AEROSPACE STANDARD	AS6969™	REV. A
	Issued 2018-06 Revised 2020-10 Superseding AS6969	

(R) Data Dictionary for Quantities Used in Cyber Physical Systems

RATIONALE

This revision A of AS6969 introduces additional quantity definitions to support unmanned systems. Further, the previous universally unique identifier (UUID) attached to each definition is now a definition universal resource indicator (URI) that includes the AS6969 namespace, the UUID and a version indicator. AS6969A is available as both a document and a UML model.

FOREWORD

This data dictionary provides definitions for quantities commonly used in the command and control of cyber physical systems. It defines mathematical and logical terms, quantities, measurement units, reference systems, measurands, and measurements. It also defines common quantity modalities. The dictionary is structured to be convenient to data modelers. It is also extendable so that users can create their own quantity domains.

In this data dictionary, a quantity is defined as a property of a phenomenon, substance, or body whose value has numerical magnitude. In contrast, a property whose value does not have numerical magnitude is a nominal property. For example, an identity number is an instance of a nominal property and the length of 0.304 meters is an instance of a quantity.

A measurand specification describes the phenomenon, body or substance and the quantity to be measured. For example, the measurand of aircraft airspeed based on the quantity of velocity. A measurement is the set of operations having the object of determining the value of the quantity.

A quantity modal qualifies the semantics of a quantity value. Four modalities are defined that concern the necessity or possibility of a value, the obligation or permissibility of a value, the uncertainty of a value, and derived quantities based on an a-priori waveform model (for example, the values associated with a quantity phasor).

At the highest level, a quantity may be a cardinal quantity or an ordinal quantity depending on whether the numerical part of the value is a cardinal number or an ordinal number respectively. Cardinal quantities may be used in algebraic operations. Ordinal quantities may be used in empirical relationships only. The previous example of length is a cardinal quantity. An example of an ordinal quantity is the octane rating of a liquid fuel for spark-ignition internal combustion engines. The value of a cardinal quantity can be presented in many different mathematical structures including the categories of scalars, true vectors, affine vectors, and true tensors. Except for scalars, these categories are defined by coordinate reference systems (or the transformations between them). Other mathematical categories such as topological spaces can be defined by users if necessary. A coordinate reference system fixes the axes of a coordinate system to the axes of a coordinate datum.

For guidance, Section 4 provides a comprehensive overview of structure and mathematics of this data dictionary. Section 10 provides advice on data modeling considerations.

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
SAE WEB ADDRESS: http://www.sae.org

For more information on this standard, visit
https://www.sae.org/standards/content/AS6969A/

TABLE OF CONTENTS

1. SCOPE

This data dictionary provides definitions for quantities, measurement units, reference systems, measurands, measurements and quantity modalities commonly used in the command and control of cyber physical systems. A cyber physical system is an engineered system that is built from, and depends upon, the seamless integration of computational algorithms and physical components. Cyber physical systems are often interconnected via data links and networks. The term encompasses intelligent vehicles and devices that operate in any environment, including robotic and autonomous systems.

1.1 Purpose

This data dictionary may be used in the development and cross-comparison of data models and in general system and software engineering. The data dictionary can also be extended by users through the creation of quantity domains.

Considerable interoperability can be achieved between different data models when these models reference the same definition URIs provided in this dictionary or its extensions. This includes data models based on different modeling languages and annotated with different spoken languages.

1.2 Limitations

This data dictionary is concerned with state data exchanged during the operational activities of cyber physical systems. It is not concerned with system design specifications or parameters. This data dictionary is not concerned with the datatypes or classes in a data model.

1.3 Viewpoint

In a data model, a class or datatype may own properties. A quantity is a property whose value has a numerical magnitude. For example, the class Aircraft may own the property of airspeed whose basic quantity is velocity. In this example, the measurand specification is Aircraft:: airspeed: Velocity.

Specific measurands may be defined in extensions to this standard. These extensions are called quantity domains. This core standard defines basic quantities together with their mathematical structures. For example, the basic quantity of velocity may be expressed in different vector spaces and measurement units. This core standard also defines the general definitions and structure of a quantity domain.

In a cyber physical system, a quantity value may have multiple modalities. A categorical value is the observable state of the measurand. Other modalities can express possible or necessary values, permissible or obligatory values, the uncertainty of a value, and so on. These modalities are defined in this core standard and would be applied in specific data models that reference this data dictionary.

2. REFERENCES

2.1 Applicable Documents

IS0 80000 Quantities and units

- Part 1: General
- Part 2: Mathematical signs and symbols to be used in the natural sciences and technology
- Part 3: Space and time
- Part 4: Mechanics
- Part 5: Thermodynamics
- Part 7: Light
- Part 8: Acoustics
- Part 9: Physical chemistry and molecular physics
- Part 10: Atomic and nuclear physics

IEC 80000 Quantities and units

- Part 6: Electromagnetism
- Part 13: Information Science and Technology

NIST Handbook 44: Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices

SAE TSB 003: Rules for SAE Use of SI (Metric) Units

DoD World Geodetic System 1984, NIMA TR8350.2, Third Edition Amendment 1

2.2 Related Publications

JCGM 100:2008 Evaluation of measurement data - Guide to the expression of uncertainty in measurement

3. DEFINITIONS AND MATHEMATICAL SYMBOLS

3.1 Definitions

3.1.1 Definitions Concerning Numbers

3.1.1.1 Cardinal Number

In general usage, a cardinal number is a countable numeral that expresses an amount of entities or an amount of measurement units.

NOTE: The numerical value of a cardinal quantity is a cardinal number.

3.1.1.2 Ordinal Number

In general usage, an ordinal number represents the numerical position of an entity in an ordered series or the numerical position of a measurement on an ordinal measurement scale.

NOTE: The numerical value of an ordinal quantity is an ordinal number.

3.1.1.3 Nominal Number

A nominal number is a numeral that represents the identity of an object or represents a measurement value without magnitude. Nominal numbers have no mathematical significance.

NOTE: A nominal number may be the value of a nominal property.

3.1.2 Definitions Concerning Quantities

3.1.2.1 Quantity

A quantity is the property of a phenomenon, body or substance where the property has a value with a numerical magnitude. Two types of quantity are defined: cardinal quantity and ordinal quantity.

3.1.2.2 Cardinal Quantity

A cardinal quantity is a quantity that has magnitude that can be expressed by a numeral multiplied with a measurement unit. A cardinal quantity is a scalar. Cardinal quantities may be used in algebraic operations.

NOTE: All quantities currently in the International System of Quantities (ISQ) (ISO/IEC 80000) are cardinal quantities.

3.1.2.3 Relative Quantity

A relative quantity is a cardinal quantity whose value is expressed as a ratio with an empirical value of the same cardinal quantity. The value of a relative quantity has a dimension of one.

NOTE: For example, the volume of liquid fuel as a fraction of the volume capacity of a liquid fuel tank.

3.1.2.4 Ordinal Quantity

An ordinal quantity is a quantity for which a total ordering relation can be established according to magnitude with other quantities of the same kind, but for which no algebraic operations among those quantities exist. Ordinal quantities can enter into empirical relations only and have neither measurement units nor quantity dimensions. Ordinal quantities are arranged according to quantity-value scales and are defined by conventional measurement procedures.

3.1.2.5 Nominal Property

A nominal property is a property that has no numerical magnitude. A nominal property has a value, which can be expressed in nominal numbers, words, by alphanumerical codes, or by other means.

NOTE: Nominal properties are beyond the scope of this data dictionary.

3.1.2.6 Quantity Kind

A cardinal quantity may be generalized into a quantity kind. All quantities of the same quantity kind have the same quantity dimension. However, not all quantities with the same quantity dimension are of the same quantity kind.

NOTE: As an example, the quantity of length is a quantity kind to which the quantities length of path and position vector belong. Each of these quantities may in turn be a quantity kind for a group of more specialized quantities.

3.1.2.7 System of Quantities

A system of quantities is a set of cardinal quantities together with a set of non-contradictory equations relating those quantities.

3.1.2.8 International System of Quantities

The International System of Quantities (ISQ) is the system of cardinal quantities based on the seven base quantities: length, mass, time, electric current, thermodynamic temperature, amount of substance, and luminous intensity. This system of quantities is published in ISO/IEC 80000.

3.1.2.9 Base Quantity

A base quantity is a cardinal quantity in a conventionally chosen subset of a given system of quantities, where no quantity in the subset can expressed in terms of the other quantities within that subset.

NOTE: Number of entities can be regarded as an additional base quantity in any system of quantities.

3.1.2.10 Derived Quantity

A derived quantity in a system of quantities is defined in terms of the base quantities of that system.

3.1.2.11 Composite Quantity

In this data dictionary, a composite quantity is quantity that is not in a system of quantities but is composed of quantities that are each within a system of quantities.

3.1.2.12 Quantity Dimension

A quantity dimension is an expression of the dependence of a cardinal quantity on the base quantities of a given system of quantities as the product of powers of factors corresponding to the base quantities, omitting any numerical factor.

NOTE: In the International System of Quantities, the seven base quantities, plus number of entities, have a single dimension as shown in Table 1. For discussion on the dimensions of derived quantities, see 4.3.

Table 1 - Base quantities in the ISQ

BASE QUANTITY	SYMBOL FOR DIMENSION
Length	L
Mass	M
Time	T
Electric current	I
Thermodynamic temperature	Θ
Amount of substance	N
Luminous intensity	J
Number of Entities	1

The dimension of any derived quantity Q is denoted:

$$\dim Q = L^{\alpha} M^{\beta} T^{\gamma} I^{\delta} \Theta^{\varepsilon} N^{\zeta} J^{\eta}$$

3.1.2.13 Quantity of Dimension One

A quantity of dimension one is a quantity for which all the exponents of the factors corresponding to the base quantities in its quantity dimension are zero.

NOTE: Number of entities is a quantity of dimension one. Ratios of quantities of the same quantity kind are quantities of dimension one.

3.1.2.14 Quantity Equation

A quantity equation is the mathematical relation between quantities in a given system of quantities, independent of measurement units.

3.1.3 Definitions Concerning Measurement Units

3.1.3.1 Measurement Unit

A measurement unit is a real scalar quantity with which any other quantity of the same quantity kind can be compared to express the ratio of the second quantity to the first one as a number. Measurement units are defined and adopted by convention.

NOTE: A measurement unit for a quantity of dimension one is a number. In some case such measurement units are given special names, e.g., radian and decibel, or are expressed as quotients, such as milligrams per gram.

3.1.3.2 System of Units

A system of units is a set of base units and derived units together with the multiples and submultiples that is defined in accordance with given rules for a given system of quantities.

3.1.3.3 Coherent System of Units

A coherent system of units is a system of units that is based on a given system of quantities and for which the measurement unit for each derived quantity is a coherent derived unit.

3.1.3.4 International System of Units

The International System of Units (SI) is the system of units based on the International System of Quantities including their unit names and symbols and a series of unit prefixes and their names and symbols together with rules for their use adopted by the General Conference on Weights and Measures (CGPM).

3.1.3.5 U.S. Customary Measurement System

The U.S. Customary Measurement System is the system of units based on the yard of length and the pound of mass that is commonly used in the United States of America and is defined by the National Institute of Standards and Technology (NIST) Handbook 44.

NOTE: Units having the same common names in other countries may differ in magnitude. For example, the U.S. liquid gallon has a different magnitude to the British imperial gallon.

3.1.3.6 Base Unit

A base unit is a measurement unit that is adopted by convention for a base quantity in a system of quantities.

NOTE: For number of entities, the number one (symbol 1) can be regarded as a base unit in any system of units.

3.1.3.7 Derived Unit

A derived unit is a measurement unit for a derived quantity.

3.1.3.8 Coherent Derived Unit

A coherent derived unit is a derived unit that for a given system of quantities and for a chosen set of base units is the product of powers of base units with no other proportionality factor than one.

3.1.3.9 Off-System Measurement Unit

An off-system measurement unit is a measurement unit that does not belong to a given system of units.

3.1.3.10 Unit Equation

A unit equation is a mathematical relation between base units, coherent derived units or other measurement units.

3.1.3.11 Conversion Factor Between Units

A conversion factor between units is the ratio of two measurement units for cardinal quantities of the same kind.

3.1.3.12 Measurement Scale

A measurement scale is an ordered set of quantity values of a given quantity kind used in ranking according to magnitude quantities of that kind.

3.1.3.13 Conventional Reference Scale

A conventional reference scale is a measurement scale defined by formal agreement.

3.1.4 Definitions Concerning Scalars, Vectors, and Tensors

3.1.4.1 Scalar

A scalar is a cardinal quantity having only magnitude and not geometric direction.

NOTE: A scalar quantity is represented in this data dictionary by a symbol of the form q (in any font and case, depending on the convention for that quantity).

3.1.4.2 Vector

A vector is a cardinal quantity that has both magnitude and geometric direction.

NOTE: A vector is represented in this data dictionary by a symbol of the form $\vec{q}$ (in any font and case, depending on the convention for that quantity).

NOTE: A vector quantity may be described by a coordinate tuple or by a coordinate matrix, which are both ordered lists of scalar quantities (coordinates) that are related to a common coordinate reference system (CRS).

3.1.4.3 Unit Vector

A unit vector is a vector that has a magnitude of 1 and a measurement unit of 1. A unit vector in the direction of ‘a’ is denoted by the symbol $\vec{e}_a$.

NOTE: A vector can be represented as a unit vector multiplied by a scalar quantity. For example, displacement $\Delta\vec{r} = \Delta r\vec{e}_a$.

3.1.4.4 Component Vector

In a Cartesian coordinate system, a vector may be described by the summation of its component vectors where each component vector is in the direction of one of the axes.

NOTE: For example, in a Cartesian coordinate system, displacement $\Delta\vec{r} = \Delta x\vec{e}_x + \Delta y\vec{e}_y + \Delta z\vec{e}_z$, where $\Delta x\vec{e}_x, \Delta y\vec{e}_y, \Delta z\vec{e}_z$ are the component vectors of $\Delta\vec{r}$ and $(\Delta x, \Delta y, \Delta z)$ is its coordinate tuple.

3.1.4.5 Tensor

A tensor is a quantity that describes the linear relations between vectors or other tensors.

NOTE: A tensor of the second order is represented in this data dictionary by a symbol of the form $\vec{\vec{q}}$ (in any font and case, depending on the convention for that quantity). This tensor may be described by a matrix.

NOTE: A coordinate transformation matrix is an example of a secondar-order tensor.

3.1.4.6 Coordinate System

A coordinate system (CS) is a set of mathematical rules for specifying how coordinates are assigned to quantities.

3.1.4.7 Vector Coordinate System

A vector CS defines a vector space in which a quantity value is a vector.

NOTE: The Cartesian coordinate tuple $(0, 0, 0)$ of a vector space denotes the zero vector in that space. For example, zero displacement $\Delta\vec{r} = (0, 0, 0)$. It does not denote a position of origin.

3.1.4.8 Affine Coordinate System

An affine CS defines an affine space in which a quantity value is a vector related to a position of origin.

NOTE: Euclidean space is an example of an affine space. The Cartesian coordinate tuple $(0, 0, 0)$ of an affine space denotes the position of origin. For example, position vector $\vec{r} = (0, 0, 0)$.

3.1.4.9 Axis

In this data dictionary, the term axis is defined as a reference direction in a coordinate reference system, coordinate system, or coordinate datum.

NOTE: The vector direction of an axis may be represented by a unit vector. For example, the vector direction of the x-axis may be represented by $\vec{e}_x$.

3.1.4.10 Coordinate Reference System

A coordinate reference system (CRS) is a coordinate system that is anchored to a spatial object by a coordinate datum.

NOTE: This data dictionary defines CRS based on two spatial objects: The Earth, and engineering bodies for which a point of origin and reference axes are defined.

3.1.4.11 Coordinate Datum

A coordinate datum (CD) is a parameter or set of parameters that define the position of origin and orientation of a coordinate system within a CRS.

NOTE: The position of origin is only used in an affine CS. The orientation is used by both a vector CS and affine CS.

3.1.4.12 Coordinate Operation

A coordinate operation is a change of coordinates, based on a one-to-one relationship, from one CRS to another.

3.1.4.13 Coordinate Transformation

A coordinate transformation is a coordinate operation (often a transformation matrix) in which the two CRS are based on different coordinate datums.

3.1.4.14 Coordinate Conversion

A coordinate conversion is a coordinate operation in which both CRS are based on the same CD.

3.1.5 Definitions Concerning Statistical Quantities

3.1.5.1 Expected Value

The expected value of a quantity q that is a continuous random variable with the probability density function $f(q)$ is defined as

$$E(q) = \int_{-\infty}^{\infty} qf(q)dq$$

NOTE: The arithmetic mean of an infinite series of quantity values will converge on the expected value.

3.1.5.2 Standard Deviation

The standard deviation of a quantity q that is a continuous random variable with an expected value $E(q)$ is defined as

$$\sigma_q = \sqrt{E[(q - E[q])^2]}$$

3.1.5.3 Variance

The variance of a quantity q that is a continuous random variable with a standard deviation σ_q is defined as

$$var(q) = \sigma_q^2$$

3.1.5.4 Covariance

The covariance of quantities q_1 and q_2 is defined as

$$cov(q_1, q_2) = E[(q_1 - E[q_1])(q_2 - E[q_2])]$$

NOTE: $cov(q_1, q_2)$ can be expressed as σ_{q_1,q_2}.

3.1.6 Definitions Concerning Measurements

3.1.6.1 Measurement

The set of operations having the object of determining the value of a quantity.

3.1.6.2 Measurand

The particular quantity subject to measurement.

NOTE: The measurand comprises the general quantity to be measured (e.g., defined in Section 5) and the specification of the phenomenon, body, or substance that is the subject of the measurement.

3.1.6.3 Principle of Measurement

The scientific basis or context of measurement.

NOTE: For example, the Doppler effect applied to the measurement of velocity.

3.1.6.4 Method of Measurement

The logical sequence of operations, described generically, used in the performance of measurements.

3.1.6.5 Measurement Procedure

The set of operations, described specifically, used in the performance of particular measurements according to a given method.

3.1.6.6 Influence Quantity

A quantity that is not the measurand but that affects the result of the measurement.

NOTE: In accordance with JCGM 100, the definition of influence quantity is understood to include values associated with measurement standards, reference materials and reference data upon which the result of a measurement may depend, as well as phenomena such as short-term measuring instrument fluctuations and quantities such as ambient temperature, barometric pressure and humidity.

3.1.7 Definitions Concerning Quantity Modalities

3.1.7.1 Quantity Modal

A quantity modal is a logical or mathematical operator that qualifies the truth-semantics of a quantity value.

3.1.7.2 Quantity Modality

A quantity modality is a system of quantity modals.

NOTE: A modality may be concerned with necessity and possibility, obligation and permission, uncertainty, past and future values, the properties of a set of quantity values, and so on.

3.1.7.3 Categorical Quantity

The term used to make explicit that a quantity definition does not have a modal.

3.2 Mathematical Symbols

3.2.1 Symbols for Cardinal Quantities

The symbols for cardinal quantities are arranged into tables that correspond with the parts of ISO 80000. The listing is alphabetical within each table. Where possible, the symbols follow ISO/IEC 80000, which sometimes results in a symbol being used for more than one quantity (but not within the same table). The symbols for quantities are always Times Roman italic.

NOTE: Quantities that are vectors have a scalar symbol followed by a vector symbol (in parentheses). Symbols for vector components and coordinates are not provided unless these symbols have been established by convention.

Table 2 - Symbols for numbers of entities

QUANTITY	SYMBOL
Number of entities	1

NOTE: In accordance with ISO 80000-1, number of entities can be added to any system of quantities.

Table 3 - Symbols for basic quantities of space and time

QUANTITY	SYMBOL
acceleration (and vector)	a ($\vec{a}$)
angle (plane angle)	θ
- angle of deflection in spherical CS	ϑ
- angle of elevation in spherical (RAE) CS	φ
- angle of latitude in ellipsoidal CS	φ
- angle of rotation in any coordinate system	λ
- Euler angle, first rotation	Ψ
- Euler angle, second rotation	Θ
- Euler angle, third rotation	Φ
angular acceleration of plane angle θ	α
angular velocity of plane angle θ	ω
area	A
displacement	$\Delta\vec{r}$
distance	r
duration	t
ellipsoidal height (in ellipsoidal CS)	h
frequency	f
length	l
length of path	s
level of a power quantity	L_P
position	$\vec{r}$
position coordinates (in Cartesian CS)	x, y, z
radius	ρ
period duration	T
rotation	N
rotational frequency	η
solid angle	Ω
speed	v_s
speed acceleration	a_s
velocity (and vector)	v ($\vec{v}$)
volume	V

Table 4 - Symbols for basic quantities of mechanics

QUANTITY	SYMBOL
density	ρ
dynamic viscosity	η
force (and vector)	$\boldsymbol{F}$ ($\vec{\boldsymbol{F}}$)
kinematic viscosity	ν
kinetic energy	E_k
mass	m
mass flow rate	q_m
mechanical energy	E
mechanical power	P
mechanical work	W
moment of force (and vector)	$\boldsymbol{M}$ ($\vec{\boldsymbol{M}}$)
momentum (and vector)	$\boldsymbol{p}$ ($\vec{\boldsymbol{p}}$)
potential energy	E_p
torque	M_Q
volume flow rate	q_V

Table 5 - Symbols for basic quantities of thermodynamics

QUANTITY	SYMBOL
Celsius temperature (to ITS-90)	t_{90}
relative humidity	ϕ
thermodynamic temperature (to ITS-90)	T_{90}

Table 6 - Symbols for basic quantities of electromagnetism

QUANTITY	SYMBOL
capacitance	C
electric charge	Q
electric charge density	ρ_V
electric current	I
electric current density	$\boldsymbol{J}$
electric field strength (and vector)	$\boldsymbol{E}$ ($\vec{\boldsymbol{E}}$)
electric potential	V
electric potential difference	V_{ab}
electrical conductance	G
electrical conductivity	σ
electrical resistance	R
Electrical resistivity	ρ
inductance	L
instantaneous electrical power	p
linked inductance	Ψ
magnetic flux	Φ
magnetic flux density (and vector)	$\boldsymbol{B}$ ($\vec{\boldsymbol{B}}$)
magnetic vector potential	$\boldsymbol{A}$
source voltage	U_s
voltage	U

Table 7 - Symbols for basic quantities of light

QUANTITY	SYMBOL
illuminance	E_V
luminance	L_V
luminous efficacy of radiation	K
luminous efficiency	V
luminous flux	Φ_V
luminous intensity	I_V
radiant energy	Q_e
radiant flux	Φ
radiant intensity	I_e
spectral luminous efficacy	$K(\lambda)$
spectral luminous efficiency	$V(\lambda)$
spectral radiant flux	$\Phi_\lambda(\lambda)$
spectral radiant intensity	$I_\lambda(\lambda)$

Table 8 - Symbols for basic quantities of physical chemistry and molecular physics

QUANTITY	SYMBOL
amount of substance (B) concentration	c_B
amount of substance	n
molecular concentration of substance (B)	C_B
mass of substance (B)	m_B
mass concentration of substance (B)	ρ_B
Mass fraction of substance (B)	w_B
number of particles (of substance B)	N_B

Table 9 - Symbols for basic quantities of atomic and nuclear physics

QUANTITY	SYMBOL
absorbed dose	D
absorbed dose rate	$\dot{D}$
dose equivalent	H
energy of particle	E
linear energy transfer	L_∞
mean energy imparted	$\bar{\varepsilon}$
quality factor	Q
radiant energy	R
rest energy of particle	E_0
rest mass of particle	m_0

Table 10 - Symbols for basic quantities of information science and technology

QUANTITY	SYMBOL
storage capacity	M
binary digit rate	ν

3.2.2 Symbols for Coordinate Systems and Unit Vectors

Table 11 - Symbols for coordinate system unit vectors

QUANTITY	SYMBOL
unit vector	$\vec{e}$
length of semi-major axis of ellipse or ellipsoid	a_e
length of semi-minor axis of ellipse or ellipsoid	b_e
flattening factor of ellipse or ellipsoid	f_e
eccentricity of ellipse or ellipsoid	e_e
radius of curvature of the local parallel in ellipsoidal CS	ρ
radius of curvature of the local meridian in ellipsoidal CS	ϱ

3.2.3 Symbols for Quantity Dimensions

Table 12 - Symbols for quantity dimensions

QUANTITY DIMENSION	SYMBOL
length	L
mass	M
time	T
electric current	I
thermodynamic temperature	Θ
amount of substance	N
luminous intensity	J
number of entities	1

3.2.4 Symbols for Measurement Units

The symbols for measurement units are arranged alphabetically into SI units, the units in the U.S. Customary Measurement System, and off-system units. Whereas quantity symbols are Times Roman italic, unit symbols are always in normal text.

NOTE: The symbol for a unit may be different from the abbreviation. For example, the symbol for the mile for per hour measurement unit is mi/h, while the abbreviation is mph.

NOTE: The measurement unit of one (symbol '1') is included with the SI measurement units.

Table 13 - Symbols for SI measurement units

MEASUREMENT UNIT	SYMBOL
ampere	A
ampere per square meter	A/m^2
bar	Bar
bit	bit
bit per second	bit/s
byte	B
byte per second	B/s
candela	cd
candela per square meter	cd m^{-2}
coulomb	C
coulomb per cubic meter	C/m^3
cubic meter	m^3
cubic meter per second	m^3/s
day	d
decibel	dB
degree of arc	°
degree of arc per second	°/s
degree Celsius	°C
farad	F
gram	g
gram per liter	g/l
gray	Gy
gray per second	Gy/s
henry	H
hertz	Hz
hour	h
joule	J
kelvin	K
kilogram	kg
kilogram meter per second	kg m/s
kilogram per cubic meter	kg/m^3
kilogram per second	kg/s
kilometer	km
kilometer per hour	km/h
kilopascal	kPa
liter	l
lumen	lm

lumen per watt	$lm\ W^{-1}$
lux	lx
meter of length	m
meter per second	m/s
meter per second squared	m/s^2
meter squared per second	m^2/s
meter squared per second squared	m^2/s^2
meter to the power minus three	m^{-3}
minute of time	min
mole	mol
neper	Np
newton	N
newton meter	N m
ohm	Ω
ohm meter	Ω m
one	1
parts per thousand	ppt
pascal	Pa
pascal second	Pa s
percent	pc
rad	rad
radian	rad
radian per second	rad/s
radian per second squared	rad/s^2
rem	rem
second	s
second to the power minus one	s^{-1}
siemens	S
siemens per meter	S/m
sievert	Sv
square meter	m^2
steradian	sr
tesla	T
volt	V
volt per meter	V/m
watt	W
watt per hertz	$W\ Hz^{-1}$
watt per steradian	$W\ sr^{-1}$
watt per steradian per hertz	$W\ sr^{-1}\ Hz^{-1}$
weber	Wb
weber per meter	Wb/m

Table 14 - Symbols for measurement units in the U.S. customary measurement system

MEASUREMENT UNIT	SYMBOL
cubic foot	ft^3
degree Fahrenheit	°F
foot per second	ft/s
foot per second squared	ft/s^2
foot pounds per second squared	$ft\ lb/s^2$
inch	in
inch per second	in/s
mile per hour	mi/h
pound force	lbf
pound of force per square inch	psi
pound of mass	lb
pound of mass per cubic foot	lb/ft^3
pound of mass per cubic inch	lb/in^3
pound of mass per second	lb/s
square foot	ft^2
statute foot	ft
statute mile	mi
yard of length	yd

Table 15 - Symbols for off-system measurement units

MEASUREMENT UNIT	SYMBOL
inches mercury (60 °F)	inHg (60 °F)
revolutions per minute	r/min
year	a

3.2.5 Mathematical Symbols and Signs

This data dictionary is conformant to ISO 80000-2:2009 in its use of mathematical symbols and signs. The following table is informational only.

