, such as different heights of vehicles’ front and side structures; a tendency of some vehicles to inflict more damage on another vehicle in a crash.

concrete pavement: A solidified pavement with an upper layer of aggregate (such as sand and stone) mixed with Portland cement paste binder.

conservation of momentum: The principle of physics for vehicles in dynamic contact stating that in the absence of external forces, the sum of the preimpact momentum is equal to the sum of the postimpact momentum of the vehicles.

contact damage: Deformation sustained in a vehicle from physical engagement with another vehicle or object; see induced damage, residual crush, dynamic crush.

contact patch: The area or region of mutual contact between a tire and the surface over which it rests or moves.

contact point: The point of intersection of the resultant contact impulse with the intervehicular contact surface of each of two colliding vehicles; see impact center.
contact surface: See intervehicular contact surface.

coordinate system, vehicle: See three-axis vehicle coordinate system.

cornering coefficient: See sideslip coefficient.

CPR: Crash Pulse Recorder, a device that measures acceleration during a crash; see accelerometer.

CRAF: Civil Reserve Air Fleet.

crash duration: The period of time defined by the moment when two vehicles come in contact until that time when they separate.

crash pulse: The shape of the intervehicular force curve during the crash duration.

crash reconstruction: See accident reconstruction.

crash: An event in which one or more vehicles make unintended contact with another vehicle or other object producing injury, death, and/or property damage; see accident, impact, collision.

CRASH3: An acronym for Calspan Reconstruction of Speeds on the Highway, Version 3; a method of reconstruction that uses the calculation of the crush energy of a collision and an approximate postimpact trajectory spinout simulation.

crashworthiness: The characteristics of a motor vehicle which represent occupant protection of that vehicle in a specific collision.

critical speed formula: A formula, $v_{cr} = \sqrt{fgR}$, that calculates the speed of a vehicle from its radius of curvature, $R$, frictional drag coefficient, $f$, and acceleration of gravity, $g$.

critical speed: The maximum speed at which a vehicle can traverse a path with a specific radius of curvature without loss of directional control; the speed of a vehicle undergoing a sudden turn maneuver at which the tires leave visible sideslip marks.

crumple zone: That portion of the front or rear of a vehicle designed to absorb energy of a collision for the protection of the occupants.

crush area: Area defined by the original vehicle exterior and a crush profile.

crush equivalent speed: See energy equivalent speed, EES.

crush profile: The geometric shape in a specified plane (e.g., vertical, horizontal) which describes the vehicle damage resulting from an impact.

crush stiffness coefficient: An empirical quantity used in the calculation of the energy dissipated in a collision and associated with each vehicle’s velocity change, $\Delta V$; see CRASH3.
crush stiffness: See crush stiffness coefficient.

CTE: Coefficient of Thermal Expansion.

curb weight: The weight of a motor vehicle with standard equipment and maximum fuel capacity.

CVT: Continuously Variable Transmission.

delta-t (Δt or Δτ): A time interval associated with an event such as vehicle-to-vehicle contact; the time duration of impulse.

delta-v (ΔV): The difference or change of a velocity vector over a time interval; the difference in the velocity vector of the center of gravity of a vehicle between separation and first contact in a crash.

departure velocity: See separation velocity.

deployment (event): Actuation of a supplementary restraint, based on an enabling algorithm, following which acceleration and other data are recorded and made available to an event data recorder.

deployment level (event): An acceleration level sufficient to cause the GM SDM’s crash-sensing algorithm to “enable” and anticipate a collision severity which otherwise warrants a deployment for that vehicle but a deployment had been previously commanded.

decibel: A logarithmic measure of the level, L, of a time-varying signal, s(τ), relative to a reference value s_{ref}.

\[
L = 10 \log \frac{s^2}{s_{ref}^2}
\]

where s^2 is the mean square value of the signal.

DGPS: Differential Global Positioning System.

direction of principal force (DOPF): See principal direction of force, PDOF.

divot: A piece of turf or sod torn up by dynamic contact.

DLC: Diagnostic Link Connector, may also be seen as Data Link Connector.


DoT, DOT: United States Department of Transportation; see NHTSA.
**drag factor**: An equivalent acceleration expressed as a fraction of the acceleration of gravity, g; also see frictional drag coefficient.