Table 16 - Mathematical symbols and signs

MATHEMATICAL MEANING	SYMBOL, EXPRESSION
a is, by definition, equal to b	$a := b$
a is exactly equal to b	$a = b$
a is approximately equal to b	$a \approx b$
base of natural logarithm	e
expected value of q	$E(q)$
standard deviation of q	σ_q
variance of q	$var(q)$
covariance of q_1, q_2	$cov(q_1, q_2)$

NOTE: In Table 16 the symbols a, b are arbitrary.

4. OVERVIEW OF QUANTITIES

This data dictionary is concerned with the definition of quantities, measurement units, reference systems, measurands, measurements, and quantity modalities.

4.1 Numbers

In this data dictionary, three types of number are used: cardinal, ordinal, and nominal. A cardinal number is a numeral that expresses an amount of entities or an amount of measurement units (e.g., 1, 2, 3). An ordinal number is a numeral that expresses the position of an entity in an ordered series (e.g., 1st, 2nd, 3rd) or the position of a measurement on an ordinal quantity-value scale. A nominal number is a numeral that expresses the identity of an entity (e.g., #1, #2, #3) or the numerical value of a measurement that does not have a magnitude.

4.2 Quantities

A quantity is the property of a phenomenon, body, or substance where the property has a value with magnitude. Two types of quantity are identified: cardinal and ordinal. A cardinal quantity has a magnitude that has algebraic meaning and is always a cardinal number multiplied with a measurement unit. An ordinal quantity has a magnitude without algebraic meaning. An ordinal quantity does not have a measurement unit or quantity dimension but is defined according to an established measurement scale. Ordinal quantities may enter into empirical relationships with other quantities but not algebraic relationships.

NOTE: A nominal property has a value without magnitude. The value of a nominal property may be a nominal number.

4.3 Cardinal Quantities

In this data dictionary, cardinal quantities are traceable to the International System of Quantities (ISQ) as defined in ISO/IEC 80000. The ISQ defines seven base quantities (or dimensions) as shown in Table 17. To the ISQ is added an eighth quantity or dimension: number of entities, which has a dimension of one.

Table 17 - Base quantities in the ISQ

BASE QUANTITY	QUANTITY SYMBOL	DIMENSION SYMBOL
length	l	L
mass	m	M
time	t	T
electric current	I	I
thermodynamic temperature	T_{90}	Θ
amount of substance	n	N
luminous intensity	I_V	J
number of entities	1	1

Derived quantities are defined by a quantity equation and a dimension equation. For example, inductance (symbol L) has the following quantity equation [1] and dimension equation:

$$L = {}^{\Psi}/_{I}$$

$$\dim L = \mathrm{L^2MT^{-2}I^{-1}}.$$

It is sometimes the case that a general quantity (called a quantity kind) can be refined into a more specialized quantity. For example, length l can be refined into length of path s or position vector r. Within the context of a given coordinate system, position vector r can in turn be refined into its component vectors. For example, in a Cartesian coordinate system, r can be refined into its component lengths x, y, and z.

In this data dictionary, a basic cardinal quantity is strictly a quantity that is defined completely by the ISQ or by its components within a given coordinate system. Table 18 is an example of a definition of a basic cardinal quantity (inductance).

Table 18 - Defining elements of inductance quantity (example)

DEFINING ELEMENT	DESCRIPTION
Quantity name	Inductance quantity
Version	1.1
Definition URI	Namespace, UUID conformant to RFC4122 standard, and version
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	IEC 80000-6:2008
Quantity kind	Inductance quantity
Quantity symbol	L
Quantity dimension	dim L = $\mathrm{L^2MT^{-2}I^{-1}}$
Quantity equation	$L = {}^{\Psi}/_{I}$ where I is an electric current in a thin conducting loop and Ψ is the linked flux caused by that electric current
Field of application	Electromagnetism
Quantity application	General
Preferred measurement unit	Henry unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

[1] NOTE: In this example, I is an electric current in a thin conducting loop (a base quantity) and Ψ is the linked flux caused by that electric current (a derived quantity).

In this data dictionary, basic cardinal quantities are initially organized according to their field of application following ISO/IEC 80000:

a. Space and time (ISO 80000 Part 3)

b. Mechanics (ISO 80000 Part 4)

c. Thermodynamics (ISO 80000 Part 5)

d. Electromagnetism (IEC 80000 Part 6)

e. Light (ISO 80000 Part 7)

f. Acoustics (ISO 80000 Part 8)

g. Physical chemistry and molecular physics (ISO 80000 Part 9)

h. Atomic and nuclear physics (ISO 80000 Part 10)

i. Information science and technology (IEC 80000 Part 13)

NOTE: Each of these fields of application exists within a dimensional space

Table 19 - Dimensional space of fields of application

FIELD OF APPLICATION	DIMENSION							
	1	T	L	M	I	Θ	J	N
Space and time	X	X	X					
Mechanics	X	X	X	X				
Thermodynamics	X	X	X	X		X		
Electromagnetism	X	X	X	X	X			
Light	X	X	X	X			X	
Acoustics	X	X	X	X				
Physical chemistry and molecular physics	X	X	X	X				X
Atomic and nuclear physics	X	X	X	X	X			
Information Science and Technology	X	X						

4.4 Ordinal Quantities

Ordinal quantities have magnitude but no dimension or measurement unit. Ordinal quantities are measured empirically using a specified (but arbitrary) measurement procedure and scale, which is, therefore, intrinsic to the measurement semantics. An important distinction between an ordinal quantity and cardinal quantity is the type of numerical value. The numerical value of an ordinal quantity is not a scalar (or more generally a tensor) that can be used in algebraic expressions.

Ordinal quantities typically have very specific empirical applications. Examples of ordinal quantities are:

- **Engine fuel octane rating** - Engine fuel octane rating measured with a test engine according to a specified measurement procedure and scale including, for example, the Research Octane Number (RON), Motor Octane Number (MON), or Anti-Knock Index (AKI or (R+M)/2).

- **Metal hardness scale** - Metal indentation hardness measured with a specified indenter and load. Hardness scales include the Rockwell hardness test (scales A through H, K, N, and T).

- **Earthquake magnitude scale** - Magnitude of an earthquake based on an agreed empirical formula or correlation table using the maximum excursion of a Wood-Anderson torsion seismograph and its epicentral distance. Scales include the Richter scale, which implicitly incorporates the attenuative properties of the Southern California crust and mantle.

In general, an ordinal quantity is defined by an authoritative industry standard and if necessary a selected measurement procedure and scale. At this time, no ordinal quantities are used in this standard. However, Table 20 is a notional example of an ordinal quantity definition (the Rockwell A hardness scale).

Table 20 - Defining elements of Rockwell A Hardness Scale quantity (notional example)

DEFINING ELEMENT	DESCRIPTION
Quantity name	Rockwell A hardness scale
Version	1.0
Definition IRU	Namespace, UUID conformant to RFC4122 standard and version
Quantity type	Ordinal
Authoritative reference	ISO 6508-1:2015 (Metallic materials - Rockwell hardness test - Part 1: Test method)
Field of application	Mechanics
Quantity application	Indentation hardness test for hard metals
Measurement procedure and scale	ISO 3738-1:1982 (Hard metals - Rockwell hardness test (scale A) - Part 1: Test method)
Scale symbol	HRA
Reference material (if applicable)	None

4.5 Nominal Properties

A nominal property is a property without magnitude. The value of a nominal property may be expressed non-numerically or by a nominal number. Specific nominal properties are not defined in this data dictionary.

4.6 Measurement Units

A measurement unit (or simply a unit) is a scalar that can be multiplied with a cardinal number to denote the magnitude of a cardinal quantity. In this data dictionary, units are traceable to the International System of Units (SI). The SI defines a base unit for each of the base quantities in the ISQ as shown in Table 21. In addition, the unit of one can be used to express number of entities, any derived quantity of dimension one, or the ratio between two quantities with the same dimension equation.

Table 21 - Base units in the SI

BASE UNIT	BASE QUANTITY	UNIT SYMBOL
meter	length	m
kilogram	mass	kg
second	time	s
ampere	electric current	A
kelvin	thermodynamic temperature	K
mole	amount of substance	mol
candela	luminous intensity	Cd
one	number of entities	1

Derived units in the SI are defined by a unit equation. For example, the henry (symbol H) is defined by the unit equation[2]:

$$1\ \mathrm{H} := 1\ \mathrm{Wb/A}$$

In this data dictionary, non-SI units are defined by a conversion factor from the SI unit. For example, the pound of mass (symbol lb) is defined by the conversion factor:

$$1\ \mathrm{lb} := 0.45359237\ \mathrm{kg}$$

[2] NOTE: In this example, the symbol Wb denotes a weber (a derived unit), and A denotes an ampere (a base unit).

4.7 Scalars, Vectors, and Tensors

In mathematical terms, a tensor of zero-order is a scalar, a tensor of the first order is a vector, and a tensor of the second order (or higher orders) is a true tensor. Cardinal quantities can, therefore, be scalars, vectors, or tensors.

4.7.1 Scalar Quantity

A scalar quantity is a quantity that has magnitude but no geometric direction. It is mathematically denoted in this data dictionary by a symbol of the form q. In this data dictionary, all quantities can be scalars, even when their context is implicitly a vector (for example, force).

4.7.2 Vector Quantity

A vector quantity has both magnitude and geometric direction and, therefore, is always associated with a coordinate reference system (CRS). In this data dictionary, a vector is denoted by a symbol of the general form $\vec{q}$. The value of the vector within a given coordinate system can be expressed in compact form as either a coordinate tuple or as a coordinate matrix where in both cases q_1, q_2, q_3 are the coordinates of $\vec{q}$.

The coordinate tuple is of the general form:

$$\vec{q} = (q_1, q_2, q_3)$$

The coordinate matrix is of the general form:

$$\vec{q} = \begin{pmatrix} q_1 \\ q_2 \\ q_3 \end{pmatrix}$$

In equation form, any vector can be mathematically represented by a scalar multiplied by the unit vector $\vec{e}_q$ in the direction q. Therefore, in a three-dimensional Cartesian coordinate system:

$$\vec{q} = q\,\vec{e}_q$$

$$\vec{q} = q_x\vec{e}_x + q_y\vec{e}_y + q_z\vec{e}_z$$

where $q_x\vec{e}_x$, $q_y\vec{e}_y$, and $q_z\vec{e}_z$ are the components of $\vec{q}$. In this example, the unit vectors $\vec{e}_x, \vec{e}_y, \vec{e}_z$ have a magnitude of one and represent the directions of the orthonormal X-axis, Y-axis, and Z-axis respectively.

4.7.3 Affine Quantity

An affine quantity is a quantity related to an arbitrary but standardized reference. Two affine quantities therefore cannot be added together. However, subtraction produces the difference. Examples of affine quantities are position vector, system time, and Celsius temperature.

An important example of an affine quantity is position in Euclidean space. In this data dictionary, the quantity kind length (l) can be refined into displacement $(\Delta\vec{r})$, which is a vector quantity, and position vector $(\vec{r})$, which is an affine quantity.

4.7.4 Second Order Tensor Measurements

A tensor is a measurement that describes the linear relationship between vectors, between vectors and tensors, or between tensors. In this data dictionary, a tensor of the second order is denoted by a symbol and coordinate matrix of the general form:

$$\vec{\vec{q}} = \begin{pmatrix} q_{11} & q_{12} & q_{13} \\ q_{21} & q_{22} & q_{23} \\ q_{31} & q_{32} & q_{33} \end{pmatrix}$$

In a three-dimensional Cartesian coordinate system, the equation form of the tensor is:

$$\vec{\vec{q}} = q_{xx}\vec{e}_x\vec{e}_x + q_{xy}\vec{e}_x\vec{e}_y + \cdots + q_{zz}\vec{e}_z\vec{e}_z$$

$$\vec{\vec{q}} = \begin{pmatrix} q_{xx} & q_{xy} & q_{xz} \\ q_{yx} & q_{yy} & q_{yz} \\ q_{zx} & q_{zy} & q_{zz} \end{pmatrix}$$

An example of a tensor in this data dictionary is a coordinate transformation matrix between one set of Cartesian axes and another. For example:

$$\vec{q}_2 = \vec{\vec{q}}_{21}\, \vec{q}_1$$

where $\vec{q}_1$ and $\vec{q}_2$ are the same vector described in CRS 1 and CRS 2 respectively, and

$$\vec{\vec{q}}_{21}$$

is the coordinate transformation from CRS 1 to CRS 2. It will be noted that some quantities of interest to this data dictionary are, in fact, the parameters of such a coordinate transformation matrix.

4.8 Spatial Coordinate Systems

In this data dictionary, the difference between a vector quantity and an affine quantity is denoted by the quantity kind, which is part of the quantity definition. For example, displacement ($\Delta\vec{r}$) is a vector quantity and position vector ($\vec{r}$) is an affine quantity.

A given coordinate system (CS) may be used to describe both a true vector quantity and a position vector with its differential (which is always a true vector). This allows, for example, both position and motion to be described in the same CS. This is achieved by diagrammatically and mathematically defining the position vector $\vec{r}$ and its differential $d\vec{r}$. The differential is always described using a right-handed system of orthonormal unit vectors. Thus, the core of a coordinate system is the definition of the coordinates plus the definition of the component vectors of the differential, where each component vector has a unit vector and scalar quantity equation.

To illustrate these concepts, the example of a spherical coordinate system for the position vector $\vec{r}$ is provided. In the case of a vector quantity, the point O denotes the zero vector and the axes define the direction of the basis vectors $\vec{e}_x$, $\vec{e}_y$, and $\vec{e}_z$ (from the right-hand rule). In the case of an affine quantity (such as position), the point O additionally denotes a position of origin. In both cases, the red dot indicates a coordinate.

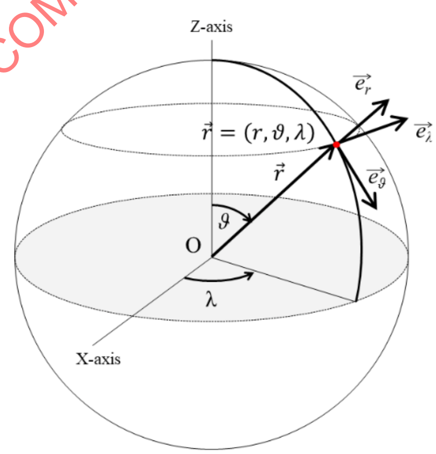


Figure 1 - Right-handed spherical coordinate system (for vector)

In this example, the position vector value is represented by the following coordinate tuple and coordinate matrix:

$$\vec{r} = (r, \vartheta, \lambda)$$

$$\vec{r} = \begin{pmatrix} r \\ \vartheta \\ \lambda \end{pmatrix}$$

Where ϑ denotes the angle of deflection from the Z-axis and λ denotes the right-handed angle of rotation about the Z-axis from the X-axis. The differential of the position vector, $d\vec{r}$, at coordinate (r, ϑ, λ) is represented by the equation below where the unit vectors $\vec{e}_r(\vartheta, \lambda), \vec{e}_\vartheta(\vartheta, \lambda), \vec{e}_\lambda(\lambda)$ form an orthonormal right-handed system as shown the figure:

$$d\vec{r} = dr\,\vec{e}_r + r\,d\vartheta\,\vec{e}_\vartheta + r\,\sin\vartheta\,d\lambda\,\vec{e}_\lambda$$

Additional vector quantities based on the position differential are defined by quantity equations. For example, in the spherical coordinate system, the velocity, $\vec{v}$, of an object at position (r, ϑ, λ) may be represented by the following coordinate tuple and quantity equations:

$$\vec{v} = (v_r, v_\vartheta, v_\lambda)$$

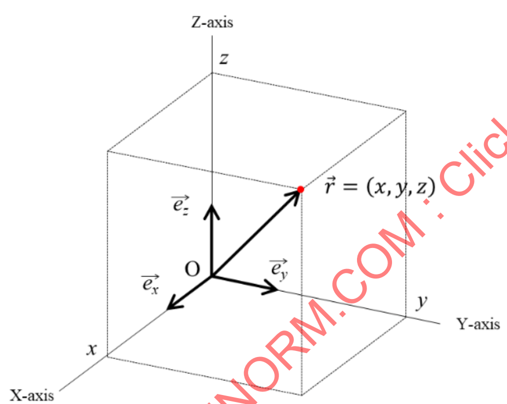
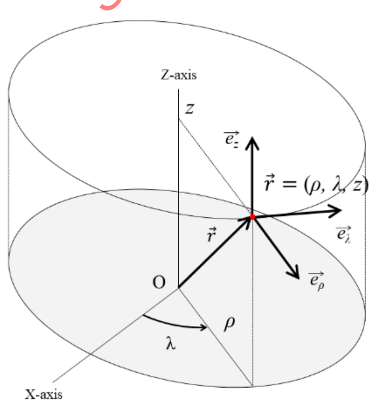
$$\vec{v} = v_r\vec{e}_r + v_\vartheta\,\vec{e}_\vartheta + v_\lambda\,\vec{e}_\lambda$$

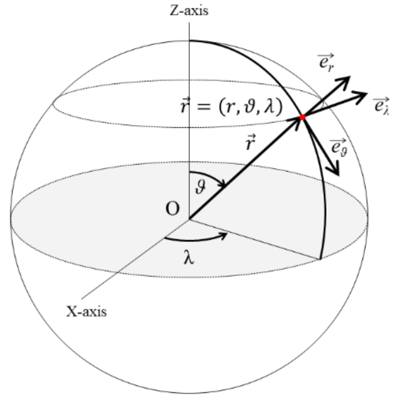
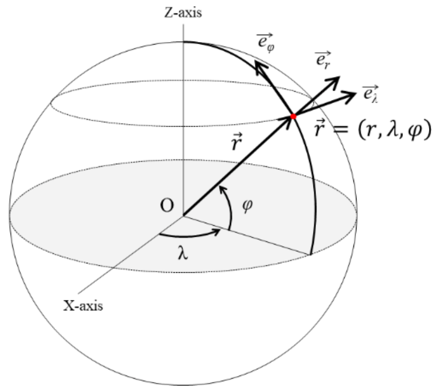
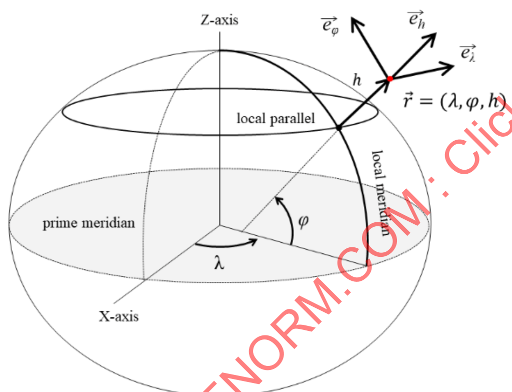
where:

$$v_r = \frac{dr}{dt}, v_\vartheta = r\,\frac{d\vartheta}{dt}, v_\lambda = r\,\sin\vartheta\,\frac{d\lambda}{dt}$$

In this data dictionary, a coordinate system defines quantities and quantity equations. It does not define the measurement unit for each quantity or any other properties that depend on the measurement unit such as range or resolution. The basic three-dimensional coordinate systems defined in this data dictionary are summarized in Table 22.

Table 22 - Summary of 3D right-handed coordinate systems

<table>
<tr>
<td>
</td>
<td>Cartesian vector CS
Quantity vector tuple: $\vec{q} = (q_x, q_y, q_z)$
Position tuple: $\vec{r} = (x, y, z)$
Components: $\vec{r} = x\vec{e}_x + y\vec{e}_y + z\vec{e}_z$
Differential components:
$d\vec{r} = dx\vec{e}_x + dy\vec{e}_y + dz\vec{e}_z$</td>
</tr>
<tr>
<td>
</td>
<td>Cylindrical vector CS
Quantity vector tuple: $\vec{q} = (q_\rho, \lambda, q_z)$
Position tuple: $\vec{r} = (\rho, \lambda, z)$
Components: $\vec{r} = \rho\vec{e}_\rho + z\vec{e}_z$
Differential components:
$d\vec{r} = d\rho\,\vec{e}_\rho + \rho\,d\lambda\,\vec{e}_\lambda + dz\,\vec{e}_z$</td>
</tr>
</table>

	**Spherical vector CS** Quantity vector tuple: $\vec{q} = (q, \vartheta, \lambda)$ Position tuple: $\vec{r} = (r, \vartheta, \lambda)$ Components: $\vec{r} = r\,\vec{e}_r$ Differential components: $d\vec{r} = dr\,\vec{e}_r + r\,d\vartheta\,\vec{e}_\vartheta + r\,\sin\vartheta\,d\lambda\,\vec{e}_\lambda$
	**Spherical (RAE) vector CS** Quantity vector tuple: $\vec{q} = (q, \lambda, \varphi)$ Position tuple: $\vec{r} = (r, \lambda, \varphi)$ Components: $\vec{r} = r\,\vec{e}_r$ Differential components: $d\vec{r} = dr\,\vec{e}_r + r\,\cos\,\varphi\,d\lambda\,\vec{e}_\lambda + q\,d\varphi\,\vec{e}_\varphi$
	**Ellipsoidal CS (see note)** Position tuple $\vec{r} = (\lambda, \varphi, h)$ Components: position $\vec{r} = h\,\vec{e}_h$ Differential components: e.g., position differential $d\vec{r} = (\rho + q)\cos\,\varphi\,d\lambda\,\vec{e}_\lambda + (\varrho + q)\,d\varphi\,\vec{e}_\varphi + dh\,\vec{e}_h$

NOTE: The ellipsoidal CS is used for geodetic positioning and has no general application for the quantity q in practice. The ellipsoidal CS is based on an ellipsoid with a specific magnitude and eccentricity. Its magnitude is defined by the length of its semi-major axis a_e, and its eccentricity is defined by a second defining parameter, which can be:

a. length of its semi-minor axis b_e

b. flattening factor f_e, where $f_e = 1 - b_e/a_e$

c. eccentricity e_e, where $e_e^2 = 1 - b_e^2/a_e^2$

The equation for the differential components depends on the radius of curvature, ρ, of the local parallel and the radius of curvature, ϱ, of the local meridian, where:

$$\rho = \frac{a_e}{\sqrt{1 - e_e^2 \sin^2 \varphi}}$$

$$\varrho = \frac{a_e(1 - e_e^2)}{(1 - e_e^2 \sin^2 \varphi)^{3/2}}$$

4.9 Spatial Coordinate Reference Systems

A coordinate reference system (CRS) is a coordinate system (CS) that is anchored to a coordinate datum (CD). A CD has a point of origin and an orthonormal system of axes that are tied to a real body. The CS is anchored to the CD by equating the two sets of axes. In principle, there are twenty-four ways in which one CS can be anchored to one CD: the first CS axis can be equated to any one of the three CD axes in either the positive or negative direction; the second CS axis can be equated to any one of the two remaining CD axes in either the positive or negative direction, and the third CS axis is then equated to the remaining CD axis in the direction that complies with the right-hand rule.

In this data dictionary, there are four principal classes of coordinate datum to which coordinate systems can be anchored to create coordinate reference systems. They are:

a. Terrestrial reference frame (TRF)

b. Earth-fixed local reference frame (LRF)

a. Earth-fixed local tangent plane (LTP)

b. Earth-fixed vehicle pose

c. Vehicle-carried LRF CD

a. Vehicle-carried LTP

b. Vehicle-carried pose

d. Engineering body

In addition to anchoring a CS to a CD, the CRS may establish limitations on its use and establish quantity coordinate name aliases.

4.9.1 Geodetic CRS

The principal application of a geodetic CRS is positioning (in Euclidean space). To avoid over generalizing, the following discussion will therefore concentrate on position and the position differential.

A geodetic CRS is anchored to a terrestrial reference frame (TRF) that is defined within a conventional terrestrial reference system (CTRS). A CTRS has its origin at the Earth’s center of mass and co-rotates with the Earth in its diurnal rotation. In this data dictionary, the principal CTRS of interest is the WGS 84 CTRS. The WGS 84 CTRS follows the criteria outlined by the International Earth Rotation and Reference Systems Service (IERS) and is defined as:

a. Origin - Earth’s center of mass

b. Z-axis - The direction of the IERS Reference Pole (IRP)

c. X-axis -Intersection of the IERS Reference Meridian (IRM) and the plane passing through the origin to the Z-axis

d. Y-axis -Completes a system of right-handed orthonormal axes.

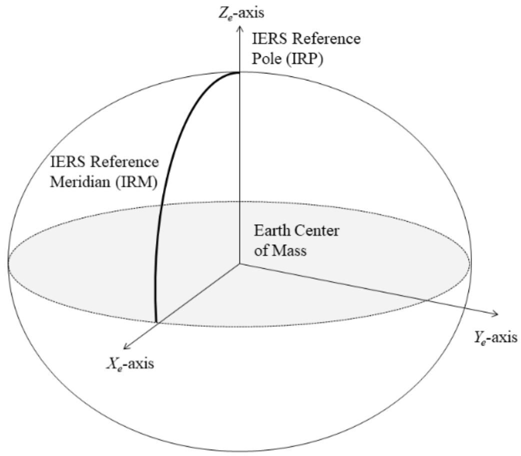


Figure 2 - WGS 84 CTRS

A TRF is a realization of a CTRS based on a set of observations and on alignments with international conventions. At the time of writing, the current realization of the WGS 84 CTRS is WGS 84 (G1762) as defined in NGA.STND.0036_1.0.0_WGS84. The complete list of realizations of WGS 84 CTRS at the time of writing is provided in Table 23 noting that further realizations are anticipated. Note that G1762 is aligned with the IERS International Terrestrial Reference Frame ITRF2008 (2005.0).

Table 23 - WGS 84 reference frames

NAME	IMPLEMENTATION DATE		EPOCH
	GPS BROADCAST ORBITS	NGA PRECISE EPHEMERIS	
WGS 84	1987	1 Jan 1987	
WGS 84 (G730)	29 Jun 1994	2 Jan 1994	1994.0
WGS 84 (G873)	29 Jan 1997	29 Sep 1996	1997.0
WGS 84 (G1150)	20 Jan 2002	20 Jan 2002	2001.0
WGS 84 (G1674)	8 Feb 2012	7 May 2012	2005.0
WGS 84 (G1762)	16 Oct 2013	16 Oct 2013	2005.0

In this data dictionary, the following classes of geodetic CRS are considered:

a. Earth-centered, Earth-fixed (ECEF) CRS

b. Geodetic ellipsoid CRS

c. Geoid CRS

d. Map projection CRS

The first two classes of CRS are three-dimensional coordinate systems tied to a given TRF. A geodetic ellipsoid CRS describes a position in terms of longitude, geodetic latitude and ellipsoidal height. The principal geodetic ellipsoid CRS of interest is the WGS 84 Ellipsoid.

In common practice a geoid CRS is based on a given geodetic ellipsoid CRS in which, at a given longitude and geodetic latitude, orthometric height (usually taken as mean sea level (MSL) height) is expressed as a geoid undulation above or below ellipsoidal height. The principal geoid CRS of interest is the WGS 84 Ellipsoid partnered with geoid undulations defined the WGS 84 EGM2008 Geoid.

A map projection CRS is the projection of a geodetic ellipsoid CRS onto a two-dimensional surface for a given longitudinal and latitudinal zone. The map projection CRS is considered historical and is discouraged in this data dictionary. An example of a map projection CRS would be the Universal Transverse Mercator (UTM) projection.

4.9.1.1 Earth-Centered, Earth-Fixed (ECEF) CRS

An Earth-centered, Earth-fixed (ECEF) CRS is a Cartesian CS that is anchored to given TRF such that the X-axis is simply the CTRS Xe-axis, and so on. The coordinate tuple for the ECEF position vector is:

$$\vec{r} = (x_e, y_e, z_e)$$

Other quantity vectors may be referenced to the ECEF CRS as required.