**drag sled**: A weighted device (whose bottom surface is covered with a portion of tire tread) which is pulled along a roadway surface and provides a sliding friction coefficient of that device and roadway surface by computing the ratio of the pull force to its weight.

**dwt**: Deadweight tons.

**drop axle**: An unpowered auxiliary axle on a truck that can be raised or lowered to change the vertical load distribution of permanent axles (also called tag axle).

**DTC**: Diagnostic Trouble Code.

**dual wheels**: The use of two closely spaced wheels on one side of an axle, typically used on trucks and semitrailers.

**DXF**: Drawing Exchange Format, graphical format for drawings made with CAD programs.

**dynamic crush**: The deformation formed by the external surface of a vehicle at any time during an impact, usually measured relative to the corresponding as-manufactured undeformed surface; see crush area, crush profile, static crush, residual crush.

**eccentric impact**: See oblique impact.

**ECE**: Economic Commission for Europe (United Nations).

**ECI**: Electronic Conductive Immunity.

**EDS**: Explosive Detection Systems.

**EDR**: Event Data Recorder; a function within a vehicle module (ACM, PCM...) which has the capability to save certain crash data parameters after primary functions are completed.

**elastic deformation**: Deformation which is fully recovered after an applied force is removed.

**elastic impact**: An idealized impact where the kinetic energy at separation equals the kinetic energy at the initiation of contact; a fully elastic impact is an impact where the coefficient of restitution is equal to one.

**electronic control module (ECM)**: See Electronic Control Unit (ECU).

**electronic control unit (ECU)**: The computer in a vehicle that controls vehicle system operation, including functions such as engine operation, On Board Diagnostics (OBD), Stability Control, Safety System Operation, etc.
**electronic data recorder (EDR):** See event data recorder.

**EMC:** Electromagnetic Compatibility.

**EMI:** Electromagnetic Interference.

**energy equivalent speed (EES):** The speed and corresponding kinetic energy with which a vehicle must contact a fixed rigid object with no rebound for equivalence to conditions of another collision; for example, the energy may be equal to a specified level of residual crush; EES is a preferred term, broader than barrier equivalent velocity (BEV), equivalent barrier speed (EBS), and equivalent test speed (ETS).

**energy equivalent velocity:** See energy equivalent speed and equivalent barrier speed.

**engine control module (ECM):** An electronic device in a vehicle (especially heavy trucks) that controls engine operation.

**EPA:** U.S. Environmental Protection Agency.

**EPS:** Electronic Power Steering.

**ERI:** Electronic Radiated Immunity.

**ESD:** Electrostatic Discharge.

**ESC:** Electronic stability control.

**ESP:** An acronym for Chrysler’s Electronic Stability Program (see ESC).

**equivalent barrier speed (EBS):** The forward speed and corresponding kinetic energy with which a vehicle must contact a flat, fixed, rigid barrier at 90° with no rebound for equivalence to conditions of another collision; for example, the energy may be equal to a specified level of residual crush; see also equivalent energy speed (EES).

**equivalent test deformation:** See EES.

**equivalent test speed (ETS):** ISO term and is a non-preferred term, see EBS and EES.

**ETC:** Electronic Throttle Control (can also mean: electronic toll collection).

**ETMS:** Enhanced Traffic Management System.

**EU:** European Union.

**EVC:** Electronic Vehicle Control.

**event data recorder (EDR):** An onboard electronic module or device capable of monitoring, recording, and displaying precrash, crash, and postcrash data and information from a vehicle, event, and driver.
EXIF: Exchangeable Image File Format (photographs).

FAA: Federal Aviation Administration.

FAF: Freight Analysis Framework.

farm tractor: A powered farm vehicle designed to pull farm implements (such as a plow, farm trailer, manure spreader, etc.)

FARS: Fatality Analysis Reporting System.

FARs: Federal Aviation Regulations.

FHWA: U.S. Federal Highway Administration.

first contact position: The position, or location, at an accident scene (measured relative to a coordinate system fixed to the earth) of a vehicle, pedestrian, or other object at the time it first has contact with another body in a collision.

first contact velocity: The velocity of the center of gravity of a vehicle, pedestrian, or other object at its first contact position.

fixed object: A stationary object such as a guardrail, bridge railing or abutment, construction barricade, impact attenuator, tree, embedded rock, utility pole, ditch side, steep earth or rock slope, culvert, fence, or building [B.4].

flip: Movement of a vehicle from a place where the forward velocity of a part of the vehicle suddenly is stopped by an object below its center of gravity such as a curb, rail, or furrow with the result that the ensuing rotation lifts the vehicle from the ground.

FMCSA: Federal Motor Carrier Safety Administration.

FMCSR: Federal Motor Carrier Safety Regulations.

FMEA: Failure Modes and Effects Analysis.

FMVSS: Federal Motor Vehicle Safety Standard; see NHTSA.

forward projection pedestrian collision: A frontal collision of vehicle and pedestrian or cyclist where the initial contact area is at or above the height of the center of gravity of the pedestrian or cyclist and where a single impact with the frontal geometry of the vehicle causes the pedestrian or cyclist to be projected straight forward relative to the vehicle.

four point transformation: A photogrammetric technique whereby points positioned on a surface reasonably approximated by a plane with unknown locations can be located through the use of four additional points whose locations are known; see photogrammetry.
FRA: Federal Railroad Administration.

friction: Resistance to sliding over a contact surface between two materials.

friction coefficient: See coefficient of friction.

frictional drag coefficient: An average, uniform (constant) value of a sliding friction coefficient applied to a specific sliding event such as when an object slides from an initial speed to a stop over a distance, \( d \), or during a speed change, \( \Delta V \).

frictional drag factor: See frictional drag coefficient.

frontal impact: An impact or collision involving the front of a vehicle.

FTA: Federal Transit Administration, also Fault Tree Analysis.

full trailer: A towed vehicle with a fixed rear axle and a front axle that pivots and is made to be pulled by a powered tow vehicle (an example is a farm trailer).

furrow: A channel in a loose or soft material, such as snow or soil, made by a vehicle tire or some other part of a moving vehicle.

GA: General Aviation.

GAW: Gross Axle Weight is the total weight carried by an individual axle (front and rear) including the vehicle weight and cargo.

GAWR: Gross Axle Weight Rating is the maximum allowable weight that can be carried by a single axle (front or rear).

GCW: Gross Combined Weight is the weight of a loaded vehicle plus the weight of a fully loaded semitrailer.

GCWR: Gross Combined Weight Rating is the maximum allowable weight of a vehicle and loaded semitrailer.

GHG: Greenhouse Gas.

GIF: Graphics Interchange Format, digital photograph file format.

GIS: Geographic Information Systems.

glare: Interference to a driver’s vision due to natural or artificial, direct or reflected light.

gouge or gouge mark: Pavement or ground scar deep enough to be easily felt with the fingers; see Fig. B6 and also chop and groove.

GMLAN: A General Motors implementation of the Controller Area Network (CAN) type serial communication protocol.
GPS: Global Positioning System.

groove: A long, narrow, pavement gouge or a channel in a pavement.

gross vehicle weight rating: The upper limit of combined weight and cargo for a vehicle established by design, regulation, or both

gross vehicle weight: The combined weight of a vehicle and its cargo.

GVWR: See Gross Vehicle Weight Rating.

HAPs: Hazardous Air Pollutants.

heading angle, ψ: The angle between a reference axis fixed in the vehicle and a reference axis fixed in the roadway, giving a measure of vehicle yaw rotation or directional orientation relative to the roadway; see Fig. B2 [B.5].

head-on impact: Frontal impact where the PDOF is at or near zero degrees.

heavy truck classifications: See truck classifications.

HEV: Hybrid Electric Vehicle.

HELP: Heavy Vehicle Electronic License Plate.


HPMS: Highway Performance Monitoring System.
HSI: Human-System Integration.

HSR: High-Speed Rail.

HTF: Highway Trust Fund.

HV: Heavy Vehicle.

Hydroplaning: A phenomenon where a layer of fluid (usually water) on a roadway separates the load-bearing surface of one or more tires of a moving vehicle from the road surface and causes a full loss of traction (longitudinal) and steering (transverse) force components.

IBET: Intermodal Bottleneck Evaluation Tool.