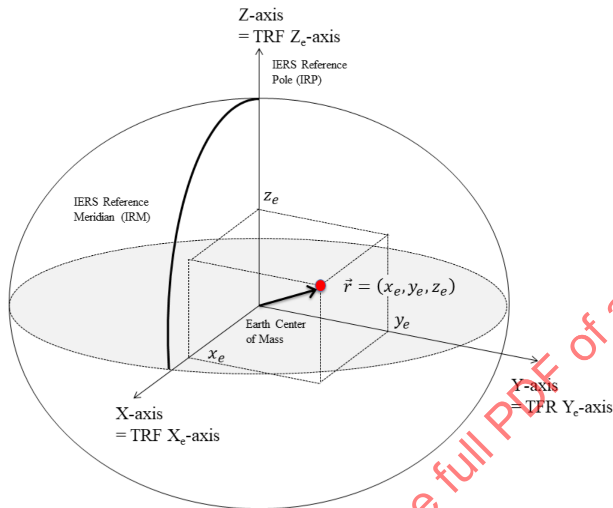


Figure 3 - Earth-centered, earth-fixed (ECEF) CRS

4.9.1.2 Geodetic Ellipsoid CRS

The intended application of the geodetic ellipsoid CRS is geodetic positioning. A geodetic ellipsoid CRS is an ellipsoidal CS that is anchored to a TRF and has defining parameters that approximate to the size and shape of the Earth. The defining parameters of the WGS 84 Ellipsoid that are of interest to a CRS are:

A. Length of semi-major axis, a_e = 6378137.0 meters

b. Inverse flattening $1/f_e$ = 298.257223563

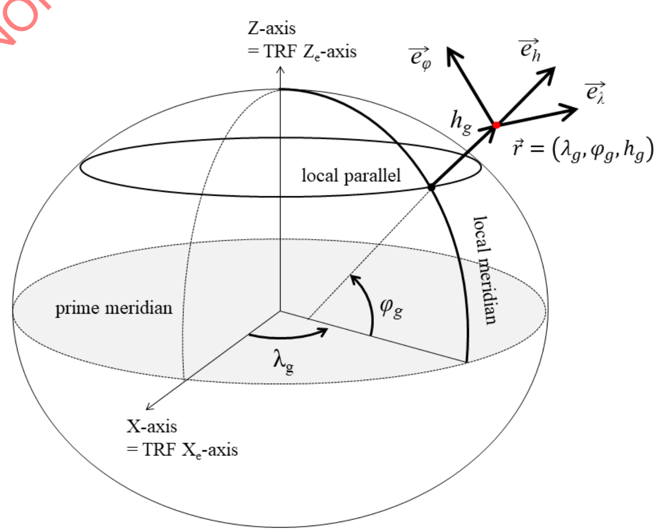


Figure 4 - Geodetic ellipsoid CRS

The coordinate tuple for the geodetic ellipsoid position vector is denoted by:

$$\vec{r} = (\lambda_g, \varphi_g, h_g)$$

When both the geodetic ellipsoidal CRS and ECEF CRS are anchored to the same terrestrial reference frame then the coordinate conversion is:

$$x_e = (\rho + h_g)\cos\varphi_g \ \cos\lambda_g$$

$$y_e = (\rho + h_g)\cos\varphi_g \ \sin\lambda_g$$

$$z_e = \{(1 - e_e^2)\rho + h_g\}\sin\varphi_g$$

where the parameters ρ and e_e are defined in Table 22.

4.9.1.3 Geoid CRS

A geoid CRS is based on a geodetic ellipsoidal CRS except that ellipsoidal height, h_g, at a given point $\vec{r} = (\lambda_g, \varphi_g, h_g)$ is replaced with orthometric height, H_{geoid}.

$$\vec{r} = (\lambda_g, \varphi_g, H_{geoid})_{geoid}$$

Orthometric height is the height of a body above or below the geoid rather than the height above or below the ellipsoid. The geoid serves as the vertical reference surface for Mean Sea Level (MSL). For WGS 84 based measurements, it is common practice to define the geoid at a point in terms of the distance above (+N_{geoid}) or below (-N_{geoid}) the WGS 84 Ellipsoid such that:

$$H_{geoid} = h_g - N_{geoid}$$

The current geoid model is WGS 84 EGM2008. Several data products are available for WGS 84 EGM2008 undulations including undulation grid files and mathematical models.

4.9.2 Earth-Fixed Local Tangent Plane CRS

The second class of CRS is anchored to an Earth-fixed local tangent plane (LTP) whose axes are determined by the unit vectors of the position differential of a geodetic ellipsoid CRS (see Figure 4). The orthonormal unit vectors $\vec{e}_\lambda$, $\vec{e}_\varphi$, and $\vec{e}_h$ define the LTP axes where:

a. $\vec{e}_\lambda$ is tangential to the local parallel eastwards and defines the east-axis (E) (X-axis). In the LTP, this is known as the unit vector $\vec{e}_E$.

b. $\vec{e}_\varphi$ is tangential to the local meridian northwards and defines the north-axis (N) (Y-axis). In the LTP, this is known as the unit vector $\vec{e}_N$.

c. $\vec{e}_h$ completes the right-handed system and defines the up-axis (U) (Z-axis). In the LTP, this is known as the unit vector $\vec{e}_U$. Note that $\vec{e}_D = -\vec{e}_U$.

The origin of the LTP coordinate datum is an arbitrarily chosen Earth-fixed point. The Earth-fixed LTP may be used for local Earth positioning and as the basis for geo-referenced vector quantities. Table 24 shows four examples of coordinate reference systems that are anchored to the Earth-fixed local tangent plane:

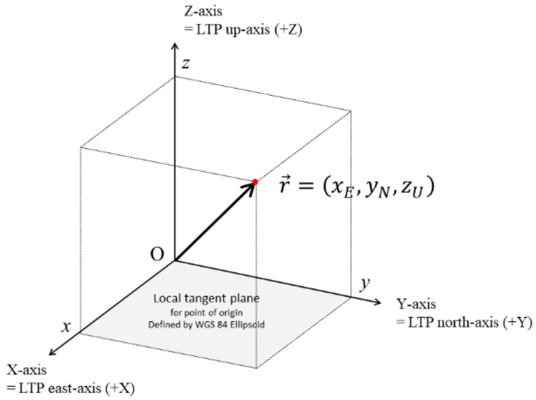
a. East-north-up (ENU)

b. North-east-down (NED)

c. Cylindrical

d. Spherical range-elevation-azimuth (RAE)

Table 24 - Earth-fixed LTP CRS

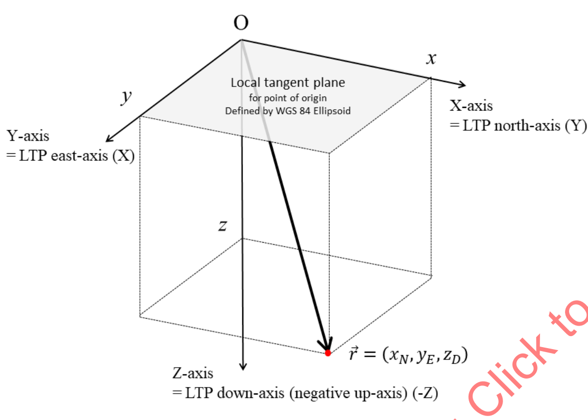
<table>
<tr>
<td>
</td>
<td>

Earth-fixed ENU CRS

Quantity vector tuple: $\vec{q} = (q_E, q_N, q_U)$

Position tuple: $\vec{r} = (x_E, y_N, z_U)$

Components: $\vec{r} = x_E\vec{e}_E + y_N\vec{e}_N + z_U\vec{e}_U$

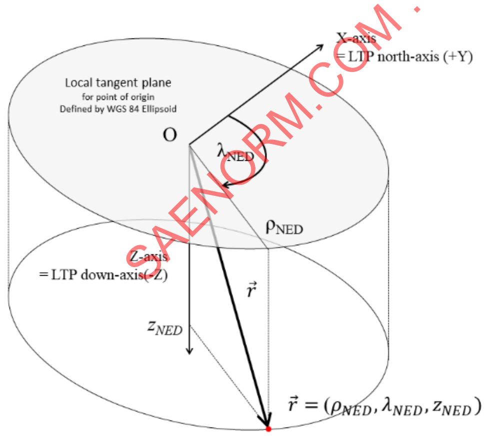
Differential components:
$\overrightarrow{dr} = dx_E\vec{e}_E + dy_N\vec{e}_N + dz_U\vec{e}_U$
</td>
</tr>
<tr>
<td>
</td>
<td>

Earth-fixed NED CRS

Quantity vector tuple: $\vec{q} = (q_N, q_E, q_D)$

Position tuple: $\vec{r} = (x_N, y_E, z_D)$

Components: $\vec{r} = x_N\vec{e}_N + y_E\vec{e}_E + z_D\vec{e}_D$

Differential components:
$d\vec{r} = dx_N\vec{e}_N + dy_E\vec{e}_E + dz_D\vec{e}_D$
</td>
</tr>
<tr>
<td>
</td>
<td>

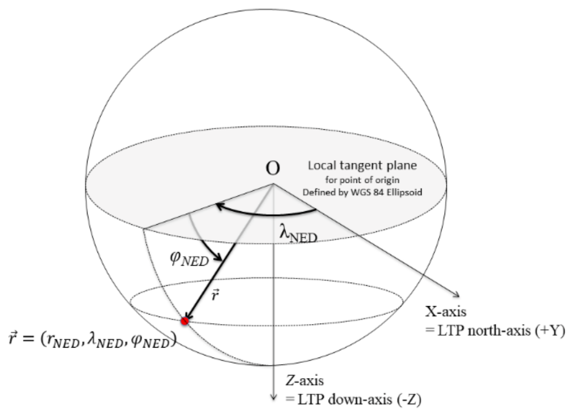
Earth-fixed Cylindrical NED CRS

Quantity vector tuple: $\vec{q} = (q_{NE}, \lambda_{NE}, q_D)$

Position tuple: $\vec{r} = (\rho_{NED}, \lambda_{NED}, z_{NED})$

Components: $\vec{r} = \rho_{NED}\vec{e}_\rho + z_{NED}\vec{e}_D$

Differential components:
$d\vec{r} = d\rho_{NED}\ \vec{e}_\rho + \rho_{NED}\ d\lambda_{NED}\ \vec{e}_{\lambda NED} + dz_{NED}\ \vec{e}_D$
</td>
</tr>
</table>



Earth-fixed Spherical (RAE) NED CRS

Quantity vector tuple: $\vec{q} = (q_{NED}, \lambda_{NED}, \varphi_{NED})$

Position tuple: $\vec{r} = (r_{NED}, \lambda_{NED}, \varphi_{NED})$

Components: $\vec{r} = r_{NED}\vec{e}_r$

Differential components:

$$d\vec{r} = dr\,\vec{e}_q + r\,\cos\,\varphi_{NED}\,d\lambda_{NED}\,\vec{e}_{\lambda NED} + r\,d\varphi_{NED}\,\vec{e}_{\varphi NED}$$

The cylindrical and spherical systems follow the NED convention where the primary axis of rotation is anchored to the down-axis ($\vec{e}_D$). This results in the azimuth being in a clockwise direction from north when projected on a map.

4.9.3 Earth-Fixed Vehicle Pose

An earth-fixed vehicle pose CRS differs from an earth-fixed LTP CRS in that its orthonormal axes are arbitrarily chosen instead of being fixed to the local tangent plane. These axes might fixed to the orientation of the vehicle body at some epoch or chosen according to some other criterion.

4.9.4 Vehicle-Carried LTP CRS

There are two variants of the vehicle-carried LTP CRS, which differ according to their gravitational acceleration reference.

A vehicle-carried LTP (freefall) CRS is associated with a vehicle in free-fall or free-flight and is typically used for flight dynamics. Whereas an Earth-fixed LTP CRS is stationary, the origin and orientation of a vehicle-carried local tangent plane varies as the vehicle moves. Strictly speaking, the origin is a free-fall observer momentarily at rest at the origin of the vehicle's engineering body coordinate datum. Therefore, measurements of vehicle motion in this CRS are relative to this free-fall observer in the experienced gravitational field and are not relative to an origin moving at the same velocity and acceleration as the vehicle itself.

To distinguish this CRS from the Earth-fixed LTP CRS, the coordinate tuple and component vectors for a vehicle-carried ENU position are represented as:

$$\vec{r} = (x_{vE}, y_{vN}, z_{vU})$$

$$\vec{r} = x_{vE}\vec{e}_E + y_{vN}\vec{e}_N + z_{vU}\vec{e}_U$$

where it will be remembered that the unit vectors are rotating with varying geodetic position, i.e., $\vec{e}_E = \vec{e}_\lambda(\lambda_g)$, $\vec{e}_N = \vec{e}_\varphi(\lambda_g, \varphi_g)$, and $\vec{e}_U = \vec{e}_h(\lambda_g, \varphi_g)$. Other CRS can be anchored to vehicle-carried LTP in a similar fashion to the Earth-fixed LTP.

A vehicle-carried LTP (non-freefall) CRS differs from the freefall variant in that the origin is a non-freefall observer.

4.9.5 Vehicle-Carried Pose CRS

A vehicle-carried pose CRS is the same as a vehicle-carried LTP CRS except that its axes are arbitrarily chosen instead of being fixed to the local tangent plane. As with an earth-fixed vehicle pose CRS, the axes could be fixed to the vehicle orientation at some epoch or chosen according to another criterion. Currently, no application for a freefall variant of this class of CRS has been identified.

4.9.6 Engineering Body CRS

The final class of CRS is a coordinate system that is anchored to an engineering body. The most important subtype is vehicle body. The exact point of origin and axis orientation of the CD relative to the engineering body will be design specific. However, for vehicles, the axis labels will follow the following convention.

a. Forward-axis (+X) - tied to the fuselage reference line through the point of origin in the direction of forward travel.

b. Right-axis (+Y) - assuming the vehicle has a symmetrical plane, the axis through the point of origin that is orthogonal to the symmetrical plane in the direction of right when facing forwards (i.e., starboard).

c. Body down-axis (+Z) - the axis that completes the right-handed orthonormal system. It passes through the point of origin in the symmetrical plane at a right-angle to the fuselage reference line in the direction of body down.

    a. If the vehicle has a navigation system, then the navigation system will define the reference for the CD.

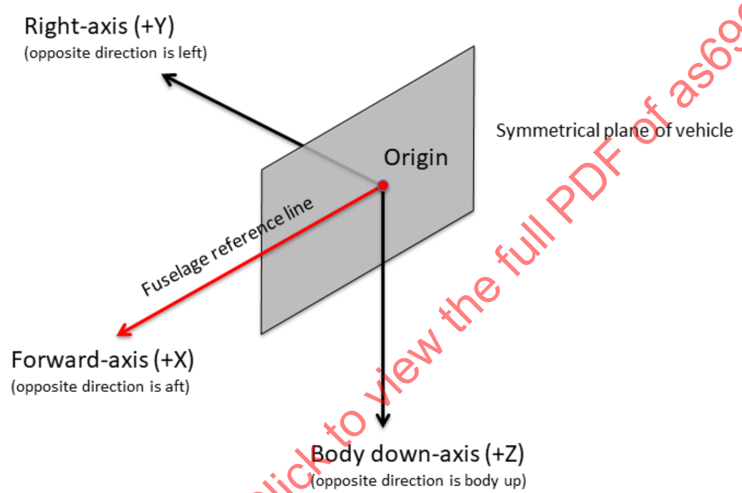


Figure 5 - Vehicle body CD or payload body CD

Figure 6 is an example of a vehicle body CD applied to an aircraft.

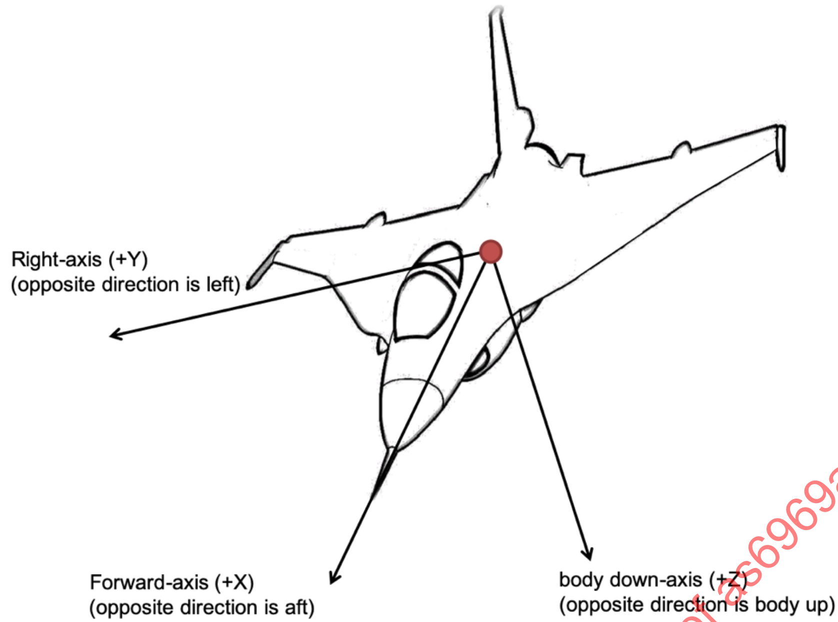
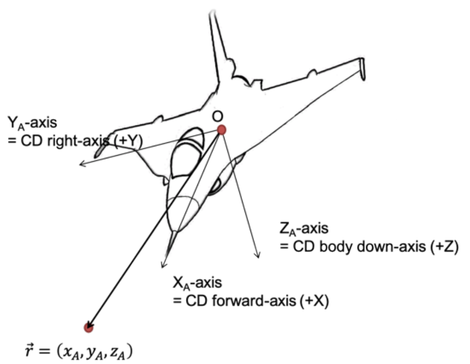
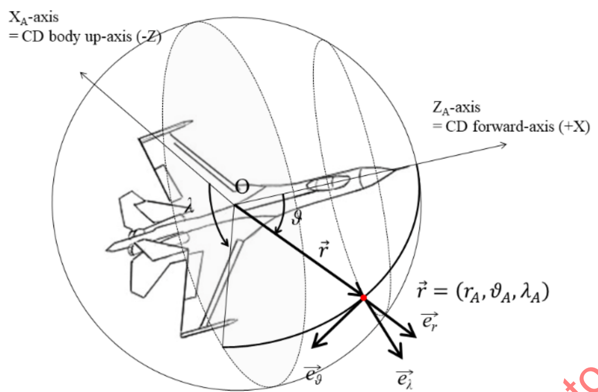
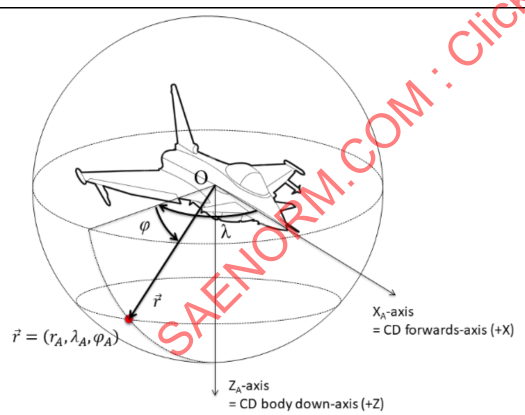


Figure 6 - Vehicle body CD applied to aircraft

Table 25 shows various CRS that are anchored to a vehicle body coordinate datum. The vehicle body Cartesian CRS anchors the Cartesian CS X-axis to the CD forward-axis (+X), the CS Y-axis to the CD right-axis (+Y), and the CS Z-axis to the CD down-axis (+Z). There are two spherical CRS. The first anchors the CD Z-axis to the CD forward-axis (+X) and the CD X-axis to the CD up-axis (-Z). In contrast, the spherical (RAE) system, anchors the CD Z-axis to the CD down-axis (+Z), and the CS X-axis to the CD forward-axis (+X).

Table 25 - Example vehicle body CRS

	**Vehicle Body Cartesian CRS** Quantity vector tuple: $\vec{q} = (q_{Ax}, q_{Ay}, q_{Az})$ Position tuple: $\vec{r} = (x_A, y_A, z_A)$ Components: $\vec{r} = x_A\vec{e}_x + y_A\vec{e}_y + z_A\vec{e}_z$ Differential components: $d\vec{r} = dx_A\vec{e}_x + dy_A\vec{e}_y + dz_A\vec{e}_z$
	**Vehicle Body Spherical CRS** Quantity vector tuple: $\vec{q} = (q_A, \vartheta_A, \lambda_A)$ Position tuple: $\vec{r} = (r_A, \vartheta_A, \lambda_A)$ Components: $\vec{r} = r_A\vec{e}_r$ Differential components: $d\vec{r} = dr\ \vec{e}_q + r\ d\vartheta_A\ \vec{e}_{\vartheta A} + r\ \sin\vartheta_A\ d\lambda_A\ \vec{e}_{\lambda A}$
	**Vehicle Body Spherical (RAE) CRS** Quantity vector tuple: $\vec{q} = (q_A, \lambda_A, \varphi_A)$ Position tuple: $\vec{r} = (r_A, \lambda_A, \varphi_A)$ Components: $\vec{r} = r\vec{e}_r$ Differential components: $d\vec{r} = dr\ \vec{e}_r + r\ \cos\ \varphi_A\ d\lambda_A\ \vec{e}_{\lambda A} + r\ d\varphi_A\ \vec{e}_{\varphi A}$

4.10 Coordinate Operations

In this data dictionary, coordinate operations re-reference a quantity from one CRS to another. The value of the quantity itself does not change. Coordinate operations are different from vector operations. In a vector operation, the CRS would remain the same and the vector would be operated on within that CRS, for example by a rotation matrix.

It is not the purpose of this data dictionary to define normative coordinate operations between every CRS, nor to define algorithms for software. However, many parameters of coordinate operations are exchanged between systems and, therefore, a notional coordinate operation reference system is required.

A hypothetical coordinate operation from CRS1 to CRS2 involves three basic stages:

a. Conversion of CRS1 from its ‘coordinate form’ into its ‘datum form.’

b. Transformation of the CRS1 CD into the CRS2 CD

c. Conversion of CRS2 from its 'datum form' to its 'coordinate form.'

The 'coordinate form' of a CRS is the complete definition of the CRS coordinate tuple (or coordinate matrix) that is exchanged. The 'datum form' is as follows:

a. SI units (where units must be specified).

b. Cartesian CS.

c. X-axis of Cartesian CS mapped to +X-axis of CD, and so on.

The remapping of CS axes to CD axes involves a sign matrix if required or a simple identity matrix if not. For example, the Earth-fixed LTP CD follows the ENU convention, therefore, any CRS rendered into an Earth-fixed NED CRS would require the following sign matrix to realize it in its datum form:

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix}_{LTP} = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & -1 \end{bmatrix} \begin{pmatrix} x_N \\ y_E \\ z_D \end{pmatrix}_{NED}$$

The coordinate datum transformation is then of the general form:

$$\begin{pmatrix} x_2 \\ y_2 \\ z_2 \end{pmatrix}_{CD2} = \overset{\rightrightarrows}{\mathbf{T}}_{21} \begin{pmatrix} x_1 - x_{O,1} \\ y_1 - y_{O,1} \\ z_1 - z_{O,1} \end{pmatrix}_{CD1}$$

where $(x_{O,1}, y_{O,1}, z_{O,1})$ is the position of the origin of the CD2 axis system in the CD1 axis system and where the transformation tensor that performs the re-orientation of the axes from CD1 to CD2 is denoted by

$$\overset{\rightrightarrows}{\mathbf{T}}_{21}$$

In general, the transformation tensor can be represented as a function of three Euler angles, where each Euler angle is a rotation of two axes about the third to be performed in the sequence Z-Y-X. That is, a clockwise rotation of the X, Y axes about the Z axis by the Euler angle ψ to produce the X_{ψ}, Y_{ψ} axes, followed by a clockwise rotation of the X_{ψ}, Z axes about the new Y_{ψ} axis by the Euler angle θ to produce the $X_{\psi\theta}, Z_{\theta}$ axes, followed by a clockwise rotation of the Y_{ψ}, Z_{θ} axes about the new $X_{\psi\theta}$ axis by the Euler angle φ to produce the final set of $X_{\psi\theta}, Y_{\psi\varphi}\ Z_{\theta\varphi}$ axes. Examples of Euler angles are vehicle heading, pitch, and roll. These are associated with the axis rotation from the vehicle-carried NED CRS to the vehicle body Cartesian CRS.

It will be noted that in operational systems the use of Euler angles can sometimes result in mathematical singularities, in which case a different mathematical approach will be used in software. Euler angles, however, may be exchanged in messages such as aircraft heading, pitch and roll.

Once CRS1 has been transformed into the datum form of CRS2, it is now necessary to convert it to its coordinate form by reversing the steps before the CS transformation outlined above. In software, or course, it may be desirable to use a different transformation algorithm to the notional sequence identified in this data dictionary.

The following subsections provide additional discussion but are not indented to be a complete survey of coordinate operations.

4.10.1 Geodetic CRS Coordinate Operations

Strictly speaking, coordinate conversions only apply to geodetic CRS that share the same terrestrial reference frame, such as WGS 84 (G1762). Otherwise we must include a coordinate transformation from one TRF to another. For example, when using historical WGS 84 positional data. In practice, the differences between successive WGS 84 reference frames are increasingly small. Transformations are also required between WGS 84 frames and other (non WGS 84) reference frames.

For WGS 84, the coordinate conversions are provided in 4.9.1 for the conversion from the Geodetic Ellipsoid CRS to the ECEF CRS, and from the Geodetic Ellipsoid to the Geoid.

4.10.2 Earth-Fixed LTP CRS Coordinate Operations

The principal coordinate transformations of interest are between the Earth-fixed local tangent plane and the geodetic CRS, noting that the first is the position differential of the second. For small distances, the transformation from the geodetic ellipsoid to the ENU system with point of origin $(\lambda_{gO}, \varphi_{gO}, h_{gO})$ is given by:

$$x_E \approx (\rho + h_g)\cos\varphi \;(\lambda_g - \lambda_{gO})$$

$$y_N \approx (\varrho + h_g)(\varphi_g - \varphi_{gO})$$

$$z_U \approx (h_g - h_{gO})$$

The equations for the radius of curvature of the local parallel (ρ) and the radius of curvature of the local meridian (ϱ) are provided in 4.8. At point $(\lambda_O, \varphi_O, h_O)$ the ENU velocity is given by:

$$\vec{v} = v_E \vec{e}_E + v_N \vec{e}_N + v_U \vec{e}_U$$

where:

$$v_E = (\rho + h_g)\cos\varphi_g \frac{d\lambda_g}{dt}$$

$$v_N = (\varrho + h_g)\frac{d\varphi_g}{dt}$$

$$v_U = \frac{dh_g}{dt}$$

4.10.3 Vehicle Kinematic Coordinate Operations

Kinematic relationships between the vehicle-carried local tangent plane and the vehicle body coordinate datum are important to modeling vehicle dynamics and control. The transformation from the vehicle-carried NED CRS to the vehicle body Cartesian CRS is given by:

$$\begin{pmatrix} x_A \\ y_A \\ z_A \end{pmatrix}_A = \vec{\vec{\mathbf{T}}}_{21} \begin{pmatrix} x_N \\ y_E \\ z_D \end{pmatrix}_{NED,v}$$

where the transformation tensor can be a function of these Euler rotations:

a. Adjusting for heading results in the clockwise rotation of the $\mathrm{X}_N, \mathrm{Y}_E$ axes about the Z_D axis by the Euler angle ψ to produce the $\mathrm{X}_{\mathrm{N}\psi}, \mathrm{Y}_{\mathrm{E}\psi}$ axes, which are the horizontal components of the final $\mathrm{X}_\mathrm{A}, \mathrm{Y}_\mathrm{A}$ axes.

b. Adjusting for pitch results in the clockwise rotation of the $\mathrm{X}_{N\psi}, \mathrm{Z}_D$ axes about the new $\mathrm{Y}_{E\psi}$ axis by the Euler angle θ to produce the $\mathrm{X}_{\mathrm{N}\psi\theta}, \mathrm{Z}_{\mathrm{D}\theta}$ axes, where $\mathrm{X}_{\mathrm{N}\psi\theta} = \mathrm{X}_\mathrm{A}$.

c. Adjusting for roll resulting in the clockwise rotation of the $\mathrm{Y_{N\psi}}, \mathrm{Z_{D\theta}}$ axes about the new $\mathrm{X_A}$ axis by the Euler angle φ to produce the final set of $\mathrm{X_A}, \mathrm{Y_A}\ \mathrm{Z_A}$ axes.