Illumination: Placement or existence of natural or artificial light on an area presented to a driver.

Impact center: The point of intersection of the contact impulse and the intervehicular contact surface for an impact; see contact point.

Impact force (lever arm) moment arm: See impulse moment arm.

Impact velocity: The velocity of an object’s center of gravity relative to a coordinate system fixed in the earth during an impact; see preimpact velocity, postimpact velocity.

Impact: The striking of one body against another; short-duration, high-force contact of two objects; a collision of a vehicle with another vehicle, a pedestrian, or some other object; see collision, crash.

Impulse moment arm: The perpendicular distance from an object’s center of gravity to the line of action of an impulse; see Fig. B3; see also impact force moment arm.

Figure B3. Illustration of the moment arm, \( d \), of an impulse and the PDOF, Principal Direction of Force.
**impulse ratio**: The ratio of the tangential and normal impulse components in planar impact mechanics; see impulse.

**impulse**: A combination of force, \( F \), and time, \( \tau \), defined as a mathematical integral, \( \int F \, d\tau \), of the force over a specific time duration.

**induced damage**: Residual deformation caused without direct contact by virtue of being adjacent to deformation caused by direct contact; see residual crush.

**initial contact**: The point in time and space when two objects begin to touch or interact with no significant force. The beginning of an impact.

**INS**: Immigration and Naturalization Service.

**intervehicular contact surface**: A single, planar surface that represents the average (over time and space) deformed contact surface between two vehicles or a vehicle and barrier.

**intervehicular crush plane**: See intervehicular contact surface.

**intrusion**: Reduction of the pre-crash space within the passenger space compartment [B.6].

**IPCC**: Intergovernmental Panel on Climate Change.

**ISO**: International Organization for Standardization, Geneva, Switzerland.

**ISTEA**: Intermodal Surface Transportation Efficiency Act.

**ITS**: Intelligent Transportation System.

**JPEG**: Joint Photographic Experts Group, digital photograph file format.

**KPH**: Kilometers Per Hour (also km/h).

**leading edge**: The foremost part of a vehicle with respect to the vehicle’s motion and attitude.

**light vehicle**: An automobile, passenger van, pickup truck, or sport utility vehicle.

**LNG**: Liquefied Natural Gas.

**LPG**: Liquefied Petroleum Gas.

**LTV**: Light Trucks and Vans.

**LV**: See light vehicle.

**MAIT**: Multidisciplinary Accident Investigation Team (NHTSA).

**maximum crush depth**: Deepest part of a crush profile; see dynamic crush or residual crush.
maximum engagement: The point in time when the maximum dynamic crush occurs.

MDB: Moving Deformable Barrier.

MMUCC: Model Minimum Uniform Crash Criteria.

moment of inertia: A physical property of a body that represents its resistance to rotational acceleration.

MPG: Miles Per Gallon.

MPH: Miles Per Hour.

MTBE: Methyl-tertiary-butyl-ether.

MTC: Mechanical Throttle Control.


NASS: National Automotive Sampling System.

NCAP: New Car Assessment Program (DoT, NHTSA).

NDR: National Driver Register.

neutral steer: When a vehicle, traveling on a circular path at constant speed and a constant front wheel steer angle, is accelerated it will remain on a path with the same radius, tend to increase its radius, or tend to decrease its radius; these are defined as neutral steer, understeer, and oversteer, respectively; see oversteer and understeer.

NHTSA: National Highway Traffic Safety Administration; see DoT.

NO2 (NO₂): Nitrogen dioxide.

NOX: Nitrogen oxides.

NPTS: Nationwide Personal Transportation Survey.

NTL: National Transportation Library.

NTSB: National Transportation Safety Board.

OBD: On Board Diagnostics.

oblique impact: An impact in which the contact impulse does not pass through the center of gravity; see central impact.

occupant compartment: That portion of a vehicle’s interior designed for the use of passengers during operation of the vehicle.

ODI: Office of Defects Investigation (NHTSA).
offset: The distance between the longitudinal heading axes of two vehicles in frontal contact; see Fig. B4; see overlap.

OPEC: Organization of Petroleum Exporting Countries.

ORC: Occupant Restraint Controller, see event data recorder (EDR).