Therefore

$$\vec{\vec{\mathbf{T}}}_{21} = \begin{bmatrix} c_\theta c_\psi & c_\theta s_\psi & -s_\theta \\ s_\varphi s_\theta c_\psi - c_\varphi s_\psi & s_\varphi s_\theta s_\psi + c_\varphi c_\psi & s_\varphi c_\theta \\ c_\varphi s_\theta c_\psi + s_\varphi s_\psi & c_\varphi s_\theta s_\psi - s_\varphi c_\psi & c_\varphi c_\theta \end{bmatrix}$$

where c_* and s_* denote $\cos(*)$ and $\sin(*)$ respectively.

As a simple example, consider a position vector (3, 2, 1) in the vehicle-carried NED CRS. When an aircraft is flying level and due north (all Euler angles are zero) then the transformation tensor will be:

$$\vec{\vec{\mathbf{T}}}_{21} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

and, therefore, the position vector in the vehicle body Cartesian CRS will also be (3, 2, 1). On the other hand, if the aircraft were to remain level but turn due east with a heading of +90°, the transformation tensor would change to:

$$\vec{\vec{\mathbf{T}}}_{21} = \begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

and, therefore, the position vector in the vehicle-carried NED CRS would be transformed to (2, -3, 1) in the vehicle body Cartesian CRS.

4.11 Statistical Quantities

Analysis of a population of sampled values for a single quantity or for a collection of causally-related quantities may give rise to secondary statistical quantities or waveform quantities. The statistical quantities discussed here are mean, standard deviation, variance, covariance, and joint covariance.

If quantity q is a random variable, then its value samples may be described by:

- Mean (or expected) value, $E[q]$
- Standard deviation, $\sigma_q = \sqrt{E[(q - E[q])^2]}$
- Variance, $var(q) = \sigma_q^2 = E[(q - E[q])^2]$

The quantity dimension for the mean and standard deviation are the same as the quantity; the quantity dimension of the variance is the square.

When q is a vector, then its coordinates (or components) are random variables. Consider $\vec{q}$, where $\vec{q}$ has the coordinates q_1, q_2, and q_3.

$$\vec{q} = \begin{pmatrix} q_1 \\ q_2 \\ q_3 \end{pmatrix}$$

This gives rise to the covariance matrix

$$cov(\vec{q}) = \begin{bmatrix} var(q_1) & cov(q_1, q_2) & cov(q_1, q_3) \\ cov(q_1, q_2) & var(q_2) & cov(q_2, q_3) \\ cov(q_1, q_3) & cov(q_2, q_3) & var(q_3) \end{bmatrix}$$

Where, for example, $var(q_1)$ is the variance of the coordinate q_1 (also denoted as $\sigma_{q_1}^2$) and $cov(q_1, q_2)$ is the covariance of the coordinates q_1 and q_2 (also denoted as σ_{q_1,q_2}).

$$cov(q_1, q_2) = E[(q_1 - E[q_1])(q_2 - E[q_2])]$$

As the covariance matrix is symmetrical, the covariance of the three-dimensional vector $\vec{q}$ is given by six parameters: $var(q_1)$, $cov(q_1, q_2)$, $cov(q_1, q_3)$, $var(q_2)$, $cov(q_2, q_3)$, and $var(q_3)$. The quantity dimension for the covariance is the quantity dimension of the first quantity multiplied by the quantity dimension of the second quantity.

Consider the example of a two-dimensional position vector in an east-north coordinate reference system, where

$$\vec{r} = \begin{pmatrix} x_E \\ y_N \end{pmatrix}$$

$$cov(\vec{r}) = \begin{bmatrix} var(x_E) & cov(x_E, y_N) \\ cov(x_E, y_N) & var(y_N) \end{bmatrix}$$

i.e., by the parameters: $var(x_E)$, $cov(x_E, y_N)$, and $var(y_N)$.

It is often convenient to express covariance as an ellipse denoting the confidence of the two-dimensional value of $\vec{r}$. The ellipse is defined by a point of origin (denoting the mean value of $\vec{r}$), the semi-major and semi-minor axes (denoting the size and shape of the ellipse), and the orientation (for example, the right azimuth) of the semi-major axis.

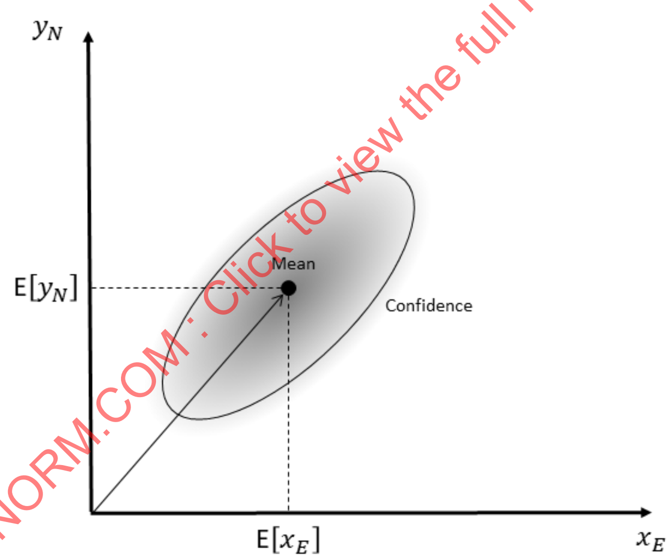


Figure 7 - Mean and covariance of random values of position vector

In this two-dimensional example, the axes of the 1σ confidence ellipse are equal to the square roots of the magnitudes of the eigenvalues, λ_1, λ_2 of the covariance matrix, where:

$$\lambda = \frac{1}{2}\left[var(x_E) + var(y_N) \pm \sqrt{\left(2cov(x_E, y_N)\right)^2 + \left(var(x_E) - var(y_N)\right)^2}\right]$$

with the greater value being the semi-major axis and the lesser value being the semi-major axis. The axes can be scaled for a given probability value based on its corresponding σ value. For example, the scale factor for the 95% confidence ellipse is approximately 2.45.

For a quantity vector that is not resolved into its coordinates, $cov(\vec{q}) = var(\vec{q})$. The joint covariance matrix for two different vector quantities, for example the position vector $\vec{r}$ and velocity vector $\vec{v}$ of a moving vehicle, is the block matrix:

$$joint\ covariance(\vec{r},\vec{v}) = \begin{bmatrix} var(\vec{r}) & cov(\vec{r},\vec{v}) \\ cov(\vec{r},\vec{v}) & var(\vec{v}) \end{bmatrix}$$

where, in this context, $var(\vec{r})$ and $var(\vec{v})$ are the variance matrices of the marginal distributions of $\vec{r}$ and $\vec{v}$.

For example, when

$$\vec{r} = \begin{pmatrix} x_N \\ y_E \\ z_D \end{pmatrix}, \vec{v} = \begin{pmatrix} v_N \\ v_E \\ v_D \end{pmatrix}$$

$$cov(\vec{r},\vec{v}) = \begin{bmatrix} cov(x_N,v_N) & cov(x_N,v_E) & cov(x_N,v_D) \\ cov(y_E,v_N) & cov(y_E,v_E) & cov(y_E,v_D) \\ cov(z_D,v_N) & cov(z_D,v_E) & cov(z_D,v_D) \end{bmatrix}$$

$$var(\vec{r}) = \begin{bmatrix} var(x_N) & cov(x_N,y_E) & cov(x_N,z_D) \\ cov(x_N,y_E) & var(y_E) & cov(y_E,z_D) \\ cov(x_N,z_D) & cov(y_E,z_D) & var(z_D) \end{bmatrix}$$

$$var(\vec{v}) = \begin{bmatrix} var(v_N) & cov(v_N,v_E) & cov(v_N,v_D) \\ cov(v_N,v_E) & var(v_E) & cov(v_E,v_D) \\ cov(v_N,v_D) & cov(v_E,v_D) & var(v_D) \end{bmatrix}$$

This gives rise to twenty-one parameters: nine parameters for $cov(\vec{r},\vec{v})$, six parameters for $var(\vec{r})$, and six parameters for $var(\vec{v})$.

4.12 Time Reference Systems

Time (t) is a base quantity in the ISQ. It is specialized into system time, time duration, and period duration. System time is analogous to a spatial position, and time duration is analogous to a displacement or distance. System time and position are both affine quantities. System times, therefore, cannot be added, but can be subtracted. The difference between two system times is a time duration. A system time may be specified by another system time plus or minus a time duration.

System time is expressed by a time duration from an epoch of historical, scientific, or technical significance. The SI unit of time is the second. A global system time may also be expressed as a date plus time of day as defined in ISO 8601.

A time reference system is analogous to a coordinate datum in a spatial reference system. Time does not need a coordinate system as there are no components of time (there is only one time 'axis'). There are multiple time reference systems, including:

a. Atomic time, whose unit of duration is the SI second. International Atomic Time (TAI) is the global time reference that is calculated by the International Bureau of Weights and Measures (BIPM).

b. Universal Time (UT), whose unit of duration is the mean solar day and counted from 0 hours at midnight. UT0 is the rotational time measured at particular observation site (assuming fixed coordinates in the International Terrestrial Reference Frame). UT1 is computed by correcting UT0 for the effect of polar motion on the International Terrestrial Reference Frame).

c. Coordinated Universal Time (UTC) differs from TAI by an integer number of seconds. UTC is kept within 0.9 seconds of UT1 by the introduction of leap seconds.

d. GPS Time (GPST), which was synchronized to UTC at 1980-01-06T00:00Z. GPST has no leap seconds.

e. Galileo System Time (GST), which was synchronized to UTC at 1999-08-22T00:00Z. GST has no leap seconds.

f. GLONASS Time (GLONASST), which is synchronized to UTC plus 3 hours.

g. Local system clocks whose epochs are chosen by technical considerations (such as system start).

While global time reference systems tend to have a single epoch, local system clocks tend to have multiple epochs. These may be separated by a fixed period duration or may be triggered by an external clock reset event. This may lead to 'clock roll-over' when two system time values are separated by an epoch.

NOTE: This data dictionary does not have the notion of 4D position - i.e., the compound of a 3D position vector and time. However, there is nothing to prevent a data modeler from creating such a datatype (or any other compound data type) if they require it. In principle, time can be compounded with any other quantity. For example, force at a given system time or for a given time duration.

4.13 Overview of Measurements

4.13.1 Metrology

In this data dictionary, a quantity is defined as is the property of a phenomenon, body or substance, where the property has a value with magnitude. A quantity definition may apply to a quantity within a specialized field of application where the quantity belongs to a more general quantity kind. The defining elements of the quantity definition may include a measurement procedure or scale and a reference material.

In principle, a general quantity within the ISQ, such as mass concentration, could be specialized into a definition of blood total hemoglobin concentration, for example, which is determined for a human subject using pulse oximetry. The preferred measurement unit would also be stated, such as g/dL.

Users of this data dictionary may specialize a quantity definition in this manner. However, in the appendices a different approach is taken to defining domain-specific quantities. The principal concern in the appendices is metrology. Metrology introduces the notions of measurand and measurement.

A measurand is defined as the particular quantity that is subject to measurement. The measurand is described as the general quantity to be measured and the specification of the phenomenon, body or substance that is the subject of the measurement. In this paradigm, aircraft airspeed is a measurand and velocity is the general quantity. In the example above, total blood hemoglobin concentration is the measurand and mass concentration is the general quantity.

A measurement is defined as the set of operations having the object of determining a value of a quantity (the measurand). The concerns of a measurement specification are epistemological, i.e., how the value is to be known. The specification of a measurement is provided at three levels of detail: the principle of measurement, the method of measurement and the measurement procedure.

NOTE: The quantification of measurement uncertainty is addressed as a quantity modal. See 4.13.4.

4.13.2 Principle of Measurement

The principle of measurement is the scientific basis or context of the measurement, which is conceptual in nature. It is important in data modeling that the measurement principle does not define a reference system or other structure for the quantity value specification. Example measurement principles are:

1. Inertial measurement of vehicle acceleration

2. Doppler-effect measurement of target velocity

3. Navigation satellite measurement of vehicle position

4. Terrain-referenced measurement of target position

5. Axillary measurement of body temperature

6. Light-absorption measurement of blood total hemoglobin concentration

4.13.3 Method of Measurement

The method of measurement is the logical sequence of operations, described generically, used in the performance of measurements. If applicable to the kind of quantity, the measurement method will specify the datum (or ordinal scale) used in the measurement. Example measurement methods are:

1. For principle 1 above, Inertial Navigation System (INS) measurement based on aircraft coordinate datum

2. For 2 above, aircraft radar measurement based on WGS 84 (G1762) vehicle-carried LTP coordinate datum

3. For 3 above, GPS-aided INS measurement based on WGS 84 (G1762) coordinate datum

4. For 4 above, image geo-registration based on WGS 84 (G1674) coordinate datum

5. For 5 above, digital thermometer

6. For 6 above, pulse oximetry

NOTE: The datum specified in the measurement method can be different to the datum used in the logical data type for the quantity value. For example, the quantity value may have undergone a coordinate transformation to conform to a logical interface specification.

4.13.4 Measurement Procedure

A measurement procedure is the set of operations, described specifically, used in the performance of measurements according to a given method. In general, the measurement procedure would be defined in the context of an identified system entity and its operating mode or state.

4.13.5 Influence Quantity

An influence quantity is a quantity that is not the measurand but affects the result of the measurement. Influence quantities include values associated with measurement standards, reference materials, and reference data upon which the result of a measurement may depend, as well as phenomena such as ambient temperature, barometric pressure and humidity.

4.14 Overview of Quantity Modals

A quantity modal is a logical or mathematical operator that qualifies the truth-semantics of a quantity value. A quantity modality is a system of quantity modals. The term categorical quantity is used, were necessary, to identify a quantity without a modality. Four modalities are defined in this data dictionary, although others are possible. They are alethic, deontic, metrological and waveform. The formal definitions of these modalities and their modals is provided in Section 9.

The context of a modality is a categorical quantity, whose instantaneous value (or state) is observable in the present.

NOTE: In some data models, a categorical quantity would be an example of an observable.

4.14.1 Alethic Quantities

Alethic logic is a branch of symbolic logic that is concerned with the possibility or necessity of the truth of propositions. In this data dictionary, an alethic quantity is concerned with the range of values that are possible (in engineering terms) or the range of values that is necessary (in engineering terms). For example, an aircraft flight envelope is characterized by a set of alethic quantities.

The alethic system is based on four models:

a. Necessary

b. Possible

c. Impossible (not possible)

d. Non-necessary (not necessary)

Where the modals necessary and impossible are contraries (a value cannot both be necessary and impossible) and the modals possible and non-necessary are subcontraries (a value cannot both be not possible and not omissible).

Alethic quantities are based on operational capabilities and specifications rather than on operational objectives. Operational objectives are characterized by deontic quantities.

4.14.2 Deontic Quantities

Deontic logic is a branch of symbolic logic that is concerned with obligation and permission. In this data dictionary, a deontic quantity is concerned with the range of values (or a single value) that is required to meet an operational objective, or the range of values that represents an operational constraint. For example, geographical waypoints or boundaries.

The deontic system is based on four models:

a. Obligatory

b. Permissible

c. Impermissible (not permitted)

d. Omissible (not obligatory)

The modals obligatory and impermissible form a contrary pair, and the modals permissible and omissible form a subcontrary pair.

NOTE: A system's deontic quantities must be reconciled with its alethic quantities. For example, a valid obligatory quantity must also be a possible quantity.

4.14.3 Metrological Quantities

Metrology falls within the broader concern of epistemology, i.e., the characterization of the knowledge of a categorical value. In principle, additional epistemological modalities could be introduced. Metrology is addressed by both measurement definitions and metrological quantities. Metrological quantities include:

a. Measurement Uncertainty - a parameter, associated with the result of a measurement, that characterizes the dispersion of the values that can reasonably be attributed to the measurand.

b. Quantization Step - the smallest finite difference between two sampled values resulting from value quantization (i.e., analog to digital conversion).

NOTE: The quantization error resulting from quantization step contributes towards measurement uncertainty.

4.14.4 Waveform Quantities

A categorical quantity value represents the instantaneous value (or state) of the quantity (at a single time). A waveform quantity is a quantitative characterization of a population of values (or states) against an a-priori model, for example, the model of I as function of time, $i(t)$.

Consider the sinusoidal signal model of I, $i(t) = A\cos(\omega t - \theta)$, where A is the signal amplitude, ω is the angular frequency and θ is the initial phase. Thus, a population (in this case, a time series) of values is characterized by three waveform quantities, A (or the corresponding rms value), ω (or the corresponding frequency) and θ (within a system of sinusoids).

Waveform quantities can be cardinal or ordinal. Cardinal waveform quantities have units of measure and are algebraic in nature, for example, the sinusoidal waveform quantities just described. Ordinal waveform quantities are empirical in nature and a defined by an ordinal quantity scale. An ordinal waveform quantity might be defined by an evaluation procedure, such as an analog video network K-rating.

Noise, as distinct from measurement uncertainty, characterizes the stochastic departure of the population of values from the waveform model. Noise may be expressed as a signal-to-noise radio.

4.15 Overview of Quantity Domains

Appendices of this data dictionary describe quantity domains. A quantity domain is a collection of tables that define domain-specific:

- Cardinal quantities
- Ordinal quantities
- Measurement units
- Reference Systems
- Measurands and Measurements
- Nominal properties (that are derived stated measurements)
- Measurement modalities (singly or in combination)

4.15.1 Domain-Specific Cardinal Quantities

Domain-specific cardinal quantities are defined using the template provided in Table 28. Cardinal quantities have a quantity kind that is one of the general quantities defined in Section 5 (via a hierarchy of domain-specific quantity kinds if necessary). The quantity definition describes the quantity application and references the preferred measurement unit (or preferred decimal or binary prefix) for that application.

If structurally convenient, a reference material and associated measurement procedure or scale is included in the quantity table, although usually this information is provided in the measurement table. The reason for this is that often there will be a series of measurements around the same reference material using different general quantities.

4.15.2 Domain-Specific Ordinal Quantities

Domain-specific cardinal quantities are defined using the template provided in Table 29. Because of their empirical nature, ordinal quantities tend to be domain-specific. Unlike cardinal quantities, the reference material is generally intrinsic to the definition of the quantity kind. For example, an Octane rating can only apply to gasoline.

4.15.3 Domain-Specific Measurement Units

Domain-specific measurement units are defined using the template provided in Table 124. A domain-specific measurement unit cannot simply be a measurement unit defined in Section 6 with a decimal or binary prefix. For example, kHz, MHz, or GHz instead of Hz. The preferred prefix, if one exists, is given with the cardinal quantity table or measurement table.

4.15.4 Domain-Specific Reference Systems

This data dictionary currently provides reference systems for space and time, which are modified for other fields of application whose dimensional space includes length and time. The field of thermodynamics is also based on a temperature reference system; however, this is included within the temperature quantity definition. In principle, other domain-specific reference systems can be defined, for example, a system of color spaces.

The reference systems for space and time are either terrestrially referenced or referenced to a local engineering datum such as the position and orientation of a vehicle or the epochs of a local clock. Terrestrial datums are intended to be universal and part of the body of this data dictionary. However, engineering datums can be domain specific.

A spatial reference system has three parts as discussed in the overview. There are the coordinate datum (CD), the coordinate system (CS) and the coordinate reference system (CRS) that binds the CS to the CD.

Domain-specific CDs are defined using the template provided in Table 223. A domain-specific CS is defined using Table 228. A domain-specific CRS is defined using Table 242 or Table 243.

NOTE: The coordinate systems in this data dictionary are based on the algebraic structure (category) of vector spaces (and related concepts). Other, more specialized, mathematical categories could be used in quantity domains (such as topographical spaces, rings, metric spaces, and so forth).

4.15.5 Domain-Specific Measurements

All measurands and their measurements are domain specific. Their defining elements are described in Tables 26 and 27.

A general quantity might have a preferred measurement unit (for example, the SI unit) that which is overridden in the definition of a measurand. For example, the preferred unit for pressure is the pascal; however, the preferred unit for blood pressure is mmHg. A measurement specification might further override the preferred measurement unit of a measurand.

NOTE: The preferred measurement unit (or its declared prefix) is not considered normative in conformant data models, which might, for example, have a non-SI unit policy.

NOTE: It is important that the measurement table is only used to define a directly observable, single-sample quantity (i.e., a categorical quantity). Modalities and other derived information will be defined in subsequent tables. This restriction is to support the needs of data modelers.

Table 26 - Defining elements of measurand

DEFINING ELEMENT	DESCRIPTION
Measurand name	Unique name/identifier for measurand
Version	Version of definition
Definition URI	Namespace, a universally unique identifier for definition table. UUID conformant to RFC4122 standard, and version
Authoritative reference	The reference document or institution used to define the measurand
Measurand description	Description of the phenomenon, body, or substance, and its property that is the subject of measurement.
Quantity name	Unique name/identifier for quantity
Quantity definition URI	Namespace plus universally unique identifier for quantity table
Measurand application	If the measurand has a specific application within a field of application, it shall be described. Otherwise the measurand application is defined as 'general'.
Remarks	Additional remarks on the measurand

Table 27 - Defining elements of measurement

DEFINING ELEMENT	DESCRIPTION
Measurement name/identifier	Unique name/identifier for measurement
Version	Version of definition
Definition URI	Namespace, a universally unique identifier for definition table and version. UUID conformant to RFC4122 standard
Authoritative reference	The reference document or institution used to define the measurand
Measurand name/identifier	Unique name/identifier for measurand
Measurand definition URI	Namespace plus universally unique identifier for measurand table
Measurement application	If the measurement has a specific application within a field of application, it shall be described. Otherwise the measurand application is defined as 'general'.
Preferred measurement unit name/identifier	Unique name/identifier for measurement unit. Note: this information may override the measurand specification
Preferred measurement unit definition URI	Namespace plus universally unique identifier for measurement unit table
Preferred measurement unit prefix or factor	If required, state preferred prefix or factor as defined in ISO: 80000-1. Other state 'none'. Note: this information may override the measurand specification
Principle of measurement	If required, the scientific basis or context of the measurement
Method of measurement	If required, the logical sequence of operations, described generically, used in the performance of measurements
Datum name/identifier	If a datum is associated with the method of measurement, the unique name/identifier of the datum is provided (for example, a coordinate datum)
Preferred CRS name/identifier	
Preferred CRS Definition URI	Definition URI for CRS table
Measurement procedure	If required, the set of operations, described specifically, used in the performance of measurements according to a given method
Influence quantity	The name/identifier and associated UUID of any influence quantity, measurand, or measurement, together with its value.
Remarks	Additional remarks on the measurement.
Coordinate measurand name	
Coordinate measurand definition URI	
Associated coordinate	
Remarks	

5. QUANTITIES

5.1 Description of Quantity

This data dictionary recognizes two types of quantity as defined in 3.1.2:

a. Cardinal quantity - A quantity with scalar magnitude that may be related to other quantities by algebraic equations. Cardinal quantities have measurement units. All cardinal quantities have quantity dimensions.

b. Ordinal quantity - A quantity with magnitude ordering determined by a conventional reference scale but without measurement units or quantity dimensions. Ordinal quantities cannot be related to other quantities by algebraic equations but can be related empirically.

A nominal property is a property without a magnitude. The value of a nominal property is established by an agreed criterion. A nominal property can be expressed either by a nominal number or by a non-numeric value.

In this data dictionary, a basic cardinal quantity is a quantity that is completely defined in ISO/IEC 80000. Where the context of a cardinal quantity is a vector measurement, its special names are provided for coordinates within a given coordinate system. It shall be noted, however, that the symbol always mathematically represents a scalar. For example, in a Cartesian coordinate system, the coordinates of the position $\vec{r}$ are x, y, z, where:

$$\vec{r} = r\vec{e}$$

$$\vec{r} = \vec{x} + \vec{y} + \vec{z} = x\vec{e}_x + y\vec{e}_y + z\vec{e}_z = (x, y, z)$$

In the context of a given coordinate reference system (which is a coordinate system anchored to a real-world coordinate datum) each coordinate can be assigned an alias. For example, the plane angle θ has the coordinate azimuth λ in the spherical (RAE) coordinate system. In the Engineering LTP Spherical (RAE) CRS, the coordinate azimuth has the coordinate alias of north azimuth.

A domain-specific cardinal quantity is a refinement of a basic cardinal quantity.

5.1.1 Defining Elements of Cardinal Quantity

The defining elements of a cardinal quantity are listed in Table 28.

Table 28 - Defining elements for cardinal quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Unique name/identifier for quantity
Version	Version of definition
Definition URI	Namespace, universally unique identifier, and version for definition table. UUID conformant to RFC4122 standard.
Quantity type	Cardinal (scalar, vector, affine)
System of quantities	ISQ or other system of quantities
Authoritative reference	The reference document or institution used to define the quantity
Quantity kind	Quantity kind to which the quantity belongs.
Quantity dimension	Quantity dimension of one or quantity equation using quantity dimension symbols
Quantity symbol	Symbol used to represent quantity in quantity equations
Quantity equation	Base quantity or quantity equation using quantity symbols
Field of application	Branch of natural sciences or technology to which the quantity belongs
Quantity application	If the quantity has a specific application within a field of application, it shall be described. Otherwise the quantity application is defined as 'general.'
Preferred measurement unit	For quantities in the ISQ, the SI unit is the preferred measurement unit.
Other measurement units and unit application (if applicable)	If applicable, identify other permitted measurement units and their specific applications.
Measurement procedure or scale (if applicable)	For cardinal quantities with a specific application, it may be necessary to define a detailed measurement procedure or scale.
Reference material (if applicable)	For cardinal quantities, it may be necessary to define a reference material.

5.1.2 Defining Elements of Ordinal Quantity

The defining elements of an ordinal quantity are listed in Table 29.

Table 29 - Defining elements of ordinal quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Unique name/identifier for quantity
Version	Version of definition
Definition URI	Namespace, universally unique identifier and version for definition table. UUID conformant to RFC4122 standard.
Quantity type	Ordinal
Authoritative reference	The reference document or body used to define the quantity
Field of application	Branch of natural sciences or technology to which the quantity belongs
Quantity application	If the quantity has a specific application within a field of application, it shall be described. Otherwise the quantity application is defined as 'general.'
Measurement procedure and scale	All ordinal quantities must have a measurement procedure or scale.
Scale symbol	The unique symbol, name, or acronym for measurement scale
Reference material (if applicable)	For ordinal quantities, it may be necessary to define a reference material.

5.2 Number of Entities

Number of entities is a cardinal quantity that can be added to any system of quantities. Its measurement unit is one.

Table 30 - Defining elements of number of entities quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Number of entities quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/5DA65F06-CE59-4EA3-BA3B-84824EB1D548/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO-80000-1:2009
Quantity kind	Number of entities
Quantity symbol	*1*
Quantity dimension	dim 1 = 1
Quantity equation	Base quantity
Field of application	General
Quantity application	General
Preferred measurement unit	One unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.3 Basic Quantities Relating to Space and Time

The principal reference for cardinal quantities relating to space and time is ISO 80000-3:2006. The taxonomy of basic space and time quantities is shown in Table 31, including the coordinates of a given quantity within one of the recognized coordinate systems.