OTR: Over The Road.

overhang, front rear: The longitudinal dimension of a vehicle from the center of the front/rear wheels to the foremost/rearmost point on the vehicle including bumper, bump guards, tow hooks, and/or rub strips if standard equipment.

overlap: The length of mutual contact damage; see Fig. B4; see offset.

override: A condition in a collision where the main structural members such as a bumper of the striking vehicle are above the main structural members such as frame rails of the struck vehicle; see Fig. B5; see underride.

oversteer: When a vehicle, traveling on a circular path at constant speed and a constant front wheel steer angle, is accelerated it will remain on a path with the same radius, tend to increase its radius, or tend to decrease its radius; these are defined as neutral steer, understeer, and oversteer, respectively; see neutral steer and understeer.

PCM: Powertrain Control Module; also Pulse Code Modulation (a way of digitally transmitting analog data).
PAR: Police Accident Report.

PCR: Police Crash Report.

PDOF: See principal direction of force.

PDR time: See perception-decision-reaction time.

perception-decision-reaction time: The time required by a person to complete a response to an event or stimulus; see reaction time.

PFD: Personal Flotation Device.

PHEV: Plug-In Hybrid Electric Vehicle.

photogrammetry: The process of determining the quantitative dimensional information of objects in two or three dimensions through the process of recording, interpreting, and transforming measurements from a flat photographic image.

pitch, roll, yaw: Terms that distinguish rotations of a vehicle about three perpendicular axes with origin at the vehicle's center of gravity; pitch is rotation about the horizontal, side-to-side axis; roll is rotation about a horizontal front-to-rear axis; and yaw is rotation about the vertical axis; see Fig. B7; see yaw angle.

planar impact: An impact in which all forces, moments, and motion takes place in a plane.

plastic impact: An impact with little or no rebound at the end of impact; a perfectly plastic impact is where the coefficient of restitution is equal to zero.

PM-10: Particulate matter of 10 microns in diameter or smaller.

PM-2.5: Particulate matter of 2.5 microns in diameter or smaller.

PMT: Passenger-Miles of Travel.

point mass: An idealized concept from mechanics where an object is considered to have mass but no extent, no finite dimensions, and as a consequence, its rotation is irrelevant; see rigid body.

point of contact: The point of intersection of the contact impulse and the intervehicular contact surface during an impact; see also impact center, first contact position, PDOF, DOPF.

postcollision trajectory, postimpact trajectory: The path of a vehicle from the time of separation to its rest position.

postcrash damage: Damage existing to a vehicle after it came to rest, including damage that may result during rescue, towing, and salvage operations.
postimpact speed: The magnitude of the velocity of an object in a collision at the time of separation, or end of contact; see postimpact velocity and separation speed.

postimpact velocity: The velocity of an object in a collision at the time of separation, or end of contact; see postimpact speed and separation speed.


preimpact velocity: The velocity of a vehicle in a collision at the instant of its initial contact.

principal direction of force (PDOF): The direction of the line of action of the contact impulse in a planar collision expressed in degrees, measured clockwise from the longitudinal axis of a vehicle; see Fig. B3.

PRNDL: Park-Reverse-Neutral-Drive-Low (shift mechanism sequence).

PTC: Positive Train Control.

PUV: Personal-Use Vehicle.

radius of gyration: The square root of the quotient of the moment of inertia and the mass of a rigid body; see moment of inertia.

RCM: Restraint Control Module (Ford).

reaction time: See perception-decision-reaction time.

residual crush: The permanent deformation formed by the nominal external surface of a vehicle caused by an impact, usually measured relative to the corresponding as-manufactured undeformed surface; see crush area, crush profile.

rest position: The location of the center of gravity of a vehicle following an accident measured relative to a coordinate system fixed in the earth.

reverse projection photogrammetry: The photogrammetric procedure of inserting a transparency that contains outlines of transient and fixed objects into a camera for the purpose of determining the position and orientation of the camera at the time the original photograph was taken to facilitate the re-location of the transient information.

RFG: Reformulated gasoline.