Table 31 - Taxonomy of basic space and time quantities

Number of entities rate $1/t$		
Length l	Length of path s	
	Position vector $\vec{r}$	
	Displacement vector $\Delta\vec{r}$	
	Distance r	
	Radius ρ	
	Ellipsoidal height h	
Area A		
Volume V		
Plane angle	Rotation N	
	Plane angle θ	
	Vector angle	Angle of rotation (about primary axis) λ
		Angle of deflection (from primary axis) ϑ
		Angle of elevation (from primary plane) φ
	Euler angle	First rotation ψ
		Second rotation θ
		Third rotation φ
Solid angle Ω		
Time t	System-time t	
	Time duration t	
	Period duration T	
Velocity	Speed v_s	
	Velocity v	
Acceleration	Speed acceleration a_s	
	Velocity acceleration a	
Angular velocity ω	Plane angle velocity ω	
	Vector angle velocity ω	Angular velocity of rotation $d\lambda/dt$
		Angular velocity of deflection $d\vartheta/dt$
		Angular velocity of elevation $d\varphi/dt$
	Euler angle velocity ω	Angular velocity of first rotation $d\Psi/dt$
		Angular velocity of second rotation $d\Theta/dt$
		Angular velocity of third rotation $d\Phi/dt$
Angular acceleration α	Plane angle acceleration α	
	Vector angle acceleration α	Angular acceleration of rotation $d^2\lambda/dt^2$
		Angular acceleration of deflection $d^2\vartheta/dt^2$
		Angular acceleration of elevation $d^2\varphi/dt^2$
	Euler angle acceleration α	Angular acceleration of first rotation $d^2\Psi/dt^2$
		Angular acceleration of second rotation $d^2\Theta/dt^2$
		Angular acceleration of third rotation = $d^2\Phi/dt^2$
Frequency f	Rotational frequency η	
Level of power L_P		

5.3.1 Number of Entities Rate

NOTE: Number of entities rate is a composite quantity of ISQ quantities. It is the differential ratio of number of entities and time duration.

Table 32 - Defining elements of number of entities rate quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Number of entities rate quantity
Version	1.1
Definition URI	https://www.sae.org/5977BD40-F16F-4A2F-8028-00D8AC340EC1/1.1
Quantity type	Cardinal
System of quantities	Differential ratio of number of entities and time duration in ISQ
Authoritative reference	None
Quantity kind	Rate of change of number of entities
Quantity symbol	$(1/t)$
Quantity dimension	$\dim(1/t) = \mathrm{T}^{-1}$
Quantity equation	$(1/t) = \frac{d}{dt}$
Field of application	General
Quantity application	General
Preferred measurement unit	Second to the power minus one
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.3.2 Length

Length l is a base quantity in the ISQ. Length is specialized into these quantities:

a. Position vector, $\vec{r}$

b. Displacement vector, $\Delta\vec{r}$

c. Distance, r

d. Radius, ρ

e. Ellipsoidal height, h.

f. Length of path, s

NOTE: Position vector, $\vec{r}$, represents a position in Euclidean space and is related to a position of origin (which would be an arbitrarily chosen position in another Euclidean space). It is, therefore, an affine quantity because two position values cannot be added but the difference produces the displacement vector, $\Delta\vec{r}$, and the straight-line distance, r.

Table 33 - Defining elements of length quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Length quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/62C7D41A-A09A-471D-97C5-2C8D421E3320/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item no. 3-1.1)
Quantity kind	Length quantity
Quantity symbol	l
Quantity dimension	dim l = L
Quantity equation	Base quantity of ISQ
Field of application	Space and time
Quantity application	General.
Preferred measurement unit	Meter unit
Other measurement units and unit application	Kilometer unit Inch unit Statute foot unit Yard of length unit Statute mile unit
Measurement procedure or scale	None
Reference material	None

Table 34 - Defining elements of position vector quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Position vector quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/42E90920-1309-4ADE-A05A-3ACCB323FBA5/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item no. 3-1.9)
Quantity kind	Length quantity
Quantity symbol	$\vec{r}$ NOTE: The distance and direction from a position of origin.
Quantity dimension	dim $\vec{r}$ = L
Quantity equation	Base quantity of ISQ
Field of application	Space and time
Quantity application	Position in Euclidean space (affine quantity)
Preferred measurement unit	Meter unit (for length coordinates)
Other measurement units and unit application	Kilometer unit Inch unit Statute foot unit Yard of length unit Statute mile unit
Measurement procedure or scale	None
Reference material	None

Table 35 - Defining elements of displacement vector quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Displacement vector quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/093487F3-3BD6-402E-993B-0405F75867BA1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item 3-1.12)
Quantity kind	Length quantity
Quantity symbol	$\Delta\vec{r}$ NOTE: The difference between one position vector and another.
Quantity dimension	dim $\Delta\vec{r}$ = L
Quantity equation	Base quantity of ISQ
Field of application	Space and time
Quantity application	Vector representation of distance between two positions.
Preferred measurement unit	meter unit (for length coordinates)
Other measurement units and unit application	Kilometer unit Inch unit Statute foot unit Yard of length unit Statute mile unit
Measurement procedure or scale	None
Reference material	None

Table 36 - Defining elements of distance quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Distance quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/CC1F1BD9-7919-4379-A168-FE66F01C1666/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item 3-1.9)
Quantity kind	Length quantity
Quantity symbol	r NOTE: The magnitude of the displacement vector.
Quantity dimension	dim r = L
Quantity equation	Base quantity of ISQ
Field of application	Space and time
Quantity application	The vector length between one position vector and another
Preferred measurement unit	meter unit
Other measurement units and unit application	Kilometer unit Inch unit Statute foot unit Yard of length unit Statute mile unit
Measurement procedure or scale	None
Reference material	None

Table 37 - Defining elements of radius quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Radius quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/FA830AAD-D40C-4CE2-8EC3-92B5170D7272/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item 3-1.5)
Quantity kind	Length quantity
Quantity symbol	ρ NOTE: The perpendicular length or distance from an axis.
Quantity dimension	dim ρ = L
Quantity equation	Base quantity of ISQ
Field of application	Space and time
Quantity application	Used in cylindrical coordinate systems and to describe the magnitude of a circle
Preferred measurement unit	Meter unit
Other measurement units and unit application	Kilometer unit Inch unit Statute foot unit Yard of length unit Statute mile unit
Measurement procedure or scale	None
Reference material	None

Table 38 - Defining elements of ellipsoidal height quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Ellipsoidal height quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/FF925EAE-F134-4A1B-8F6D-74B2053F9636/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (specialization of item 3-1.3)
Quantity kind	Length quantity
Quantity symbol	h NOTE: The distance perpendicular to an ellipsoid surface.
Quantity dimension	dim h = L
Quantity equation	Base quantity of ISQ
Field of application	Space and time
Quantity application	Used in geodetic altitude measurements.
Preferred measurement unit	Meter unit
Other measurement units and unit application	Statute foot unit
Measurement procedure or scale	None
Reference material	None

Table 39 - Defining elements of length of path quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Length of path quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/08EF5B3B-BF56-42F0-A70A-4993DE34D55F/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item 3-1.8)
Quantity kind	Length quantity
Quantity symbol	s
Quantity dimension	dim s = L
Quantity equation	Base quantity of ISQ
Field of application	Space and time
Quantity application	Scalar The odometer distance travelled along a path or the length of the path where in general the path does not follow a constant direction.
Preferred measurement unit	Meter unit
Other measurement units and unit application	Kilometer unit Inch unit Statute foot unit Yard of length unit Statute mile unit
Measurement procedure or scale	None
Reference material	None

5.3.3 Area

Table 40 - Defining elements of area quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Area quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/5FC6E1BA-3DE7-4ABA-AD04-8B46818B415B/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item 3-3)
Quantity kind	Area quantity
Quantity symbol	A
Quantity dimension	dim A = L^2
Quantity equation	$A = \iint dx\, dy$ where x and y are cartesian components
Field of application	Space and time
Quantity application	Measurement of surfaces
Preferred measurement unit	Square meter unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.3.4 Volume

Table 41 - Defining elements of volume quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Volume quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/AC33C4FA-8947-49B9-BB99-FBE53A663713/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item 3-4)
Quantity kind	Volume quantity
Quantity symbol	V
Quantity dimension	dim V = L^3
Quantity equation	$V = \iiint dx\, dy\, dz$ where x, y and z are cartesian coordinates
Field of application Type	Space and time
Quantity application	Measurement of three-dimensional size
Preferred measurement unit	Cubic meter unit
Other measurement units and unit application	Liter unit (volume of a material)
Measurement procedure or scale	None
Reference material	None

5.3.5 Plane Angle

Table 42 - Defining elements of plane angle quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Plane angle quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/8D5A8D46-D405-404C-9C22-2BFCF5C3BE81/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item 3-5)
Quantity kind	Plane angle quantity
Quantity symbol	θ
Quantity dimension	dim θ = 1
Quantity equation	$\theta = {}^{s}/_{r}$ where s is the length of the arc of a circle between two radii of the circle and r is the radius of the circle. θ is positive in clockwise (i.e., right-handed) direction about axis of rotation.
Field of application	Space and time
Quantity application	General
Preferred measurement unit	Radian unit
Other measurement units and unit application	Degree of arc unit
Measurement procedure or scale	None
Reference material	None

Table 43 - Defining elements of vector angle quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Vector angle quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/C3B532CA-5B88-421E-A72B-145A0E7C2361/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item 3-5)
Quantity kind	Plane angle quantity
Quantity symbol	General symbol θ Angle of rotation (about primary axis) λ Angle of deflection (from primary axis) ϑ Angle of elevation (from primary plane) φ
Quantity dimension	dim θ = 1
Quantity equation	$\theta = {}^{s}/_{r}$ where s is the length of the arc of a circle between two radii of the circle and r is the radius of the circle. θ is positive in clockwise (i.e., right-handed) direction about axis of rotation.
Field of application	Space and time
Quantity application	Used to define coordinates of quantity vector or position vector
Preferred measurement unit	Radian unit
Other measurement units and unit application	Degree of arc unit
Measurement procedure or scale	None
Reference material	None

Table 44 - Defining elements of euler angle quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Euler angle quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/B1E15348-6E19-4B5A-88F7-5D127470C435/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item 3-5)
Quantity kind	Plane angle quantity
Quantity symbol	General symbol θ First rotation Ψ (about third axis) Second rotation Θ (about new second axis) Third rotation Φ (about new first axis)
Quantity dimension	dim θ = 1
Quantity equation	$\theta = {}^{s}/_{r}$ where s is the length of the arc of a circle between two radii of the circle and r is the radius of the circle. θ is positive in clockwise (i.e., right-handed) direction about axis of rotation.
Field of application	Space and time
Quantity application	Used to define transformation from source CRS to target CRS
Preferred measurement unit	Radian unit
Other measurement units and unit application	Degree of arc unit
Measurement procedure or scale	None
Reference material	None

5.3.6 Solid Angle

Table 45 - Defining elements of solid angle quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Solid angle quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/C7F5FFCF-5FA4-4D07-8162-420C9190371A/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item 3-6)
Quantity kind	Solid angle quantity
Quantity symbol	Ω
Quantity dimension	dim Ω = 1
Quantity equation	$\Omega = {}^{A}/_{r^2}$ where A is the area of the included surface of a sphere in a cone with its apex at the center of the sphere and r is the radius of the sphere.
Field of application	Space and time
Quantity application	General
Preferred measurement unit	Steradian unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.3.7 Time

Time t is base quantity in the ISQ. Time is specialized into these quantities:

a. System time, t

b. Time duration, t

c. Period duration, T

NOTE: System time is an affine quantity because two system time values cannot be added together, however, the difference is a time duration. System time is stated with respect to a time reference system. A time reference system can be a calendar or clock or both.

Table 46 - Defining elements of time quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Time quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/C810C821-CF6B-44E2-8932-B9C1811CCAF0/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item 3-7)
Quantity kind	Time quantity
Quantity symbol	t
Quantity dimension	dim t = T
Quantity equation	Base quantity of ISQ
Field of application	Space and time
Quantity application	General
Preferred measurement unit	Second of time unit
Other measurement units and unit application	Minute of time unit Hour unit Day unit
Measurement procedure or scale	
Reference material	None

Table 47 - Defining elements of system time quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	System time quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/D39D445E-0889-402A-8937-06D998897ABF/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item 3-7)
Quantity kind	Time quantity
Quantity symbol	t
Quantity dimension	dim t = T
Quantity equation	Base quantity of ISQ
Field of application	Space and time
Quantity application	General
Preferred measurement unit	Second of time unit
Other measurement units and unit application	Minute of time unit Hour unit Day unit
Measurement procedure or scale	ISO 8601 date and time format
Reference material	None

Table 48 - Defining elements of time duration quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Time duration quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/FBBB7ACB-7F2E-42E4-8297-AEED5222F206/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item 3-7)
Quantity kind	Time quantity
Quantity symbol	t
Quantity dimension	dim t = T
Quantity equation	Base quantity of ISQ
Field of application	Space and time
Quantity application	General
Preferred measurement unit	Second of time unit
Other measurement units and unit application	Minute of time unit Hour unit Day unit
Measurement procedure or scale	None
Reference material	None

Table 49 - Defining elements of period duration quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Period duration quantity
Version	1.1
Definition URI	https://www.sae.org/819B2054-A8A1-4107-A25D-6521EE963831/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item 3-12)
Quantity kind	Time duration quantity
Quantity symbol	T
Quantity dimension	dim T = T
Quantity equation	Base quantity
Field of application	Space and time
Quantity application	Time duration of one cycle
Preferred measurement unit	Second of time unit
Other measurement units and unit application	Minute of time unit Hour unit Day unit
Measurement procedure or scale	None
Reference material	None

5.3.8 Speed and Velocity

The difference between speed and velocity is based on conventional usage. Speed is the rate of change of path length s and is, therefore, a scalar quantity. Velocity is the rate of change of the velocity vector $\vec{r}$ and is, therefore, a vector with coordinates. The velocity vector is denoted by:

$$\vec{v} = v\vec{e}$$

Table 50 - Defining elements of velocity quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Velocity quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/D3D26E94-234E-40D9-B856-6802C26C7479/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item 3-8.1)
Quantity kind	Velocity quantity
Quantity symbol	v (vector $\vec{v}$)
Quantity dimension	$\dim v = \mathrm{L\,T^{-1}}$
Quantity equation	$v = \lvert d\vec{r}/dt \rvert$ where $\vec{r}$ is the position vector of length r and t is time duration
Field of application	Space and time
Quantity application	Vector velocity in context of coordinate system
Preferred measurement unit	Meters per second unit
Other measurement units and unit application	Kilometer per hour unit Inch per second unit Foot per second unit Mile per hour unit
Measurement procedure or scale	None
Reference material	None

Table 51 - Defining elements of speed quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Speed quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/21134D40-7910-4B69-9B39-7A1A78554888/1.1
Quantity type	Cardinal
System of quantities type	ISQ
Authoritative reference	Derived from ISO 80000-3:2006 (item 3-8.1)
Quantity kind	Velocity quantity
Quantity symbol	v_s
Quantity dimension	$\dim v_s = \mathrm{L\,T^{-1}}$
Quantity equation	$v_s = ds/dt$ where s is length of path and t is time duration
Field of application	Space and time
Quantity application	Scalar speed outside context of coordinate system
Preferred measurement unit	Meters per second unit
Other measurement units and unit application	Kilometer per hour unit Inch per second unit Foot per second unit Mile per hour unit
Measurement procedure or scale	None
Reference material	None

5.3.9 Acceleration

Acceleration is a quantity kind that subdivides into acceleration (based on the rate of change of velocity), and speed acceleration (based on the rate of change of speed). The acceleration vector is denoted by:

$$\vec{a} = a\vec{e}$$

Table 52 - Defining elements of acceleration quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Acceleration quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/35097A4C-076B-4B26-A94E-EA8040402E22/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item 3-9.1)
Quantity kind	Acceleration quantity
Quantity symbol	a (vector $\vec{a}$)
Quantity dimension	$\dim a = \mathrm{L\,T^{-2}}$
Quantity equation	$a = \|d\vec{v}/dt\|$ where $\vec{v}$ is the velocity vector and t is time duration
Field of application	Space and time
Quantity application	Acceleration in context of coordinate system
Preferred measurement unit	meters per second squared unit
Other measurement units and unit application	Feet per second squared unit
Measurement procedure or scale	None
Reference material	None

Table 53 - Defining elements of speed acceleration quantity

ATTRIBUTE	NOTE
Quantity name/identifier	Speed acceleration quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/0FED802A-146A-4B58-BCF0-E31B873399F4/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative source	Derived from ISO 80000-3:2006 (item 3-9.1)
Quantity kind	Acceleration quantity
Quantity symbol	a_s
Quantity dimension	$\dim a_s = \mathrm{L}\,\mathrm{T}^{-2}$
Quantity equation	$a_s = dv_s/dt$ where v_s is speed (along path) and t is time duration
Field of application	Space and time
Quantity application	Acceleration of an entity along a path outside context of coordinate system.
Preferred measurement unit	Meters per second squared unit
Other measurement units and unit application	Feet per second squared unit
Measurement procedure or scale	None
Reference material	None

5.3.10 Angular Velocity

Table 54 - Defining elements of plane angle velocity quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Plane angle velocity quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/86FF5018-D56B-41A4-BBB1-9FF547C8CB98/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item 3-10)
Quantity kind	Plane angle velocity quantity
Quantity symbol	ω
Quantity dimension	$\dim \omega = \mathrm{T}^{-1}$
Quantity equation	$\omega = d\theta/dt$ where θ is plane angle and t is time duration
Field of application	Space and time
Quantity application	General
Preferred measurement unit	Radian per second unit
Other measurement units and unit application	Degree per second unit
Measurement procedure or scale	None
Reference material	None

Table 55 - Defining elements of vector angle velocity quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Vector angle velocity quantity
Version	1.0
Definition URI	https://www.sae.org/AS6969/b6b58bcc-ccfb-4cbb-9cb7-7eecf68920f2/1.0
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item 3-10)
Quantity kind	Plane angle velocity quantity
Quantity symbol	General symbol ω
Quantity dimension	$\dim \omega = \mathrm{T}^{-1}$
Quantity equation	$\omega = d\theta/dt$ where θ is vector angle and t is time duration angular velocity of rotation = $d\lambda/dt$ angular velocity of deflection = $d\vartheta/dt$ angular velocity of elevation = $d\varphi/dt$
Field of application	Space and time
Quantity application	General
Preferred measurement unit	Radian per second unit
Other measurement units and unit application	Degree per second unit
Measurement procedure or scale	None
Reference material	None

Table 56 - Defining elements of euler angle velocity quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Euler angle velocity quantity
Version	1.0
Definition URI	https://www.sae.org/AS6969/cb8eca97-c25c-44bf-9138-895f54f8d95b/1.0
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item 3-10)
Quantity kind	Plane angle velocity quantity
Quantity symbol	General symbol ω
Quantity dimension	$\dim \omega = \mathrm{T}^{-1}$
Quantity equation	$\omega = d\theta/dt$ where θ is euler angle and t is time duration angular velocity of first rotation = $d\Psi/dt$ angular velocity of second rotation = $d\Theta/dt$ angular velocity of third rotation = $d\Phi/dt$
Field of application	Space and time
Quantity application	General
Preferred measurement unit	Radian per second unit
Other measurement units and unit application	Degree per second unit
Measurement procedure or scale	None
Reference material	None

5.3.11 Angular Acceleration

Table 57 - Defining elements of plane angle acceleration quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Plane angle acceleration quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/2AADA2B4-758D-4A36-A7BB-4B801F9A6BC4/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item 3-11)
Quantity kind	Plane angle acceleration quantity
Quantity symbol	α
Quantity dimension	$\dim \alpha = \mathrm{T}^{-2}$
Quantity equation	$\alpha = d\omega/dt$ where ω is plane angle velocity and t is time duration
Field of application ype	Space and time
Quantity application	General
Preferred measurement unit	Radian per second squared unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

Table 58 - Defining elements of vector angle acceleration quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Vector angle acceleration quantity
Version	1.0
Definition URI	https://www.sae.org/AS6969/9fa6a081-b8b6-4051-a3d1-60c90c077e40/1.0
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item 3-11)
Quantity kind	Plane angle acceleration quantity
Quantity symbol	General symbol α
Quantity dimension	$\dim \alpha = \mathrm{T}^{-2}$
Quantity equation	$\alpha = d\omega/dt$ where ω is vector angle velocity and t is time duration angular acceleration of rotation = $d^2\lambda/dt^2$ angular acceleration of deflection = $d^2\vartheta/dt^2$ angular acceleration of elevation = $d^2\varphi/dt^2$
Field of application type	Space and time
Quantity application	General
Preferred measurement unit	Radian per second squared unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

Table 59 - Defining elements of euler angle acceleration quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Euler angle acceleration quantity
Version	1.0
Definition URI	https://www.sae.org/AS6969/6f63525b-d0bd-4088-aa39-43dbfc865217/1.0
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item 3-11)
Quantity kind	Plane angle acceleration quantity
Quantity symbol	General symbol α
Quantity dimension	$\dim \alpha = \mathrm{T}^{-2}$
Quantity equation	$\alpha = d\omega/dt$ where ω is euler angle velocity and t is time duration angular acceleration of first rotation = $d^2\Psi/dt^2$ angular acceleration of second rotation = $d^2\Theta/dt^2$ angular acceleration of third rotation = $d^2\Phi/dt^2$
Field of application type	Space and time
Quantity application	General
Preferred measurement unit	Radian per second squared unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.3.12 Rotation

Table 60 - Defining elements of rotation quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Rotation quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/C0EF6D9F-9D81-4E16-9F1E-611F5E77E5AC/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item 3-14)
Quantity kind	Plane angle quantity
Quantity symbol	N
Quantity dimension	dim N = 1
Quantity equation	$N = \frac{\theta}{2\pi}$ where θ is the plane angle
Field of application	Space and time
Quantity application	Measurement of rotation
Preferred measurement unit	One unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.3.13 Frequency

Table 61 - Defining elements of frequency quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Frequency quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/0A5683F6-2C7B-4AB1-A58F-F912AD376B30/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006 (item 3-15.1)
Quantity kind	Frequency quantity
Quantity symbol	f
Quantity dimension	dim f = T^{-1}
Quantity equation	$f = 1/T$ where T is period duration
Field of application	Space and time
Quantity application	General
Preferred measurement unit	Hertz
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

Table 62 - Defining elements of rotational frequency quantity

ATTRIBUTE	NOTE
Quantity name/identifier	Rotational frequency quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/09FEE440-0186-47E4-BF3E-AF716CE1DB27/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006
Quantity kind	Frequency
Quantity symbol	η
Quantity dimension	dim η = T^{-1}
Quantity equation	$\eta = dN/dt$ where N is rotation and t is time duration
Field of application	Space and time
Quantity application	General
Preferred measurement unit	Second to the power minus one unit
Other measurement units and unit application	Revolutions per minute unit
Measurement procedure or scale	None
Reference material	None

5.3.14 Level of a Power Quantity

The level of a power quantity L_p is defined as

$$L_p := \ln \sqrt{\frac{P}{P_0}}$$

where it is the argument, the power ratio P/P_0, that is of interest.

NOTE: The coherent measurement unit is the neper, Np, although it is more common in engineering applications to use the decibel, dB. The decibel should not be confused with the decibel watt, which is a non-linear measurement of power P.

Table 63 - Defining elements of level of power quantity (quantity)

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Level of a power quantity (quantity)
Version	1.1
Definition URI	https://www.sae.org/AS6969/48A3BA7B-1EC8-4DC8-925E-B724CE312964/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-3:2006
Quantity kind	Level of a power quantity
Quantity symbol	L_P
Quantity dimension	$\dim L_P = 1$
Quantity equation	$L_p := \ln \sqrt{\frac{P}{P_0}}$ where P *and* P_0 represent two power quantities of the same kind, P_0 being a reference quantity
Field of application	Space and time
Quantity application	General
Preferred measurement unit	Decibel unit (see note)
Other measurement units and unit application	Neper unit
Measurement procedure or scale	None
Reference material	None

5.4 Basic Quantities Relating to Mechanics

The principal reference for basic quantities relating to mechanics is ISO 80000-4:2006. The taxonomy of the quantities defined in this section is shown in Table 64.

Table 64 - Taxonomy of basic mechanics quantities

Mass m	
Mass density ρ	
Momentum $\boldsymbol{p}$	
Force $\boldsymbol{F}$	
Moment of force $\boldsymbol{M}$	Torque M_Q
Pressure p	Sheer stress τ
Dynamic viscosity η	
Kinematic viscosity υ	
Mechanical power P	
Mechanical energy E	Mechanical work W
	Potential energy E_p
	Kinetic energy E_k
Mass flow rate q_m	
Volume flow rate q_V	

5.4.1 Mass

Table 65 - Defining elements of mass quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	mass quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/862527B4-DE76-4EDC-81A7-8A83FE67AE5D/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-4:2006
Quantity kind	mass quantity
Quantity symbol	m
Quantity dimension	dim m = M
Quantity equation	Base quantity in ISQ
Field of application	Mechanics
Quantity application	General
Preferred measurement unit	kilogram unit
Other measurement units and unit application	pound unit
Measurement procedure or scale	None
Reference Material	None

5.4.2 Mass Density

Table 66 - Defining elements of mass density quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	mass density quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/07122F24-C972-4930-8105-E0F7067F7534/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-4:2006
Quantity kind	mass density
Quantity symbol	ρ
Quantity dimension	dim ρ = ML^{-2}
Quantity equation	$\rho = dm/dV$ where m is mass and V is volume
Field of application	Mechanics
Quantity application	General
Preferred measurement unit	kilogram per cubic meter unit
Other measurement units and unit application	pound per cubic foot unit pound per cubic inch unit
Measurement procedure or scale	None
Reference Material	None

NOTE: The systematic name, volumic mass, is not used in this data dictionary since the term mass density or density is the established term in engineering.

5.4.3 Momentum

Table 67 - Defining elements of momentum quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	momentum quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/D3ADDA8D-B092-43EE-AE11-9AD05C2FDE16/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-4:2006
Quantity kind	momentum quantity
Quantity symbol	$\boldsymbol{p}$ (vector $\vec{\boldsymbol{p}}$)
Quantity dimension	dim $\boldsymbol{p}$ = MLT^{-1}
Quantity equation	$\vec{\boldsymbol{p}} = m\,\vec{v}$ where m is mass and $\vec{v}$ is the velocity vector
Field of application	Mechanics
Quantity application	General
Preferred measurement unit	kilogram meter per second unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference Material	None

NOTE: The definition of momentum supports the definition of force. Its vector is $\vec{\boldsymbol{p}}$ and has coordinates based on the coordinates of the velocity vector $\vec{v}$. Taking into account relativity, mass is a function of velocity.

5.4.4 Force

Table 68 - Defining elements of force quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Force quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/6E162AF4-99F7-478A-8706-D47CC324F4B9/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-4:2006
Quantity kind	Force quantity
Quantity symbol	$\boldsymbol{F}$ (vector $\vec{\boldsymbol{F}}$)
Quantity dimension	dim $\boldsymbol{F}$ = MLT^{-2}
Quantity equation	$\vec{\boldsymbol{F}} = d\vec{\boldsymbol{p}}/dt$ where $\vec{\boldsymbol{p}}$ is momentum vector and t is time
Field of application	Mechanics
Quantity application	General
Preferred measurement unit	Newton unit
Other measurement units and unit application	Pounds force unit Foot pounds per second squared unit
Measurement procedure or scale	None
Reference material	None

5.4.5 Moment of Force

Table 69 - Defining elements of moment of force quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Moment of force quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/406501BD-99DD-4044-85FE-469225BC2F3F/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-4:2006
Quantity kind	Moment of force quantity
Quantity symbol	$\boldsymbol{M}$ (vector $\vec{\boldsymbol{M}}$)
Quantity dimension	dim $\boldsymbol{M}$ = ML^2T^{-2}
Quantity equation	$\vec{\boldsymbol{M}} = r\,\vec{\boldsymbol{F}}$ where r is distance and $\boldsymbol{F}$ is force.
Field of application	Mechanics
Quantity application	General
Preferred measurement unit	Newton meter unit
Other measurement units and unit application	
Measurement procedure or scale	None
Reference material	None

NOTE: This definition applies to the moment of force with respect to the origin of the position vector.

5.4.6 Torque

Table 70 - Defining elements of torque quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Torque quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/8B0C39AC-D18A-495F-A9B3-AC4879E2E663/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-4:2006
Quantity kind	Moment of force quantity
Quantity symbol	M_Q
Quantity dimension	dim M_Q = ML^{2}T^{-2}
Quantity equation	$M_Q = \boldsymbol{M}\,\vec{e}_Q$ where $\boldsymbol{M}$ is the moment of force and $\vec{e}_Q$ is a unit vector directed along a Q-axis with respect to which the torque is considered.
Field of application	Mechanics
Quantity application	General
Preferred measurement unit	Newton meter unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

NOTE: Torque is the twisting moment of force with respect to the longitudinal axis of a beam or shaft.

5.4.7 Pressure

Table 71 - Defining elements of pressure quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Pressure quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/00131AD1-0215-4E2B-B989-2AF21B35D2B2/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-4:2006
Quantity kind	Pressure quantity
Quantity symbol	p
Quantity dimension	dim p = ML^{-1}T^{-2}
Quantity equation	$p = d\boldsymbol{F}/dA$ where $d\boldsymbol{F}$ is the force component perpendicular to the surface element of area dA.
Field of application	Mechanics
Quantity application	General
Preferred measurement unit	Pascal unit
Other measurement units and unit application	Kilopascal unit Bar unit (air pressure) Inches mercury (60 °F) unit
Measurement procedure or scale	None
Reference material	None

5.4.8 Shear Stress

Table 72 - Defining elements of shear stress quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Shear stress quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/4663C4B9-08B5-457A-A41B-F17FBF56EEC9/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-4:2006
Quantity kind	Pressure quantity
Quantity symbol	τ
Quantity dimension	dim τ = ML^{-1}T^{-2}
Quantity equation	$\tau = d\boldsymbol{F}_t/dA$ where $d\boldsymbol{F}_t$ is the tangential component of force and dA is the area of the surface element
Field of application	Mechanics
Quantity application	General
Preferred measurement unit	Pascal unit
Other measurement units and unit application	Kilopascal unit
Measurement procedure or scale	None
Reference material	None

5.4.9 Dynamic Viscosity

Table 73 - Defining elements of dynamic viscosity quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Dynamic viscosity quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/5F745AF6-1FF9-4F4E-9F71-5F8BE96DD1FD/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-4:2006
Quantity kind	Dynamic viscosity quantity
Quantity symbol	η
Quantity dimension	dim η = ML^{-1}T^{-1}
Quantity equation	$\tau_{xy} = \eta dv_x/dz$ where τ_{xy} is shear stress in a fluid moving with a velocity gradient $\eta dv_x/dz$ perpendicular to the plane of shear
Field of application	Mechanics
Quantity application	General
Preferred measurement unit	Pascal second unit
Other measurement units and unit application	
Measurement procedure or scale	None
Reference material	None

NOTE: This definition applies to a laminar flow for which $v_z = 0$.

5.4.10 Kinematic Viscosity

Table 74 - Defining elements of kinematic viscosity quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Kinematic viscosity quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/2F9F6D6E-E632-4A44-86A8-8D865BC1B848/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-4:2006
Quantity kind	Kinematic viscosity quantity
Quantity symbol	ν
Quantity dimension	dim ν = L^2T^{-1}
Quantity equation	$\nu = \eta/\rho$ where η is dynamic viscosity and ρ is the mass density
Field of application	Mechanics
Quantity application	General
Preferred measurement unit	Meter squared per second unit
Other measurement units and unit application	
Measurement procedure or scale	None
Reference material	None

5.4.11 Mechanical Power

Table 75 - Defining elements of mechanical power quantity

DEFINING ELEMENTS	DESCRIPTION
Quantity name/identifier	Mechanical power quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/3F897E85-62CE-4B2C-A957-FCF0CCE649FD/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-4:2006
Quantity kind	Mechanical power quantity
Quantity symbol	P
Quantity dimension	dim P = ML^2T^{-3}
Quantity equation	$P = \boldsymbol{F}\,v$ where $\boldsymbol{F}$ is Force and v is velocity
Field of application	Mechanics
Quantity application	General
Preferred measurement unit	Watt unit
Other measurement units and unit application	
Measurement procedure or scale	None
Reference material	None

5.4.12 Mechanical Work

Table 76 - Defining elements of mechanical work quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Mechanical work quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/8F3366CF-885A-4226-902D-A0902268ED34/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-4:2006
Quantity kind	Mechanical energy quantity
Quantity symbol	W
Quantity dimension	dim W = ML^2T^{-2}
Quantity equation	$W = \int P\,dt$ where P is mechanical power and t is time
Field of application	Mechanics
Quantity application	General
Preferred measurement unit	Joule unit
Other measurement units and unit application	
Measurement procedure or scale	None
Reference material	None

NOTE: The definition implies that $W = \int \boldsymbol{F}\,dr$ where $\boldsymbol{F}$ is force and dr is the change in length of a position vector.

5.4.13 Mechanical Energy

Table 77 - Defining elements of mechanical energy quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Mechanical work quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/8BD5D113-8AEA-4EE7-A073-B5903E14CDAD/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-4:2006
Quantity kind	Mechanical energy quantity
Quantity symbol	E
Quantity dimension	dim E = ML^2T^{-2}
Quantity equation	$E = E_k + E_p$ where E_k is kinetic energy and E_p is potential energy
Field of application	Mechanics
Quantity application	General
Preferred measurement unit	Joule unit
Other measurement units and unit application	
Measurement procedure or scale	None
Reference material	None

5.4.14 Potential Energy

Table 78 - Defining elements of potential energy quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Potential energy quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/768D0787-652C-4869-92E7-F10309401F3A/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-4:2006
Quantity kind	Mechanical energy quantity
Quantity symbol	E_p
Quantity dimension	dim E_p = ML^2T^{-2}
Quantity equation	$E_p = -\int F\,dr$ where $\boldsymbol{F}$ is conservative force and dr is the change in length of a position vector.
Field of application	Mechanics
Quantity application	General
Preferred measurement unit	Joule unit
Other measurement units and unit application	
Measurement procedure or scale	None
Reference material	None

NOTE: A force is conservative when the force field is irrotational, i.e., **rot** $\boldsymbol{F} = 0$.

5.4.15 Kinetic Energy

Table 79 - Defining elements of kinetic energy quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Kinetic energy quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/F96BDF88-E9B1-4598-ADCA-63DF2B0A35BC/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-4:2006
Quantity kind	Mechanical energy quantity
Quantity symbol	E_k
Quantity dimension	dim E_k = ML^2T^{-2}
Quantity equation	$E_k = mv^2/2$ where m is mass and $\lvert v \rvert$ is speed.
Field of application	Mechanics
Quantity application	General
Preferred measurement unit	Joule unit
Other measurement units and unit application	
Measurement procedure or scale	None
Reference Material	None

NOTE: The general definition is $E_k = \frac{1}{2}\int v^2 dm$.

5.4.16 Mass Flow Rate

Table 80 - Defining elements of mass flow rate quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Mass flow rate quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/CAEF0C77-03BE-43E5-820C-1D27DB157284/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-4:2006
Quantity kind	Mass flow rate quantity
Quantity symbol	q_m
Quantity dimension	dim q_m = MT^{-1}
Quantity equation	$q_m = dm/dt$ where m is mass and t is time.
Field of application	Mechanics
Quantity application	General
Preferred measurement unit	Kilogram per second unit
Other measurement units and unit application	Pounds of mass per second unit
Measurement procedure or scale	None
Reference material	None

5.4.17 Volume Flow Rate

Table 81 - Defining elements of volume flow rate quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Volume flow rate quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/C5B030DC-5933-43D9-82B9-1F689B9F10D7/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-4:2006
Quantity kind	Volume flow rate quantity
Quantity symbol	q_V
Quantity dimension	dim q_V = L^3T^{-1}
Quantity equation	$q_V = dV/dt$ where V is volume and t is time.
Field of application	Mechanics
Quantity application	General
Preferred measurement unit	Cubic meter per second unit
Other measurement units and unit application	
Measurement procedure or scale	None
Reference material	None

5.5 Basic Quantities Relating to Thermodynamics

The principal reference for basic quantities relating to thermodynamics is ISO 80000-5:2007.

Two temperature quantities are provided. Thermodynamic temperature is the base quantity in the ISQ. Celsius temperature (an ISQ quantity) is used for practical measurements and is defined by the International Temperature Scale of 1990 (ITS-90). ITS-90 was adopted by the CIPM in 1989 and replaces the International Practical Temperature Scale of 1968, IPTS-68. Whereas thermodynamic temperature is measured in kelvins, Celsius temperature can be measured in kelvins or degrees Celsius (or in non-SI units).

5.5.1 Thermodynamic Temperature

Table 82 - Defining elements of thermodynamic temperature quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Thermodynamic temperature quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/202A94CA-5374-46D9-BAAB-9E2725198D9B/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-5:2007
Quantity kind	Thermodynamic temperature quantity
Quantity symbol	T
Quantity dimension	dim T = Θ
Quantity equation	Base quantity in ISQ.
Field of application	Thermodynamics
Quantity application	General
Preferred measurement unit	Kelvin unit
Other measurement units and unit application	
Measurement procedure or scale	None
Reference material	None

5.5.2 Celsius Temperature (ITS-90)

Table 83 - Defining elements of Celsius temperature quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Celsius temperature quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/D4A413E9-11F5-422D-B531-160A1E8E8A42/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-5:2007
Quantity kind	Celsius temperature quantity
Quantity symbol	t_{90}
Quantity dimension	dim t_{90} = Θ
Quantity equation	See note.
Field of application	Thermodynamics
Quantity application	General
Preferred measurement unit	Degree Celsius unit
Other measurement units and unit application	Kelvin unit Degree Fahrenheit unit
Measurement procedure or scale	International Temperature Scale of 1990 (ITS-90)
Reference material	None

NOTE: For the purpose of practical measurements, the International Temperature Scale of 1990, ITS-90, was adopted by the CIPM in 1989. The quantity corresponding to thermodynamic temperature defined by this scale is denoted t_{90}. This quantity replaces t_{68} defined by the International Practical Temperature Scale of 1968, IPTS-68.

5.5.3 Relative Humidity

Table 84 - Defining elements of relative humidity quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Relative humidity quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/13A3C423-6868-4F03-A7D1-A1154B6F243B/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-5:2007
Quantity kind	Relative humidity quantity
Quantity symbol	ϕ
Quantity dimension	dim ϕ = 1
Quantity equation	$\phi = p/p_{sat}$ where p is the partial pressure of water vapor and p_{sat} is its partial pressure at saturation (at the same temperature)
Field of application	Thermodynamics
Quantity application	General
Preferred measurement unit	One unit
Other measurement units and unit application	Percent unit
Measurement procedure or scale	None
Reference material	None

NOTE: For normal cases, the relative partial pressure of water vapor may be assumed to be equal to relative mass concentration of water vapor.

5.6 Basic Quantities Relating to Electromagnetism

The principal reference for quantities relating to electromagnetism is IEC 80000-6:2008. The taxonomy of electromagnetism quantities defined in this section is shown in Table 85.

Table 85 - Taxonomy of basic electromagnetism quantities

Electric current I	
Electric current density $\boldsymbol{J}$	
Electric charge Q	
Electric charge density ρ_V	
Electric field strength $\boldsymbol{E}$	
Electric potential V	Electric potential difference V_{ab}
	Voltage U
Source voltage U_s	
Capacitance C	
Magnetic flux density $\boldsymbol{B}$	
Magnetic flux ϕ	
Linked flux ψ	
Magnetic vector potential $\boldsymbol{A}$	
Inductance L	
Electrical power	Instantaneous electrical power p
	Active electrical power P
Electrical resistance R	
Electrical resistivity ρ	
Electrical conductance G	
Electrical conductivity σ	

5.6.1 Electric Current

Table 86 - Defining elements of electric current quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Electric current quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/53C1BC94-2190-4C75-9D29-268132595C23/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	IEC 80000-6:2008
Quantity kind	Electric current phasor quantity
Quantity symbol	I
Quantity dimension	dim I = I
Quantity equation	Base quantity in ISQ
Field of application	Electromagnetism
Quantity application	General
Preferred measurement unit	Ampere unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference Material	None

NOTE: The electric current through a surface is the quotient of the electric charge transferred through the surface during a time interval by the duration of that interval.

5.6.2 Electric Current Density Quantity

Table 87 - Defining elements of electric current density quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	electric current density quantity
Version	1.0
Definition URI	https://www.sae.org/AS6969/f3a2041f-68aa-4a9f-9f44-c1b572052cd3/1.0
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	IEC 80000-6:2008
Quantity kind	electric current density quantity
Quantity symbol	$\boldsymbol{J}$
Quantity dimension	dim Q = L^{-2}I
Quantity equation	$\boldsymbol{J} = \rho_v \boldsymbol{v}$ where ρ_v is electric charge density and $\boldsymbol{v}$ is velocity
Field of application	Electromagnetism
Quantity application	General
Preferred measurement unit	ampere per square meter unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference Material	None

5.6.3 Electric Charge

Table 88 - Defining elements of electric charge quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Electric charge quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/3C2AF0B5-3C04-4160-AD33-D31074DF6E6B/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	IEC 80000-6:2008
Quantity kind	Electric charge quantity
Quantity symbol	Q
Quantity dimension	dim Q = TI
Quantity equation	$Q = Idt$ where I is electric current and t is time
Field of application	Electromagnetism
Quantity application	General
Preferred measurement unit	Coulomb unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

NOTE: Electric charge is carried by discrete particles and can be positive or negative. The sign convention is such that the elementary electric charge, i.e., the charge of the proton, is positive.

5.6.4 Electric Charge Density

Table 89 - Defining elements of electric charge density quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	electric charge density quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/B2D7646B-CF6F-431D-B6EE-3EB9684A92BF/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	IEC 80000-6:2008
Quantity kind	electric charge density quantity
Quantity symbol	ρ_V
Quantity dimension	dim ρ_V = L^{-3}TI
Quantity equation	$\rho_V = {}^{dQ}/_{dV}$ where Q is electric charge and V is volume
Field of application	Electromagnetism
Quantity application	General
Preferred measurement unit	coulomb per cubic meter unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.6.5 Electric Field Strength

Table 90 - Defining elements of electric field strength quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Electric field strength quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/39E39413-F02E-47C3-83BF-1DEFF8669E4D/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	IEC 80000-6:2008
Quantity kind	Electric field strength quantity
Quantity symbol	$\boldsymbol{E}$ (vector $\vec{\boldsymbol{E}}$)
Quantity dimension	dim $\boldsymbol{E}$ = $LMT^{-3}I^{-1}$
Quantity equation	$\vec{\boldsymbol{E}} = \vec{\boldsymbol{F}}/Q$ where $\vec{\boldsymbol{F}}$ is force vector and Q is the charge of a test particle at rest.
Field of application	Electromagnetism
Quantity application	General
Preferred measurement unit	Volt per meter unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.6.6 Electric Potential

Table 91 - Defining elements of electric potential quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Electric potential quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/AB50A223-F0CF-4905-819E-6E364A25306D/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	IEC 80000-6:2008
Quantity kind	Electric potential quantity
Quantity symbol	V
Quantity dimension	dim V = $L^2MT^{-1}I$
Quantity equation	$-\operatorname{grad} V = \boldsymbol{E} + \partial\boldsymbol{A}/\partial t$ where $\boldsymbol{E}$ is electric field strength, $\boldsymbol{A}$ is magnetic vector potential, and t is time.
Field of application	Electromagnetism
Quantity application	General
Preferred measurement unit	Volt unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference Material	None

5.6.7 Electric Potential Difference

Table 92 - Defining elements of electric potential difference quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Electric potential difference quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/11364637-DED1-47C9-8950-DABC9041D094/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	IEC 80000-6:2008
Quantity kind	Electric potential quantity
Quantity symbol	V_{ab}
Quantity dimension	dim V_{ab} = $L^2MT^{-1}I$
Quantity equation	$V_{ab} = \int_{r_a}^{r_b} \left(\boldsymbol{E} + {\partial \boldsymbol{A}}/{\partial t}\right) dr$ where $\boldsymbol{E}$ is electric field strength, $\boldsymbol{A}$ is magnetic vector potential, t is time, and r is position vector along a given curve from point a to point b
Field of application	Electromagnetism
Quantity application	General
Preferred measurement unit	Volt unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference Material	None

NOTE: $V_{ab} = V_a - V_b$ where V_a and V_b are the electric potentials at points a and b respectively.

5.6.8 Voltage

Table 93 - Defining elements of voltage quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Voltage quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/1EBB015D-09FB-4B63-A84D-6FB6E452D66F/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	IEC 80000-6:2008
Quantity kind	Electric potential quantity
Quantity symbol	U
Quantity dimension	dim U = $L^2MT^{-1}I$
Quantity equation	in electric circuit theory $U_{ab} = V_a - V_b$ where V_a and V_b are the electric potentials at points a and b respectively
Field of application	Electromagnetism
Quantity application	General
Preferred measurement unit	Volt unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

NOTE: For an electric field within a medium, $U_{ab} = \int_{r_a}^{r_b} \boldsymbol{E}\ dr$ where $\boldsymbol{E}$ is electric field strength and r is position vector along a given curve from point a to point b.

5.6.9 Source Voltage

Table 94 - Defining elements of source voltage quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Source voltage quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/C00FE982-B05F-4AFB-AF3D-675C99BBDB8A/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	IEC 80000-6:2008
Quantity kind	Electric potential quantity
Quantity symbol	U_s
Quantity dimension	dim U_s = $L^2MT^{-1}I$
Quantity equation	in electric circuit theory $U_s = V_a - V_b$ where V_a and V_b are the electric potentials at points a and b respectively
Field of application	Electromagnetism
Quantity application	General
Preferred measurement unit	Volt unit
Other measurement units and unit application	Voltage between the two terminals of a voltage source when there is no electric current through the source
Measurement procedure or scale	None
Reference material	None

5.6.10 Capacitance

Table 95 - Defining elements of capacitance quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Capacitance quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/48ACA545-C7B4-4E03-9D00-E1DB9595B882/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	IEC 80000-6:2008
Quantity kind	Capacitance quantity
Quantity symbol	C
Quantity dimension	dim C = $L^{-2}M^{-1}T^2$
Quantity equation	$C = {}^{Q}/_{U}$ where Q is electric charge and U is voltage
Field of application	Electromagnetism
Quantity application	General
Preferred measurement unit	farad unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.6.11 Magnetic Flux Density

Table 96 - Defining elements of magnetic flux density quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Magnetic flux density quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/3BB05482-803E-40F7-A875-95F63AEDD0C7/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	IEC 80000-6:2008
Quantity kind	Magnetic flux density quantity
Quantity symbol	$\boldsymbol{B}$ (vector $\vec{\boldsymbol{B}}$)
Quantity dimension	dim $\boldsymbol{B}$ = $MT^{-2}I^{-1}$
Quantity equation	$\vec{\boldsymbol{F}} = Qv \times \vec{\boldsymbol{B}}$ where $\vec{\boldsymbol{F}}$ is force and v is velocity of any test particle with electric charge Q
Field of application	Electromagnetism
Quantity application	General
Preferred measurement unit	Tesla unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.6.12 Magnetic Flux

Table 97 - Defining elements of magnetic flux quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Magnetic flux quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/1ACDF98A-080A-449D-8887-F102EFE85D57/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	IEC 80000-6:2008
Quantity kind	Magnetic flux quantity
Quantity symbol	Φ
Quantity dimension	dim Φ = $L^2MT^{-2}I^{-1}$
Quantity equation	$\Phi = \int_S B\, \vec{e}_n\, dA$ over a surface S, where $\boldsymbol{B}$ is magnetic flux density and $\vec{e}_n dA$ is vector surface element.
Field of application	Electromagnetism
Quantity application	General
Preferred measurement unit	weber unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.6.13 Linked Flux

Table 98 - Defining elements of linked flux quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Linked flux quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/06AD0C74-8494-4894-9B7C-E58DA28712D5/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	IEC 80000-6:2008
Quantity kind	Linked flux quantity
Quantity symbol	Ψ
Quantity dimension	dim $\Psi = L^2MT^{-2}I^{-1}$
Quantity equation	$\Phi = \int_C \boldsymbol{A}\, d\boldsymbol{r}$ where $\boldsymbol{A}$ is magnetic flux vector potential and $d\boldsymbol{r}$ is differential of the position vector on the curve C.
Field of application	Electromagnetism
Quantity application	General
Preferred measurement unit	Weber unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.6.14 Magnetic Vector Potential

Table 99 - Defining elements of magnetic vector potential quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Magnetic vector potential quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/CBC2B42A-DD63-441E-86AC-1A8DAE86F9D0/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	IEC 80000-6:2008
Quantity kind	magnetic vector potential quantity
Quantity symbol	$\boldsymbol{A}$
Quantity dimension	dim $\boldsymbol{A} = LMT^{-2}I^{-1}$
Quantity equation	$\boldsymbol{B} = \mathrm{rot}\, \boldsymbol{A}$ where $\boldsymbol{B}$ is magnetic flux density
Field of application	Electromagnetism
Quantity application	General
Preferred measurement unit	Weber per meter unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.6.15 Inductance

Table 100 - Defining elements of inductance quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Inductance quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/F994AC0D-D1E9-466B-B6E0-B65445036F5A/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	IEC 80000-6:2008
Quantity kind	Inductance quantity
Quantity symbol	L
Quantity dimension	dim L = $L^2MT^{-2}I^{-1}$
Quantity equation	$L = \Psi / I$ where I is an electric current in a thin conducting loop and Ψ is the linked flux caused by that electric current
Field of application	Electromagnetism
Quantity application	General
Preferred measurement unit	Henry unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.6.16 Instantaneous Electrical Power

Table 101 - Defining elements of instantaneous electric power quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Instantaneous electrical power quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/035A6C11-2D2F-4916-8D9A-123E221E601F/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	IEC 80000-6:2008
Quantity kind	Instantaneous electrical power quantity
Quantity symbol	p
Quantity dimension	dim p = L^2MT^{-3}
Quantity equation	$p = U I$ where U is the instantaneous voltage and I is the instantaneous electric current
Field of application	Electromagnetism
Quantity application	General
Preferred measurement unit	Watt unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.6.17 Active Electrical Power

Table 102 - Defining elements of active electrical power quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Active electrical power quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/975ECAC7-4DD5-414A-9037-B9401345EBDE/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	IEC 80000-6:2008
Quantity kind	Active electrical power quantity
Quantity symbol	P
Quantity dimension	dim P = L^2MT^{-3}
Quantity equation	$P = \frac{1}{T}\int_0^T p \ dt$ where T is the period and p is the instantaneous electrical power
Field of application	Electromagnetism
Quantity application	General
Preferred measurement unit	Watt unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.6.18 Electrical Resistance

Table 103 - Defining elements of electrical resistance quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Electrical resistance quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/64451DE3-79A6-4962-8653-8120A07D94C3/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	IEC 80000-6:2008
Quantity kind	Electrical resistance quantity
Quantity symbol	R
Quantity dimension	dim R = $L^2MT^{-3}I^{-2}$
Quantity equation	$R = {}^{U}/_{I}$ where U is the instantaneous voltage and I is the instantaneous electric current
Field of application	Electromagnetism
Quantity application	General
Preferred measurement unit	Ohm unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.6.19 Electrical Resistivity

Table 104 - Defining elements of electrical resistivity quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Electrical resistivity quantity
Version	1.0
Definition URI	https://www.sae.org/AS6969/ d07d7b08-1659-4f85-b84d-da2fbc22401a/1.0
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	IEC 80000-6:2008
Quantity kind	Electrical resistivity quantity
Quantity symbol	ρ
Quantity dimension	dim Q = $ML^{3}T^{-3}I^{-2}$
Quantity equation	$\rho = {}^{1}/_{\sigma}$ where σ is conductivity
Field of application	Electromagnetism
Quantity application	General
Preferred measurement unit	Ohm meter unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.6.20 Electrical Conductance

Table 105 - Defining elements of electrical conductance quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Electrical conductance quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/47BD0DBE-5C5D-4AE9-AF85-608CDF60979B/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	IEC 80000-6:2008
Quantity kind	Electrical conductance quantity
Quantity symbol	G
Quantity dimension	dim G = $L^{-2}M^{-1}T^{3}I^{2}$
Quantity equation	$G = {}^{1}/_{R}$ where R is electrical resistance
Field of application	Electromagnetism
Quantity application	General
Preferred measurement unit	Siemens unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.6.21 Electrical Conductivity

Table 106 - Defining elements of electrical conductivity quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Electrical conductivity quantity
Version	1.0
Definition URI	https://www.sae.org/AS6969/ 247e63a6-016c-4d8d-a91a-3603e4c30b6c/1.0
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	IEC 80000-6:2008
Quantity kind	Electrical conductivity quantity
Quantity symbol	σ
Quantity dimension	dim Q = $L^{-3}M^{-1}T^{3}I^{2}$
Quantity equation	$\sigma = \boldsymbol{J}/\boldsymbol{E}$ where $\boldsymbol{J}$ is electric current density and $\boldsymbol{E}$ is electric field strength
Field of application	Electromagnetism
Quantity application	General
Preferred measurement unit	Siemens per meter unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

NOTE: This definition applies to an isotropic medium.

5.7 Basic Quantities Relating to Light

The principal reference for quantities relating to mechanics is ISO 80000-7:2008.

5.7.1 Radiant Energy

Table 107 - Defining elements of radiant energy quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Radiant energy quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/BDA3099A-7755-4A20-BF69-461680A12DD5/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-7:2008
Quantity kind	Radiant energy quantity
Quantity symbol	Q_e
Quantity dimension	dim Q_e = $L^{2}MT^{-2}$
Quantity equation	energy emitted, transferred or received as radiation
Field of application	Light
Quantity application	General
Preferred measurement unit	Joule unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.7.2 Radiant Flux

NOTE: Radiant flux is also known as radiant power.

Table 108 - Defining elements of radiant flux quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Radiant flux quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/71789E84-17A1-4EF3-8A6E-A7A48F91BE02/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-7:2008
Quantity kind	Radiant flux quantity
Quantity symbol	Φ
Quantity dimension	dim Φ = L^2MT^{-3}
Quantity equation	$\Phi = \frac{dQ_e}{dt}$ where dQ_e is the radiant energy emitted, transferred or received during a time duration of dt
Field of application	Light
Quantity application	General
Preferred measurement unit	Watt unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

NOTE: The quantity equation may also be expressed as:

$$\Phi = \int_0^\infty \Phi_\lambda(\lambda)\, d\lambda$$

where $\Phi_\lambda(\lambda)$ is spectral radiant flux.

NOTE: Visible radiant flux is called luminous flux.