RFI: Radio Frequency Interference.

rigid body: A concept from mechanics where an object is considered to have mass and dimensions (such as length, width, radius, etc.) that remain constant and which provide resistance to rotation; see point mass, moment of inertia.

roll out: Part or all of a postimpact trajectory in which little or no sideslip of a vehicle's wheels occur; see spinout.
roll: See pitch, roll, yaw, and yaw angle.

rollbar: A structural member placed over the occupant compartment of a vehicle to protect the occupants against the effects of roof crush during vehicle rollover: also used in some busses and construction machinery.

rolling resistance: The retarding force of a freely rolling wheel due to interaction with a contact surface, parallel to the heading axis of a wheel of a moving vehicle; also:

- a force opposite to the direction of travel resulting from deformation of a rolling tire [B.7, B.8]
- several resistances to motion that may be classified as due to friction in the wheel bearings, friction in the tire walls and tread as they flex when rolling along the road surface, deformation of road surface, impact resistance due to irregularities of road surface, and churning of air by wheels [B.9].

rollover: Vehicle motion where its wheels leave the road surface and at least one side or top of the vehicle contacts the ground; see flip and vault.

ROPS: Rollover Protection System.

ROR: Run-Off-the-Road.

SAE coordinate system: See three-axis vehicle coordinate system.

SAI (SA): Sudden Acceleration Incident (Sudden Acceleration).

scrape: A mark on a surface that is wider than it is deep that can usually be felt with fingers.

scratch: A light and usually irregular scar made on a hard surface, such as paving, by a sliding metal part without great pressure [B.2]. Scratches are visible but not normally distinguishable to the touch.

SCTG: Standard Classification of Transported Goods.

scuff marks: Relatively short marks made by a moving tire on a road or other surface in an erratic fashion with no specific, consistent features; for example, acceleration scuff, impact scuff, flat tire mark; see Fig. B6; see yaw marks, skid marks.
SDD: Sudden Deceleration Data (Cummins Engines).

SDM: Sensing and Diagnostic Module; an electronic device in a vehicle that captures and stores information in the event of a crash in which air bags may or may not deploy; see EDR.

**second impact**: An impact between an occupant and an interior surface of a vehicle caused by and following an impact between the vehicle and another object.

**secondary impact**: A second or subsequent impact between the same two vehicles during the crash.

**semi**: See tractor, semitrailer.

**semitrailer**: A semitrailer is a towed vehicle equipped with one or more axles to the rear of its laden center of gravity and whose front end forms part of a pivot joint attached to a truck tractor or other powered tow vehicle (examples are truck, cargo, recreational, boat, and livestock trailers).

**separation speed**: The speed at the time of loss of contact of two vehicles in a collision, can refer to the speed of the centers of gravity or of the contact point.

**separation velocity**: The vector velocity at the time of loss of contact of two vehicles in a collision can refer to the speed of the centers of gravity or at the contact point.

**service brake system**: The primary brake system used for slowing and stopping a vehicle.

**SI System of Units**: Metric system, (Système International d’Unités).

**side rail**: The outermost edge on the side of a vehicle’s roof connecting the upper ends of the A, B, C, and D pillars.

**sideslip angle, tire**: See tire slip angle.

**sideslip angle, vehicle**: The angle between the vehicle’s heading and its velocity vector (β in Fig. B2); see sideslip.

**sideslip coefficient**: The slope of the initial linear portion of the lateral force-slip angle curve of a tire.

**sideslip stiffness**: See sideslip coefficient

**sideslip**: Lateral/transverse translation of a vehicle perpendicular to its heading; see Fig. B2; see tire slip angle.

**sideswipe collision**: A collision of a vehicle where sliding (relative tangential motion) over the intervehicular contact surface does not end at or before separation; see common velocity conditions.
**simulation**: The use of mathematics and mechanics, usually done using a computer, to represent, reproduce or model a physical process.

**SIR**: Supplemental Inflatable Restraint.

**skid**: Motion over a surface of a vehicle with its wheels locked from rotation.

**skid number**: A number representing tire-pavement frictional drag determined by measurements made according to standard equipment, conditions, and procedures and usually stated as 100 times a friction coefficient.

**skidmark**: A friction mark on a pavement made by a tire that is sliding without rotation and, if along the heading axis of the tire, displays a tread pattern.

**sliding friction coefficient**: See coefficient of friction.

**slip angle, tire**: See wheel sideslip angle.

**slip speed**: The speed of a single wheel in the direction of its heading at a given value of longitudinal wheel slip.

**slip stiffness**: See wheel slip coefficient.

**SLIP**: See wheel slip, sideslip.

**SO2 (SO2)**: Sulfur dioxide.

**SOC**: State of Charge (electric vehicles).

**sound level**:

\[
L_p = 10 \log \frac{P^2}{P_{ref}^2}, \text{ where } s^2 \text{ is the mean square acoustic pressure and } P_{ref} = 2 \times 10^{-5} \text{ N/m}^2
\]

\[
L_{W} = 10 \log_{10} \frac{W}{W_{ref}} , \text{ where } W \text{ is the acoustic power and } W_{ref} = 1 \times 10^{-6} \text{ W}
\]

**speed**: The rate of change of vehicle displacement with respect to time; the magnitude of velocity.

**spinout**: A descriptive term for postimpact vehicle motion including significant yaw rotation; see postimpact trajectory.

**static crush**: See residual crush.

**stiffness coefficient**: See crush stiffness coefficient.
**stopping distance**: The distance taken by a driver to bring a vehicle to rest in straight forward motion by braking, including the distance traveled during perception-decision-reaction time prior to brake application; see braking distance.

**STRAHNET**: Strategic Highway Network.

**striations**: Periodic stripes that appear transverse to the tire marks from a yawing vehicle.

**superelevation**: A side-to-side slope of a road measured in degrees or percent.

**supplemental restraint system**: An interior vehicle device that inflates when actuated by accelerometers and/or crash sensors and acts between an occupant and an interior vehicle surface to prevent injury due to sudden contact; see air bag.

**SUV**: Sport Utility Vehicle.

**tag axle**: See drop axle.

**tandem axles**: The use of two closely spaced axles, front-to-rear, usually for buses, heavy trucks, and trailers.

**TAU**: Throttle Actuation Unit.

**TEA-21**: Transportation Equity Act for the 21st Century.

**three-axis vehicle coordinate system**: Fig. B7 shows the standard, three-dimensional vehicle coordinate system.

**Figure B7.**

Diagram of a three-axis SAE coordinate system.

**throw distance**: The distance a pedestrian is propelled (in the direction of vehicle motion at impact) between the location of the pedestrian at first contact and pedestrian's rest position.
TIFF (TIF): Tagged Image File Format, digital photograph file format.

tire marks: General term for marks on a surface generated by tires; can be scuffs, skids, yaw marks, prints, etc.

tire slip angle (also tire sideslip angle): See wheel slip angle.

total station: An electro-optical device, usually mounted on a tripod, used to make position measurements such as in-site surveys.

tractor, semitrailer: A truck tractor (cab) with two or more axles pulling a semitrailer; see Fig. B8.

Figure B8. Illustration of an automobile riding under the rear of a semitrailer.

tractor trailer: A truck tractor (cab) with two or more axles pulling a trailer.

tractor: See truck tractor or farm tractor.

trailer: A trailer is a towed vehicle equipped with two axles; the front axle is attached to the tow vehicle and pivoted for turning, whereas the rear axle is fixed.

trailing edge: The term used to describe that portion of a vehicle component (such as door, window, fender, quarter, etc.) which is closest to the rear of the vehicle. The rearmost part of a vehicle with respect to a vehicle’s motion and attitude.

trajectory: The path of the center of gravity of a body as it moves through space; usually associated with coordinates of the center of gravity as a function of time; see Fig. B2.

TRB: Transportation Research Board.

trip point: That location along a ground surface at which the motion of a vehicle component is suddenly halted followed by a flip, rollover, or vault.

truck classifications: Trucks are classified according to their GVWR

<table>
<thead>
<tr>
<th>Class</th>
<th>GVWR range, lb</th>
<th>Class</th>
<th>GVWR range, lb</th>
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<tbody>
<tr>
<td>1</td>
<td>0 - 6,000</td>
<td>2</td>
<td>6,001 - 10,000</td>
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<td>3</td>
<td>10,001 - 14,000</td>
<td>4</td>
<td>14,001 - 16,000</td>
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<td>5</td>
<td>16,001 - 19,500</td>
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<td>19,501 - 26,000</td>
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<td>7</td>
<td>26,001 - 33,000</td>
<td>8</td>
<td>33,001 and above</td>
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</table>
truck deformation classification (TDC): A classification system used to appropriately describe a collision-damaged truck. It consists of seven alphanumeric characters arranged in specific order to form a descriptive composite of the vehicle damage [B.6].

truck tractor: A motor vehicle designed for pulling semitrailers. Basic types are cab-over-engine and conventional.