5.7.3 Spectral Radiant Flux

NOTE: Spectral radiant flux is also known as spectral radiant power.

Table 109 - Defining elements of spectral radiant flux quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Spectral radiant flux quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/05FB802A-7178-4E36-80CA-21E3257B9F7B/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-7:2008
Quantity kind	Radiant flux quantity
Quantity symbol	$\Phi_\lambda(\lambda)$
Quantity dimension	dim $\Phi_\lambda(\lambda)$ = L^2MT^{-2}
Quantity equation	$\Phi_\lambda(\lambda) = \frac{d\Phi}{d\lambda}$ where Φ is the radiant flux, transferred or received over the wavelength interval $d\lambda$
Field of application	Light
Quantity application	General
Preferred measurement unit	Watt per hertz unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.7.4 Radiant Intensity

Table 110 - Defining elements of radiant intensity quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Radiant intensity quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/1D7209BF-1E90-4545-B5F0-A41B71C70AFA/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-7:2008
Quantity kind	Radiant intensity quantity
Quantity symbol	I_e
Quantity dimension	dim I_e = L^2MT^{-3}
Quantity equation	In a given direction from a source, $I_e = \frac{d\Phi}{d\Omega}$ where $d\Phi$ is the radiant flux leaving the source in an elementary cone containing the given direction with the solid angle $d\Omega$
Field of application	Light
Quantity application	General
Preferred measurement unit	Watt per steradian unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

NOTE: The quantity equation may also be expressed as:

$$I_e = \int_0^\infty I_\lambda(\lambda)\, d\lambda$$

where $I_\lambda(\lambda)$ is spectral radiant intensity.

NOTE: Visible radiant intensity is called luminous intensity.

5.7.5 Spectral Radiant Intensity

Table 111 - Defining elements of spectral radiant intensity quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Spectral radiant intensity quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/2E1D7886-ECEE-47DE-BD20-B7522F3F04B5/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-7:2008
Quantity kind	Spectral radiant intensity quantity
Quantity symbol	$I_\lambda(\lambda)$
Quantity dimension	dim $I_\lambda(\lambda)$ = L^2MT^{-2}
Quantity equation	$I_\lambda(\lambda) = \frac{dI_e}{d\lambda}$ where I_e is the radiant intensity, transferred or received over the wavelength interval $d\lambda$
Field of application	Light
Quantity application	General
Preferred measurement unit	Watt per steradian per hertz unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.7.6 Spectral Luminous Efficiency

NOTE: Spectral luminous efficiency is also known as luminosity function.

Table 112 - Defining elements of spectral luminous efficiency quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Spectral luminous efficiency quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/65165125-E0B2-4347-A6B3-9CF572FA6BE5/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-7:2008
Quantity kind	Spectral luminous efficiency quantity
Quantity symbol	$V(\lambda)$
Quantity dimension	dim $V(\lambda)$ = 1
Quantity equation	Ratio of the spectral radiant flux $\Phi_\lambda(\lambda_m)$ at wavelength λ_m to spectral radiant flux $\Phi_\lambda(\lambda)$ such that both radiations produce equal luminous sensations under specified photometric conditions and λ_m is chosen so that the maximum value of this ratio is equal to 1
Field of application	Light
Quantity application	Photopic vision
Preferred measurement unit	one
Other measurement units and unit application	
Measurement procedure or scale	
Reference material	None

NOTE: The luminosity function is used to convert radiant flux into luminous flux.

Standard values of $V(\lambda)$ for photopic vision (vision provided by the cones in the human eye in daylight) were originally adopted by the CIE in 1924 and adopted by the CIPM in 1983.

5.7.7 Luminous Efficiency

Table 113 - Defining elements of luminous efficiency quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Luminous efficiency quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/4375EC9C-E200-4D8A-BC70-CC392A712AC8/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-7:2008
Quantity kind	Luminous efficiency quantity
Quantity symbol	V
Quantity dimension	dim V = 1
Quantity equation	$V = \frac{\int_0^\infty V(\lambda)\Phi_\lambda(\lambda)d\lambda}{\int_0^\infty \Phi_\lambda(\lambda)d\lambda}$ where $\Phi_\lambda(\lambda)$ is the spectral radiant flux, $V(\lambda)$ is the spectral luminous efficacy, and λ is the wavelength
Field of application	Light
Quantity application	Photopic vision
Preferred measurement unit	One
Other measurement units and unit application	
Measurement procedure or scale	
Reference material	None

NOTE: The quantity equation may also be expressed as:

$$V = \frac{K}{K_m}$$

where:

K = luminous efficacy of radiation

K_m = maximum spectral luminous efficacy

The standard value for K_m is approximately 683 lm W^{-1}, which is defined for monochromatic radiation at 540 x 10^{12} Hz (555.016 nm in standard air).

5.7.8 Spectral Luminous Efficacy

Table 114 - Defining elements of spectral luminous efficacy quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Spectral luminous efficacy quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/0C7D3984-CC65-4C4F-9B33-4A2AA70D5211/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-7:2008
Quantity kind	Spectral luminous efficacy quantity
Quantity symbol	$K(\lambda)$
Quantity dimension	dim $K(\lambda)$ = J $L^{-2}M^{-1}T^{2}$
Quantity equation	$K(\lambda) = K_m V(\lambda)$ where is the maximum value of spectral luminous efficacy (approximately 683 lm W^{-1}), $V(\lambda)$ is the spectral luminous efficiency, and λ is the wavelength.
Field of application	Light
Quantity application	Photopic vision
Preferred measurement unit	Lumen per watt unit
Other measurement units and unit application	
Measurement procedure or scale	
Reference material	None

5.7.9 Luminous Flux

Table 115 - Defining elements of luminous flux quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Luminous flux quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/41388DB8-F765-4C2E-B0F4-639A3FB6BE65/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-7:2008
Quantity kind	Luminous flux quantity
Quantity symbol	Φ_V
Quantity dimension	dim Φ_V = J
Quantity equation	$\Phi_V = K_m \int_0^\infty \Phi_\lambda(\lambda)\, V(\lambda)\, d\lambda$ where K_m is the maximum spectral luminous efficacy, $\Phi_\lambda(\lambda)$ is the spectral radiant flux, $V(\lambda)$ is the spectral luminous efficiency, and λ is the wavelength
Field of application	Light
Quantity application	Photopic vision
Preferred measurement unit	Lumen unit
Other measurement units and unit application	None
Measurement procedure or scale	
Reference material	None

NOTE: Luminous flux evaluates the radiation by its visual response using the standard spectral luminous efficiency.

5.7.10 Luminous Efficacy

Table 116 - Defining elements of luminous efficacy quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Luminous efficacy quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/A43A36E7-3A83-4D8E-A148-F3F6077D484B/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-7:2008
Quantity kind	uminous efficacy quantity
Quantity symbol	K
Quantity dimension	dim K = J $L^{-2}M^{-1}T^{2}$
Quantity equation	$K = \frac{\Phi_V}{\Phi}$ where Φ_V is the luminous flux and Φ is the corresponding radiant flux
Field of application	Light
Quantity application	Photopic vision
Preferred measurement unit	Lumen per watt unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.7.11 Luminous Intensity

Table 117 - Defining elements of luminous intensity quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Luminous intensity quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/D4800540-89BD-4811-AF8C-D05BCDE195BB/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-7:2008
Quantity kind	Luminous intensity quantity
Quantity symbol	I_V
Quantity dimension	dim I_V = J
Quantity equation	Base quantity in the ISQ
Field of application	Light
Quantity application	Photopic vision
Preferred measurement unit	Candela unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference Material	None

NOTE:

$$I_V = \int_0^\infty I_\lambda(\lambda) K(\lambda) d\lambda$$

where:

$I_\lambda(\lambda)$ = spectral luminous intensity

$K(\lambda)$ = spectral luminous efficacy

5.7.12 Illuminance

Table 118 - Defining elements of illuminance quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Illuminance quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/26078D2F-9FC2-4BC3-9D2A-6832D01D3B25/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-7:2008
Quantity kind	Illuminance quantity
Quantity symbol	E_V
Quantity dimension	dim E_V = $L^{-2}J$
Quantity equation	at a point on a surface, $E_V = \frac{d\Phi}{dA}$ where $d\Phi$ is the luminous flux incident on an element of the surface with area dA
Field of application	Light
Quantity application	General
Preferred measurement unit	Lux unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.7.13 Luminance

Table 119 - Defining elements of luminance quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Luminance quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/8EF3EEC5-57DA-4B6D-87D2-1E9C2C2E9255/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-7:2008
Quantity kind	Luminance quantity
Quantity symbol	L_V
Quantity dimension	dim L_V = $L^{-2}J$
Quantity equation	At a point on a surface and in a given direction, $L_V = \frac{dI_V}{dA}$ where dI_V is the luminous intensity of an element of the surface with area dA of the orthogonal projection of this element on a plane perpendicular to the given direction
Field of application	Light
Quantity application	General
Preferred measurement unit	Candela per square meter unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.8 Basic Quantities Relating to Acoustics

The principal reference for quantities relating to acoustics is ISO 80000-8:2007. At this time, no quantities are presently defined.

5.9 Basic Quantities Relating to Physical Chemistry and Molecular Physics

The principal reference for quantities relating to physical chemistry and molecular physics is ISO 80000-9:2009.

5.9.1 Amount of Substance

Table 120 - Defining elements of amount of substance quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Amount of substance quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/1FB206A0-DEE7-4413-A2D5-1FEC05680A8D/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-9:2009
Quantity kind	Amount of substance quantity
Quantity symbol	n
Quantity dimension	dim n = N
Quantity equation	Base quantity in ISQ
Field of application	Physical chemistry and molecular physics
Quantity application	General
Preferred measurement unit	Mole unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.9.2 Amount of Substance Concentration

Table 121 - Defining elements of amount of substance concentration quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Amount of substance concentration quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/F270FA37-BC8A-416F-B9D9-24CC3EA534E8/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-9:2009
Quantity kind	Amount of substance concentration quantity
Quantity symbol	c_B
Quantity dimension	dim c_B = L^{-3}
Quantity equation	$c_B = {n_B}/{V}$ where n_B is the amount of substance B and V is volume
Field of application	Physical chemistry and molecular physics
Quantity application	General
Preferred measurement unit	Meter to the power minus three unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.9.3 Mass Fraction of Substance

Table 122 - Defining elements of mass fraction of substance quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Mass fraction of substance quantity
Version	1.0
Definition URI	https://www.sae.org/AS6969/ca50b712-1cd6-4b64-bf7a-24e4c7876775/1.0
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-9:2009
Quantity kind	Mass fraction of substance quantity
Quantity symbol	w_B
Quantity dimension	dim ρ_B = 1
Quantity equation	$w_B = {}^{m_B}/_{m}$ where m_B is the mass of substance B and m is the total mass of the mixture
Field of application	Physical chemistry and molecular physics
Quantity application	General
Preferred measurement unit	One unit
Other measurement units and unit application	Percent unit, parts per thousand unit
Measurement procedure or scale	None
Reference material	None

5.9.4 Number of Particles

Table 123 - Defining elements of number of particles quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Number of particles quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/2F855C1D-25A2-40EF-AD29-D046556FD158/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-9:2009
Quantity kind	Number of particles quantity
Quantity symbol	N_B
Quantity dimension	dim N_B = 1
Quantity equation	Equals the number of particles of substance B
Field of application	Physical chemistry and molecular physics
Quantity application	General
Preferred measurement unit	One unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.9.5 Molecular Concentration of Substance

Table 124 - Defining elements of molecular concentration of substance quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Molecular concentration of substance quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/6C6C9A1A-35FF-4AC3-8846-04E272229257/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-9:2009
Quantity kind	Molecular concentration of substance quantity
Quantity symbol	C_B
Quantity dimension	dim C_B = L^{-3}
Quantity equation	$C_B = {}^{N_B}/_{V}$ where N_B is the number of particles in substance B and V is volume
Field of application	Physical chemistry and molecular physics
Quantity application	General
Preferred measurement unit	Meter to the power minus three unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.9.6 Mass Concentration of Substance

Table 125 - Defining elements of mass concentration of substance quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Mass concentration of substance quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/FF8A1B41-B120-4351-A8D6-A0D3461AD26C/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-9:2009
Quantity kind	Mass concentration of substance quantity
Quantity symbol	ρ_B
Quantity dimension	dim ρ_B = ML^{-3}
Quantity equation	$\rho_B = {}^{m_B}/_{V}$ where m_B is the mass of substance B and V is the volume of the mixture
Field of application	Physical chemistry and molecular physics
Quantity application	General
Preferred measurement unit	Gram per liter
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.10 Basic Quantities Relating to Atomic and Nuclear Physics

The principal reference for quantities relating to physical chemistry and molecular physics is ISO 80000-10:2009.

5.10.1 Mean Energy Imparted

Table 126 - Defining elements of mean energy imparted quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Mean energy imparted quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/2F706CD3-FE13-4B1E-AD83-4A9EC214E732/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-10:2009
Quantity kind	Mean energy imparted quantity
Quantity symbol	$\bar{\varepsilon}$
Quantity dimension	dim $\bar{\varepsilon}$ = L^2MT^{-2}
Quantity equation	To the matter in a given domain, $\bar{\varepsilon} = R_{in} - R_{out} + \sum Q$ where R_{in} is the radiant energy of all those charged and uncharged ionizing particles that enter the domain, R_{out} is the radiant energy of all those charged and uncharged ionizing particles that leave the domain, and $\sum E$ is the sum of all changes of rest energy of nuclei and elementary particles that occur in that domain.
Field of application	Atomic and nuclear physics
Quantity application	General
Preferred measurement unit	Joule unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

NOTE: For a particle, the rest energy E_0 is defined by the equation $E_0 = m_0c_0^2$, where m_0 is the rest mass of that particle, and c_0 is the speed of light in vacuum.

Based on 2006 CODATA recommended values. The rest mass of an electron is 9.1093821545 x 10^{-31} kg. The rest mass for a proton is 1.67262163783 x 10^{-27} kg. The rest mass for a neutron is 1.67492721184 x 10^{-27} kg.

Radiant energy R is equal to the product $N \times E$ where N is the number of particles that are emitted, transferred or received, and E is the energy of those particles excluding their rest energy E_0.

5.10.2 Absorbed Dose

Table 127 - Defining elements of absorbed dose quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Absorbed dose quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/2F845253-B15C-46EE-A943-79E3DA4BACE1/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-10:2009
Quantity kind	Absorbed dose quantity
Quantity symbol	D
Quantity dimension	dim D = L^2T^{-2}
Quantity equation	$D = \frac{d\bar{\varepsilon}}{dm}$ where $d\bar{\varepsilon}$ is the mean energy imparted by ionizing radiation to an element of irradiated matter with the mass dm
Field of application	Atomic and nuclear physics
Quantity application	General
Preferred measurement unit	Gray unit
Other measurement units and unit application	Rad unit
Measurement procedure or scale	None
Reference material	None

5.10.3 Dose Equivalent

Table 128 - Defining elements of dose equivalent quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Dose equivalent quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/1E909FA4-20A2-416B-86DA-158CFABD2058/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-10:2009
Quantity kind	Dose equivalent quantity
Quantity symbol	H
Quantity dimension	dim H = L^2T^{-2}
Quantity equation	At the point of interest in tissue, $H = DQ$ Where D is the absorbed dose and Q is the quality factor at that point. See note.
Field of application	Atomic and nuclear physics
Quantity application	General
Preferred measurement unit	Sievert unit
Other measurement units and unit application	Rem unit
Measurement procedure or scale	None
Reference material	None

NOTE: The quality factor Q is the factor in the calculation and measurement of dose equivalent by which the absorbed dose is to be weighted to account for the biological effectiveness of radiations. Q is determined by the unrestricted linear energy transfer L_∞ of charged particles passing through a small volume at this point. The value of L_∞ is given for charged particles in water, not in tissue. However, the difference is small.

5.10.4 Absorbed Dose Rate

Table 129 - Defining elements of absorbed dose rate quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Absorbed dose rate quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/6667583D-C9C6-4999-9B93-42AE92C99887/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	ISO 80000-10:2009
Quantity kind	Absorbed dose quantity
Quantity symbol	$\dot{D}$
Quantity dimension	dim $\dot{D}$ = L^2T^{-2}
Quantity equation	$\dot{D} = \frac{dD}{dt}$ where dD is the increment of absorbed dose during a time interval with duration dt.
Field of application	Atomic and nuclear physics
Quantity application	General
Preferred measurement unit	Gray per second unit
Other measurement units and unit application	None
Measurement procedure or scale	None
Reference material	None

5.11 Basic Quantities Relating to Characteristic Numbers

The authoritative reference for characteristic numbers is ISO 80000-11:2008.

5.12 Basic Quantities Relating to Solid State Physics

The authoritative reference for quantities relating to solid-state physics is ISO 80000-12:2009.

5.13 Basic Quantities Relating to Information Science and Technology

The authoritative reference for quantities relating to information science and technology is IEC 80000-13:2008.

5.13.1 Storage Capacity

Table 130 - Defining elements of storage capacity quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Storage capacity quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/58E196CD-FA94-457A-BA78-59967E5FFBF0/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	IEC 80000-13:2008
Quantity kind	Storage capacity quantity
Quantity symbol	M
Quantity dimension	dim M = 1
Quantity equation	See Note
Field of application	Information Science and Technology
Quantity application	General
Preferred measurement unit	One unit
Other measurement units and unit application	Bit unit Byte unit
Measurement procedure or scale	None
Reference material	None

NOTE: Storage capacity (or storage size) is the amount of binary digits of data that can be contained in a storage device.

5.13.2 Binary Digit Rate

Table 131 - Defining elements of binary digit rate quantity

DEFINING ELEMENT	DESCRIPTION
Quantity name/identifier	Binary digit rate quantity
Version	1.1
Definition URI	https://www.sae.org/AS6969/CA20CAB9-0CB5-4110-9F72-B4B13E7486A9/1.1
Quantity type	Cardinal
System of quantities	ISQ
Authoritative reference	IEC 80000-13:2008
Quantity kind	Binary digit rate quantity
Quantity symbol	ν
Quantity dimension	dim ν = T^{-1}
Quantity equation	See Note
Field of application	Information Science and Technology
Quantity application	General
Preferred measurement unit	Second to the power minus one unit
Other measurement units and unit application	Bit per second unit Byte per second unit
Measurement procedure or scale	None
Reference material	None

NOTE: Binary digit rate is the transfer rate binary digits of data.

5.14 Basic Quantities Relating to Telebiometrics

This section is reserved.

6. MEASUREMENT UNITS

6.1 Description of Measurement Unit

Measurement units apply to cardinal quantities. Measurement units can belong to a system of units or be off-system measurement units. Within a system of units, a measurement unit can be a base unit or a derived unit. Derived units are defined by a unit equation of base units. Non-coherent derived units are defined by a conversion factor from a coherent derived unit.

6.1.1 Defining Elements of Measurement Unit

The defining elements of a measurement unit are enumerated in Table 132.

Table 132 - Defining elements of measurement unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Unique name/identifier for measurement unit
Version	The version of the table
Definition URI	Namespace and UUID conformant to RFC4122 standard
System of units	SI or non-SI system, or off-system
Measurement unit symbol	The symbol, for example kg for kilogram
Quantity measured	The quantity or quantities to which the measurement unit applies.
Definition	A unit can be base unit, a derived unit defined by a unit equation, or a unit defined by a conversion factor from another unit (that is defined).
Remarks	

6.1.2 Decimal and Binary Multiples of Measurement Units

With a few exceptions, additional measurement units are not provided for decimal and binary multiples of SI measurement units. For example: kilohertz and megahertz as multiples of the Hertz unit, or millimeters and centimeters as submultiples of the meter unit. The exceptions are the kilometer and kilopascal, which are defined in the SI. The kilogram, of course, is a base unit of the SI rather than the gram. Multiples and submultiples of SI units result in non-coherent units.

The SI prefixes and factors may be used, however, as defined in ISO 80000-1:2009.

6.2 Measurement Unit of One and Related Units

The unit of one is a base unit in any system of units. It gives raise to multiple non-coherent units, for example percent, bit, and byte.

6.2.1 One

Table 133 - Defining elements for one unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	One unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/100D54D9-6480-4EE8-B2BB-6FC919845BA1/1.1
System of units	None
Measurement unit symbol	1
Quantity measured	Number of entities quantity Rotation quantity Relative humidity quantity Number of particles quantity Storage capacity quantity Luminous efficiency
Definition	Base unit
Remarks	The unit of one is a base unit in any system of units.

6.2.2 Percent

Table 134 - Defining elements for percent unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Percent unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/6C6DC2E3-29FA-4EC5-8BAD-52B3D98CBD3D/1.1
System of units	None
Measurement unit symbol	pc
Quantity measured	Relative humidity Mass fraction of substance
Definition	1 pc := 1/100
Remarks	Alternative to one unit for ratios

6.2.3 Bit

Table 135 - Defining elements for bit unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Bit unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/A10B3CE6-19FF-4DBA-B581-383786E8CB95/1.1
System of units	None
Measurement unit symbol	bit
Quantity measured	Storage capacity quantity
Definition	1 bit := 1
Remarks	Used for binary digits of data

6.2.4 Byte

Table 136 - Defining elements for byte unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Byte unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/01C5D194-EC4B-4C39-B887-94D18E173D9D/1.1
System of units	None
Measurement unit symbol	B
Quantity measured	Storage capacity quantity
Definition	1 byte := 8 bit
Remarks	Used for binary digits of data

6.2.5 Parts per thousand unit

Table 137 - Defining elements for parts per thousand unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Parts per thousand unit
Version	1.0
Definition URI	https://www.sae.org/AS6969/ 4d1bfae9-c828-46c8-9a48-0182b3af2c7e/1.0
System of units	None
Measurement unit symbol	ppt
Quantity measured	mass fraction of substance
Definition	1 ppt := 1/1000
Remarks	Alternative to one unit for ratios

6.3 SI Measurement Units

6.3.1 Ampere

Table 138 - Defining elements for ampere unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Ampere unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/4921566E-6514-48B0-976E-07F1F33D77CC/1.1
System of units	SI
Measurement unit symbol	A
Quantity measured	Electrical current quantity
Definition	Base unit of SI
Remarks	Ampere is that constant electric current which, if maintained in two parallel conductors of infinite length, of negligible circular cross-section, and placed 1 meter apart in vacuum, would produce between these conductors a force equal to 2 x 10^{-7} newton per meter of length

6.3.2 Ampere per Square Meter

Table 139 - Defining elements for ampere per square meter unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Ampere per square meter unit
Version	1.0
Definition URI	https://www.sae.org/AS6969/ 74d90338-1fa9-4757-946f-bcf76ac49360/1.0
System of units	SI
Measurement unit symbol	A/m^2
Quantity measured	Electric current density quantity
Definition	Base unit of SI
Remarks	Coherent derived unit in the SI

6.3.3 Bar

Table 140 - Defining elements for bar unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Bar unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/184B85CA-45E5-4F9E-A043-C3734419758C/1.1
System of units	SI
Measurement unit symbol	Bar
Quantity measured	Pressure quantity Shear stress quantity
Definition	1 bar := 10^5 Pa = 100kPa
Remarks	Non-coherent derived unit in the SI

6.3.4 Bit per Second

Table 141 - Defining elements for bit per second unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Bit per second unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/897E7740-0C09-4B29-8446-0814343F87E4/1.1
System of units	None
Measurement unit symbol	Bit/s
Quantity measured	Binary digit rate quantity
Definition	1 bit/s := 1/s
Remarks	Coherent derived unit used for binary digits of data. It is a special name for seconds to the power minus one unit.

6.3.5 Byte per Second

Table 142 - Defining elements for byte per second unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Byte per second unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/E65DDDEB-81B6-4951-AA89-3CF1DE4232CD/1.1
System of units	None
Measurement unit symbol	B/s
Quantity measured	Binary digital rate quantity
Definition	1 B/s := 8 bit/s
Remarks	A non-coherent derived unit used for binary digits of data

6.3.6 Candela

Table 143 - Defining elements for candela unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Candela unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/02C4EDBD-A8EF-4666-A459-1348A622F1A5/1.1
System of units	SI
Measurement unit symbol	cd
Quantity measured	Luminous intensity quantity
Definition	Base unit in SI
Remarks	The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 x 10^{12} Hz and that has a radiant intensity in that direction of 1/683 W/sr

6.3.7 Candela per Square Meter

Table 144 - Defining elements for candela per square meter unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Candela per square meter unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/495EB289-436C-4804-88E4-FE7143291016/1.1
System of units	SI
Measurement unit symbol	cd m^{-2}
Quantity measured	Luminance quantity
Definition	
Remarks	Coherent derived unit in the SI

6.3.8 Coulomb

Table 145 - Defining elements for coulomb unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Coulomb unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/F6876A8C-EE6B-41D9-9446-EA0537D88FF0/1.1
System of units	SI
Measurement unit symbol	C
Quantity measured	Electrical charge quantity
Definition	1 C := 1 A s
Remarks	Coherent derived unit in the SI This definition implies that the magnetic constant μ_0 is equal to 4π x 10^{-7} H/m

6.3.9 Coulomb per Cubic Meter

Table 146 - Defining elements for coulomb per cubic meter unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Coulomb per cubic meter unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/0A8C2CC7-00D9-4931-AD67-3A28B7E03105/1.1
System of units	SI
Measurement unit symbol	C/m^3
Quantity measured	Electrical charge density quantity
Definition	
Remarks	Coherent derived unit in the SI

6.3.10 Cubic Meter

Table 147 - Defining elements for cubic meter unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Cubic meter unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/0181B0AD-387B-4F72-A6C6-15B19486A6F1/1.1
System of units	SI
Measurement unit symbol	m^3
Quantity measured	Volume
Definition	
Remarks	A coherent derived unit in the SI

6.3.11 Cubic Meter per Second

Table 148 - Defining elements for cubic meter per second unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Cubic meter per second unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/2985A91D-92FB-4138-9F09-59C5D2E018CB/1.1
System of units	SI
Measurement unit symbol	m^3/s
Quantity measured	Volume flow rate quantity
Definition	
Remarks	Coherent derived unit in the SI

6.3.12 Day

Table 149 - Defining elements for day unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Day measurement unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/EBECCE38-C419-4995-ADA8-4213A266362E/1.1
System of units	SI
Measurement unit symbol	D
Quantity measured	Duration Period Duration
Definition	1 d := 24 h n = 84,400 s
Remarks	Non-coherent derived unit in the SI

6.3.13 Decibel

Table 150 - Defining elements for decibel unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Decibel unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/7C5AAAEE-1C90-4184-8331-554D6FCFE99F/1.1
System of units	SI
Measurement unit symbol	dB
Quantity measured	Level of a power quantity
Definition	1 dB = $\frac{1}{10}\ln\sqrt{10}$ Np
Remarks	Coherent derived unit in the SI

6.3.14 Degree of Arc

Table 151 - Defining elements for degree of arc unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Degree of arc unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/327BCC3B-2A85-4670-815B-AC462F523296/1.1
System of units	SI
Measurement unit symbol	°
Quantity measured	Plane angle
Definition	1° := (π/180) rad
Remarks	Non-coherent derived unit in the SI. Fractions of a degree of arc are decimals.