TSA: Transportation Security Administration.


TSC: Transportation Systems Center (NHTSA).

UA: Unintended Acceleration.

underride: A condition in a collision where the main structural components of one vehicle are below the main structural components of the other vehicle; see Fig. B8; see override.

understeer: When a vehicle, traveling along a circular path on a flat, level surface with a constant speed and a constant front-wheel steer angle is accelerated, it will remain on a path with the same radius, tend to increase its radius, or tend to decrease its radius; these are defined as neutral steer, understeer, and oversteer, respectively; see neutral steer and oversteer.


UST: Underground Storage Tank.

V2I: Vehicle To Infrastructure (electronic communication).

V2V: Vehicle To Vehicle (electronic communication).

VCE: Vehicle Control Electronics.

VIIC: Vehicle Information Integration Consortium.

V-MAC: Vehicle Management and Control Unit (Mack Trucks).

vault: A roll or pitch motion of a vehicle made following loss of ground contact.

vehicle coordinate system: See Figs. B2 and B7; see three-axis vehicle coordinate system.

vehicle length: The maximum dimension measured longitudinally between the foremost point and the rearmost point in the vehicle, including bumper, bumper guards, tow hooks, and/or rub strips, if standard equipment [B.1]. Also known as overall length (OAL).

vehicle width: The maximum dimension measured between the widest point on the vehicle, excluding exterior mirrors, flexible mud flaps, and marker lamps, but including
bumpers, moldings, sheet metal protrusions, or dual wheels if standard equipment [B.1]. Also known as overall width (OAW).

**velocity**: The rate of change of displacement with both a magnitude and direction; the magnitude of velocity is referred to as speed.

**velocity-time curve** (*v*-τ or *v*-t curve): A graphical depiction of velocity of the center of gravity of a vehicle as it changes over time.

**vmt**: Vehicle-miles of travel.

**VOC**: Volatile Organic Compounds.

**VOQ**: Vehicle Owner Questionnaire (NHTSA).

**VRTX**: Vehicle Research and Test Center (NHTSA).

**wheel base**: The perpendicular distance between axes through front and rear wheel centerlines of a vehicle. In case of dual axles, the distance is to the midpoint of the centerlines of the dual axles.

**wheel slip angle** (also wheel sideslip angle): The angle between a wheel’s heading axis (*x* axis) and direction of the velocity vector of the center of the wheel.

**wheel slip coefficient**: The slope of the initial linear portion of the longitudinal force-wheel slip curve of a tire.

**wheel slip**: The ratio of the forward velocity of a tire at the road contact patch to the forward velocity at the center of the wheel (for braking) or the ratio of the forward velocity of a tire at the center of the wheel to the forward velocity at the road contact patch (for traction or acceleration).

**windshield header**: The structural body member which connects the upper portions of the left and right A-pillars and is above the top edge of the windshield.

**WOT**: Wide Open Throttle.

**wrap pedestrian collision**: A frontal collision of vehicle and pedestrian or cyclist where initial contact occurs at a point below the center of gravity of the pedestrian or cyclist and where the frontal geometry of the vehicle allows the pedestrian to move rearward relative to the vehicle and strike another portion of the vehicle, such as a windshield. The latter impact causes the pedestrian or cyclist to develop an airborne trajectory followed by an impact with the ground.

**WWC**: Windshield Wiper Control.

**yaw angle**: The angle between the heading of a vehicle and a fixed reference; see Fig. B2.
**yaw mark**: A tire mark caused by a sideslipping tire, often showing a striped pattern called striations.

**yaw moment of inertia**: The moment of inertia about a vertical axis of a vehicle; see moment of inertia, radius of gyration.

**yaw rate**: Angular velocity about the z-axis; see Fig. B2.

**yaw**: See pitch, roll, yaw, and yaw angle.
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**Chapter 5**


Chapter 6


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