6.3.15 Decrees of Arc Per Second

Table 152 - Defining elements for degrees of arc per second unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Degrees of arc per second unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/D0E18C5A-51BB-4FB7-A70D-90D402C67720/1.1
System of units	SI
Measurement unit symbol	°/s
Quantity measured	Angular velocity
Definition	1 °/s = (π/180) rad/s
Remarks	Non-coherent derived unit in the SI

6.3.16 Degree Celsius

Table 153 - Defining elements for degree Celsius unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Degree Celsius unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/4A6F527A-C56C-4F69-9E13-F13D84288AD2/1.1
System of units	SI
Measurement unit symbol	°C
Quantity measured	Celsius temperature quantity
Definition	Special name for the kelvin for use in stating values for Celsius temperature. 1 °C := 1 K
Remarks	Coherent derived unit in the SI

6.3.17 Farad

Table 154 - Defining elements for farad unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Farad unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/275730ED-020A-4F9B-A907-3EFEB4376DC9/1.1
System of units	SI
Measurement unit symbol	F
Quantity measured	Capacitance quantity
Definition	1 F := 1 C/V
Remarks	Coherent derived unit in the SI

6.3.18 Gram

Table 155 - Defining elements for gram unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Gram per liter unit
Version	1.0
Definition URI	https://www.sae.org/AS6969/ 3bce8c55-494a-4525-9ec5-e294572cc85d/1.0
System of units	SI
Measurement unit symbol	g
Quantity measured	Mass quantity
Definition	1 g := 0.001 kg
Remarks	This unit is introduced for convenience in data modeling.

6.3.19 Gram per Liter

Table 156 - Defining elements for gram per liter unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Gram per liter unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/24332A68-2B37-4770-ACF1-DE4834537388/1.1
System of units	SI
Measurement unit symbol	g/l
Quantity measured	Mass concentration of substance quantity
Definition	1 g/l := 1 kg/m^3
Remarks	Coherent derived unit in the SI

6.3.20 Gray

Table 157 - Defining elements for gray unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Gray unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/A0E883D9-D073-4ED2-A857-D20A05C767E7/1.1
System of units	SI
Measurement unit symbol	Gy
Quantity measured	Absorbed dose quantity
Definition	1 Gy := 1J/kg
Remarks	The gray is a special name for joule per kilogram, to be used as the coherent SI unit for the quantities listed.

6.3.21 Gray per Second

Table 158 - Defining elements for gray per second unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	gray per second unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/FC423428-09A4-4583-A73B-C997A2B60CCE/1.1
System of units	SI
Measurement unit symbol	Gy/s
Quantity measured	absorbed dose quantity
Definition	1 Gy/s = 1 W/kg
Remarks	The gray is a special name for watt per kilogram, to be used as the coherent SI unit for the quantities listed.

6.3.22 Henry

Table 159 - Defining elements for henry unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Henry unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/F53C4D01-3A71-49D8-846D-D6165997A956/1.1
System of units	SI
Measurement unit symbol	H
Quantity measured	Inductance quantity
Definition	1 H := 1 Wb/A
Remarks	Coherent derived unit in the SI

6.3.23 Hertz

Table 160 - Defining elements for hertz unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Hertz unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/76170ACC-DEA1-48C6-8DB0-B452389BC5C51.1
System of units	SI
Measurement unit symbol	Hz
Quantity measured	Frequency
Definition	1 Hz := 1 s^{-1}
Remarks	Coherent derived unit in the SI

6.3.24 Hour

Table 161 - Defining elements for hour unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Hour unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/90D3ABE1-A3A7-46D6-8592-9161A2EA38DE/1.1
System of units	SI
Measurement unit symbol	h
Quantity measured	Duration Period duration
Definition	1 h := 60 min = 3,600 s
Remarks	Non-coherent derived unit in the SI

6.3.25 Joule

Table 162 - Defining elements for joule unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Joule unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/1AEE8287-DBFC-4ADB-A631-62C58ABA1000/1.1
System of units	SI
Measurement unit symbol	J
Quantity measured	Mechanical work quantity Mechanical energy quantity Potential energy quantity Kinetic energy quantity Radiant energy quantity Mean energy imparted quantity
Definition	1 J := 1 W s
Remarks	Coherent derived unit in the SI

6.3.26 Kelvin

Table 163 - Defining elements for kelvin unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Kelvin unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/CDE0992B-2B06-4A70-8753-8D31CD43D80D1.1
System of units	SI
Measurement unit symbol	K
Quantity measured	Thermodynamic temperature quantity
Definition	Unit of thermodynamic temperature that is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.
Remarks	Base unit in the SI

6.3.27 Kilogram

Table 164 - Defining elements for kilogram unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Kilogram unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/60A24AEF-7806-41CD-8BED-DBA9208C48EE/1.1
System of units	SI
Measurement unit symbol	kg
Quantity measured	Mass quantity
Definition	SI base unit
Remarks	Equal to the mass of the international prototype of the kilogram [3rd CGPM (1901)]

6.3.28 Kilogram Meter per Second

Table 165 - Defining elements for kilogram meter per second unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Kilogram meter per second unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/1023A870-02E3-4EDC-89C4-470D08CAD0B7/1.1
System of units	SI
Measurement unit symbol	kg m/s
Quantity measured	Momentum quantity
Definition	
Remarks	Coherent derived unit in the SI

6.3.29 Kilogram per Cubic Meter

Table 166 - Defining elements for kilogram per cubic meter unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Kilogram per cubic meter unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/20C1B621-0459-40CA-9D82-C7405E81AF92/1.1
System of units	SI
Measurement unit symbol	kg/m^3
Quantity measured	Mass density quantity
Definition	
Remarks	Coherent derived unit in the SI

6.3.30 Kilogram per Second

Table 167 - Defining elements for kilogram per second unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Kilogram per second unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/91A269AA-3688-489F-A911-C53DF3E2DB66/1.1
System of units	SI
Measurement unit symbol	kg/s
Quantity measured	Mass flow rate quantity
Definition	
Remarks	Coherent derived unit in the SI

6.3.31 Kilometer

Table 168 - Defining elements for kilometer unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Kilometer unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/5416E748-8DF8-4651-AB8E-67DA9164419E/1.1
System of units	SI
Measurement unit symbol	km
Quantity measured	Length of path Length of position vector
Definition	1 km := 1000 m
Remarks	A non-coherent derived unit in the SI

6.3.32 Kilometer per Hour

Table 169 - Defining elements for kilometer per hour unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Kilometer per hour unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/BCA7E5DA-758D-4A6E-8B59-256A21311143/1.1
System of units	SI
Measurement unit symbol	km/h
Quantity measured	Velocity Speed
Definition	1 km/h = (1/3.6) m/s
Remarks	Non-coherent derived unit in the SI

6.3.33 Kilopascal

Table 170 - Defining elements for kilopascal unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Kilopascal unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/EFE77342-DE4A-4477-BD81-4EBF2C30A07B/1.1
System of units	SI
Measurement unit symbol	kPa
Quantity measured	Pressure quantity Shear stress quantity
Definition	1 kPa := 1000 Pa
Remarks	Non-coherent derived unit in the SI

6.3.34 Liter

Table 171 - Defining elements for liter unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Liter unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/6A7BEEB2-BB2E-451D-BD0B-16F112273D57/1.1
System of units	SI
Measurement unit symbol	L
Quantity measured	Volume
Definition	$1\ l := 10^{-3}\ m^3 = 1\ dm^3$
Remarks	Non-coherent derived unit in the SI

6.3.35 Lumen

Table 172 - Defining elements for lumen unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Lumen unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/B943804C-BB1C-41FC-8730-E785D48C7B20/1.1
System of units	SI
Measurement unit symbol	lm
Quantity measured	Luminous flux quantity
Definition	1 lm := 1 cd sr
Remarks	Coherent derived unit in the SI

6.3.36 Lumen per Watt

Table 173 - Defining elements for lumen per watt unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Lumen per watt unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/89D6150C-9F40-4A46-A268-46E2024956E9/1.1
System of units	SI
Measurement unit symbol	$lm\ W^{-1}$
Quantity measured	Spectral luminous efficacy quantity Luminous efficacy of radiation
Definition	
Remarks	Coherent derived unit in the SI

6.3.37 Lux

Table 174 - Defining elements for lux unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Lux unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/4A1E46BF-2F3E-480E-B1A9-E3A97295391B/1.1
System of units	SI
Measurement unit symbol	lx
Quantity measured	Illuminance quantity
Definition	1 lx := 1 lm m^{-2}
Remarks	Coherent derived unit

6.3.38 Meter of Length

Table 175 - Defining elements for meter of length unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Meter of length unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/865C5BA6-73E5-4015-925B-4A0C77D7AA6B/1.1
System of units	SI
Measurement unit symbol	m
Quantity measured	Length
Definition	A base unit in the SI.
Remarks	The length of the path travelled by light in a vacuum during a time interval of 1/299,792,458 of a second

6.3.39 Meter Per Second

Table 176 - Defining elements for meter per second unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Meter per second unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/977FCDAF-5FA2-45ED-B46D-BA7DFFAC026F/1.1
System of units	SI
Measurement unit symbol	m/s
Quantity measured	Velocity Speed
Definition	
Remarks	Coherent derived unit in the SI

6.3.40 Meter Per Second Squared

Table 177 - Defining elements for meter per second squared unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Meter per second squared unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/CF7AB552-76E6-420E-8E0F-4DDB4A4CCBE2/1.1
System of units	SI
Measurement unit symbol	m/s^2
Quantity measured	Velocity acceleration Speed acceleration
Definition	
Remarks	Coherent derived unit in the SI

6.3.41 Meter Squared per Second

Table 178 - Defining elements for meter squared per second unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Meter squared per second unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/8FC0E6AC-7C5D-4ADB-B194-11368FDCB291/1.1
System of units	SI
Measurement unit symbol	m^2/s
Quantity measured	Kinematic viscosity quantity Statistical covariance of length and velocity, i.e., $cov(l, v)$
Definition	
Remarks	Coherent derived unit in the SI

6.3.42 Meter Squared per Second Squared

Table 179 - Defining elements for meter squared per second squared unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Meter squared per second squared unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/CD30B1B4-EC5A-45C5-8E49-A24AC6C7944A/1.1
System of units	SI
Measurement unit symbol	m^2/s^2
Quantity measured	Statistical variance of velocity, i.e., $var(v)$
Definition	
Remarks	Coherent derived unit in the SI

6.3.43 Meter to the Power Minus Three

Table 180 - Defining elements for meter to the power minus three unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Meter to the power minus three unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/1BC5891A-6906-4B48-A720-D8FAD837D379/1.1
System of units	SI
Measurement unit symbol	m^{-3}
Quantity measured	Molecular concentration of substance quantity Amount of substance concentration
Definition	
Remarks	Coherent derived unit in the SI

6.3.44 Minute of Time

Table 181 - Defining elements for minute of time unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Minute of time unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/2E8CDDA4-A608-4ABD-8D00-4ACD3A662E61/1.1
System of units	SI
Measurement unit symbol	min
Quantity measured	Duration Period duration
Definition	1 min := 60 s
Remarks	Non-coherent derived unit in the SI

6.3.45 Mole

Table 182 - Defining elements for mole unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	mole unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/EBB2A61D-C9CC-42FB-933E-CA3B7C17C016/1.1
System of units	SI
Measurement unit symbol	mol
Quantity measured	amount of substance quantity
Definition	Base unit in the SI
Remarks	The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kg of carbon 12 [14th CGPM]

6.3.46 Neper

Table 183 - Defining elements for neper unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Neper unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/92690625-63FD-4FB6-9334-6696F51B5CB4/1.1
System of units	SI
Measurement unit symbol	Np
Quantity measured	Level of a power quantity
Definition	1 Np $:= \ln e = 1$
Remarks	Coherent unit in the SI

6.3.47 Newton

Table 184 - Defining elements for newton unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Newton unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/24C79A40-A34A-42E8-83F7-661457A87B12/1.1
System of units	SI
Measurement unit symbol	N
Quantity measured	Force quantity
Definition	1 N := 1 kg m/s^2
Remarks	Coherent derived unit in the SI

6.3.48 Newton Meter

Table 185 - Defining elements for newton meter unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Newton meter unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/739BCBB8-F1F8-4947-983A-D51ADA84EF3C/1.1
System of units	SI
Measurement unit symbol	N m
Quantity measured	Moment of force quantity Torque quantity
Definition	
Remarks	Coherent derived unit in the SI

6.3.49 Ohm

Table 186 - Defining elements for ohm unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Ohm unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/ADE76780-8163-4B6A-B406-0C78ADCE3CEE/1.1
System of units	SI
Measurement unit symbol	Ω
Quantity measured	Electrical resistance quantity
Definition	1 Ω := 1 V/A
Remarks	Coherent derived unit in the SI

6.3.50 Ohm Meter

Table 187 - Defining elements for ohm meter unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Ohm meter unit
Version	1.0
Definition URI	https://www.sae.org/AS6969/ fbb1bd80-f5bc-428a-b8b0-772a95f219b4/1.0
System of units	SI
Measurement unit symbol	Ω m
Quantity measured	Electrical resistivity quantity
Definition	1 Ω m := 1 V m/A
Remarks	Coherent derived unit in the SI

6.3.51 Pascal

Table 188 - Defining elements for pascal unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Pascal unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/823C61A3-02F4-43FB-8B09-5EE11F5F1ACC/1.1
System of units	SI
Measurement unit symbol	Pa
Quantity measured	Pressure quantity Shear stress quantity
Definition	1 Pa := 1N/m^2
Remarks	Coherent derived unit in the SI

6.3.52 Pascal Second

Table 189 - Defining elements for pascal second unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Pascal second unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/FA0E7E1E-A662-4BF5-B22F-7F65928A6D88/1.1
System of units	SI
Measurement unit symbol	Pa s
Quantity measured	Dynamic viscosity quantity
Definition	
Remarks	Coherent derived unit in the SI

6.3.53 Rad

Table 190 - Defining elements for rad unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Rad unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/81147860-55FF-4E6C-8140-076BB8A6AF37/1.1
System of units	SI
Measurement unit symbol	rad
Quantity measured	Absorbed dose quantity
Definition	1 rad := 10^{-2} Gy
Remarks	Non-coherent derived unit in the SI

6.3.54 Radian

Table 191 - Defining elements for radian unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Radian unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/C3EA800B-7873-4DFC-8D9C-C601DD338103/1.1
System of units	SI
Measurement unit symbol	rad
Quantity measured	Plane angle
Definition	1 rad := 1 m/m = 1
Remarks	The radian is the angle between two radii of a circle that cuts off on the circumference an arc equal in length to the radius of the circle.

6.3.55 Radian per Second

Table 192 - Defining elements for radian per second unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Radian per second unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/3FC74B02-BAE3-4D9E-BD01-04723F329E44/1.1
System of units	SI
Measurement unit symbol	rad/s
Quantity measured	Angular velocity
Definition	
Remarks	Coherent derived unit in the SI

6.3.56 Radian per Second Squared

Table 193 - Defining elements for radian per second squared unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Radian per second squared unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/B92F4DA9-B36A-4CA1-96BB-BFB3AD321253/1.1
System of units	SI
Measurement unit symbol	rad/s^2
Quantity measured	Angular acceleration
Definition	
Remarks	Coherent derived unit in the SI

6.3.57 Rem

Table 194 - Defining elements for rem unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Rem unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/86C9C561-4269-464B-BE7F-B0921D12AF6E/1.1
System of units	SI
Measurement unit symbol	rem
Quantity measured	Dose equivalent quantity
Definition	1 rem := 10^{-2} Sv
Remarks	Non-coherent derived unit in the SI

6.3.58 Second

Table 195 - Defining elements for second unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Second unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/E4EE26A1-134B-4A6A-B5DA-E5F419633948/1.1
System of units	SI
Measurement unit symbol	s
Quantity measured	Duration Period duration
Definition	Base unit in the SI. Duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom.
Remarks	Duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom

6.3.59 Second to the Power Minus One

Table 196 - Defining Elements for second to the power minus one Unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Second to the power minus one measurement unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/5914F4FA-8CBE-40C0-AFE8-2BBF6B72330F/1.1
System of units	SI
Measurement unit symbol	s^{-1}
Quantity measured	Rotational frequency Number of entities rate
Definition	
Remarks	Coherent derived unit in the SI

6.3.60 Siemens

Table 197 - Defining elements for siemens unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Siemens unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/509DB6CE-49AE-4FF9-83E9-535A0D00C5B1/1.1
System of units	SI
Measurement unit symbol	S
Quantity measured	Conductance quantity
Definition	$1 S := 1/\Omega$
Remarks	Coherent unit in the SI

6.3.61 Siemens per Meter

Table 198 - Defining elements for siemens per meter unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Siemens per meter unit
Version	1.0
Definition URI	https://www.sae.org/AS6969/ 785407ee-95e6-4ba3-b749-5affc3cafc43/1.0
System of units	SI
Measurement unit symbol	S/m
Quantity measured	Electrical conductivity quantity
Definition	1 S/m := 1/(Ω m)
Remarks	Coherent unit in the SI

6.3.62 Sievert

Table 199 - Defining elements for sievert unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Sievert unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/8FBBE0F5-984C-40C6-ADD7-CD759D8E025D/1.1
System of units	SI
Measurement unit symbol	Sv
Quantity measured	Dose equivalent quantity
Definition	1 Sv := 1 J/kg
Remarks	The sievert is a special name for joule per kilogram, to be used as the coherent SI unit for dose equivalent

6.3.63 Square Meter

Table 200 - Defining elements for square meter unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Square meter unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/94D59E2A-7883-40EC-AEAF-A4FF8FF029A9/1.1
System of units	SI
Measurement unit symbol	m^2
Quantity measured	area statistical variance of length, i.e., $var(l)$
Definition	
Remarks	A coherent derived unit in the SI

6.3.64 Steradian

Table 201 - Defining elements for steradian unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Steradian unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/AF222D7E-4F72-4B49-86F2-1D8D5E6BCD5B/1.1
System of units	SI
Measurement unit symbol	sr
Quantity measured	Solid angle
Definition	1 sr := 1 m^2/m^2 = 1
Remarks	The steradian is the solid angle of a cone that, having its apex in the center of the sphere, cuts off on the sphere a surface equal in area to a square with sides of length equal to the radius of the sphere. A coherent unit in the SI.

6.3.65 Tesla

Table 202 - Defining elements for tesla unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Tesla unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/1CFFE032-1D79-4295-B4B7-C9F83B91D835/1.1
System of units	SI
Measurement unit symbol	T
Quantity measured	Magnetic flux density quantity
Definition	1 T := 1 N(A m)
Remarks	A coherent unit in the SI. 1T = 1 Wb/m^2

6.3.66 Volt

Table 203 - Defining elements for volt unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Volt unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/6E7CA0E7-43C5-4B73-8D0B-D8DF5073F186/1.1
System of units	SI
Measurement unit symbol	V
Quantity measured	Electric potential quantity Electric potential difference quantity Voltage quantity Source voltage quantity
Definition	1 V := 1 W/A
Remarks	A coherent unit in the SI

6.3.67 Volt per Meter

Table 204 - Defining elements for volt per meter unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Volt per meter unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/A193DDA4-E5D0-452F-B8C4-12BC463B4481/1.1
System of units	SI
Measurement unit symbol	V/m
Quantity measured	Electric field strength quantity
Definition	1 V/m := 1 N/C
Remarks	A coherent unit in the SI

6.3.68 Watt

Table 205 - Defining elements for watt unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Watt unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/A6D0001A-627B-4731-B490-D4351923351F/1.1
System of units	SI
Measurement unit symbol	W
Quantity measured	Power quantity Instantaneous electrical power quantity Active electrical power quantity Radiant flux quantity
Definition	1 W := 1 N m/s
Remarks	Coherent derived unit in the SI

6.3.69 Watt per Hertz

Table 206 - Defining elements for watt per hertz unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Watt per hertz unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/A8FA84B1-844C-4D4C-86DA-88E7FB9693A2/1.1
System of units	SI
Measurement unit symbol	W Hz^{-1}
Quantity measured	Spectral radiant flux quantity
Definition	
Remarks	Coherent derived unit in the SI

6.3.70 Watt per Steradian

Table 207 - Defining elements for watt per steradian unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Watt per steradian unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/DCDB492E-CEBE-42E0-AC52-B69151FACE61/1.1
System of units	SI
Measurement unit symbol	W sr^{-1}
Quantity measured	Radiant intensity quantity
Definition	
Remarks	Coherent derived unit in the SI

6.3.71 Watt per Steradian per Hertz

Table 208 - Defining elements for watt per steradian per hertz unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Watt per steradian per hertz unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/5EAAAE42-FE40-48F1-8CA8-D2934AD56D85/1.1
System of units	SI
Measurement unit symbol	W sr^{-1} Hz^{-1}
Quantity measured	Spectral radiant intensity quantity
Definition	
Remarks	Coherent derived unit in the SI

6.3.72 Weber

Table 209 - Defining elements for weber unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Weber unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/85524DEC-E492-41AB-BFC1-E4B63E02CD0C/1.1
System of units	SI
Measurement unit symbol	Wb
Quantity measured	Magnetic flux quantity Linked flux quantity
Definition	1 Wb := 1 V s
Remarks	A coherent unit in the SI

6.3.73 Weber per Meter

Table 210 - Defining elements for weber per meter unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Weber per meter unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/3A5A3BF6-02BF-42C3-B454-AD931350863C/1.1
System of units	SI
Measurement unit symbol	Wb/m
Quantity measured	Magnetic vector potential quantity
Definition	
Remarks	A coherent unit in the SI

6.4 U.S. Customary Measurement System

The U.S. Customary Measurement System is the system of units based on the yard of length and the pound of mass that is commonly used in the United States of America and is defined by the National Institute of Standards and Technology (NIST).

6.4.1 Degree Fahrenheit

Table 211 - Defining elements for degree Fahrenheit unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Degree Fahrenheit unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/3DF0B368-4B7A-455D-9D1D-1E674FDCCB33/1.1
System of units	U.S. Customary Measurement System
Measurement unit symbol	°F
Quantity measured	Celsius temperature quantity
Definition	°F := 1.8 x °C + 32
Remarks	

6.4.2 Foot per Second

Table 212 - Defining elements for foot per second unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Foot per second unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/71153EC8-07BF-4D76-B944-6D85C9EAFF55/1.1
System of units	U.S. Customary Measurement System
Measurement unit symbol	ft/s
Quantity measured	Velocity quantity Speed quantity
Definition	1 ft/s := 0.3048 m/s
Remarks	Based on statute foot

6.4.3 Foot per Second Squared

Table 213 - Defining elements for foot per second unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Foot per second squared unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/EEF2300B-CADC-4D30-968F-70705E0EE02A/1.1
System of units	U.S. Customary Measurement System
Measurement unit symbol	ft/s^2
Quantity measured	Acceleration quantity
Definition	$1\ ft/s^2 := 0.3048\ m/s^2$
Remarks	Based on statute foot

6.4.4 Foot Pounds per Second Squared

Table 214 - Defining elements for foot pounds per second squared unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Foot pounds per second squared unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/39798AD5-2850-4536-A8FF-4BE8720B08B5/1.1
System of units	U.S. Customary Measurement System
Measurement unit symbol	$ft\ lb/s^2$
Quantity measured	Force quantity
Definition	$1\ ft\ lb/s^2 := 4.448222\ N$
Remarks	

6.4.5 Inch

Table 215 - Defining elements for inch unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Inch unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/A04C0861-4334-48A4-9135-B6976755E8EA/1.1
System of units	U.S. Customary Measurement System
Measurement unit symbol	in
Quantity measured	Length quantity Length of path quantity Length of position vector quantity
Definition	1 in := 25.4 mm
Remarks	

6.4.6 Inch per Second

Table 216 - Defining elements for inch per second unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Inch per second measurement unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/10CDAE38-C00D-4482-9299-7CBD8118DA67/1.1
System of units	Off-system
Measurement unit symbol	in/s
Quantity measured	Velocity quantity Speed quantity
Definition	1 in/s = 25.4 mm/s
Remarks	

6.4.7 Mile per Hour

Table 217 - Defining elements for mile per hour unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Mile per hour unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/5994B99D-E6C5-4C5A-9FB7-3BB322A6827A/1.1
System of units	U.S. Customary Measurement System
Measurement unit symbol	mi/h
Quantity measured	Velocity quantity Speed quantity
Definition	1 mi/h = 0.44704 m/s
Remarks	Based on statute mile

6.4.8 Pound Force

Table 218 - Defining elements for pound force unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Pound force unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/27CB2348-F13D-4057-ACAC-3C554BF84BB1/1.1
System of units	U.S. Customary Measurement System
Measurement unit symbol	lbf
Quantity measured	Force quantity
Definition	1 lbf ≈ 4.448222 N
Remarks	This value is based on the standard acceleration of free fall, g_n := 9.80665 m/s^2.

6.4.9 Pound Force per Square Inch

Table 219 - Defining elements for pound force per square inch unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Pound force per square inch unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/2BA6F02F-812B-47A1-A11E-A9445DBDCADA/1.1
System of units	U.S. Customary Measurement System
Measurement unit symbol	psi
Quantity measured	Pressure quantity
Definition	1 psi ≈ 6,894.757 Pa
Remarks	

6.4.10 Pound of Mass

Table 220 - Defining elements for pound of mass unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Pound of mass unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/403A7BC5-CB7A-4C5C-8A28-EBCC1D4963FE/1.1
System of units	U.S. Customary Measurement System
Measurement unit symbol	lb
Quantity measured	Mass quantity
Definition	1 lb := 0.45359237 kg
Remarks	

6.4.11 Pound of Mass per Cubic Foot

Table 221 - Defining elements for pound of mass per cubic foot unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Pound of mass per cubic foot unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/9EC34A02-C1BA-4CB8-AF5A-CB22A823ED21/1.1
System of units	U.S. Customary Measurement System
Measurement unit symbol	lb/ft^3
Quantity measured	Mass density quantity
Definition	$1\ lb/ft^3 \approx 16.01846\ kg/m^3$
Remarks	Based on statute foot (rather than survey foot)

6.4.12 Pounds of Mass per Cubic Inch

Table 222 - Defining elements for pounds of mass per cubic inch unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Pounds of mass per cubic inch unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/67962037-E5B5-455C-ACC1-A58C9CE14AA9/1.1
System of units	Off-system
Measurement unit symbol	lb/in^3
Quantity measured	Mass density
Definition	$1\ lb/in^3 = 1\ lb/ft^3 / 1728$
Remarks	

6.4.13 Pound of Mass per Second

Table 223 - Defining elements for pound of mass per second unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Pound of mass per second unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/29FFFB0A-CCDD-43B1-8445-71171EE10005/1.1
System of units	U.S. Customary Measurement System
Measurement unit symbol	lb/s
Quantity measured	Mass flow rate quantity
Definition	1 lb/s := 0.45359237 kg/s
Remarks	

6.4.14 Statute Foot

Table 224 - Defining elements for statute foot unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Statute foot unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/6333A3B3-49E9-456C-AE0D-755CD84AD327/1.1
System of units	U.S. Customary Measurement System
Measurement unit symbol	ft
Quantity measured	Length quantity Length of path quantity Length of position vector quantity
Definition	1 ft := 12 in = 0.3048 m
Remarks	Not to be confused with U.S. Survey foot

6.4.15 Square Foot

Table 225 - Defining elements for square foot unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Square foot unit
Version	1.0
Definition URI	https://www.sae.org/AS6969/79d8fd38-0f6d-45cf-8bbe-9a9c523d6221/1.0
System of units	U.S. Customary Measurement System
Measurement unit symbol	ft^2
Quantity measured	Area quantity
Definition	1 ft^2 := 144 in^2 = 0.09290304 m^2
Remarks	Based on statute foot

6.4.16 Cubic Foot

Table 226 - Defining elements for cubic foot unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Cubic foot unit
Version	1.0
Definition URI	https://www.sae.org/AS6969/ 08868605-9375-45ff-a0f2-6389a723ab07/1.0
System of units	U.S. Customary Measurement System
Measurement unit symbol	ft^3
Quantity measured	Volume quantity
Definition	1 ft^3 := 1728 in^3 = 0.3048^3 m^3
Remarks	Based on statute foot

6.4.17 Statute Mile

Table 227 - Defining elements for statute mile unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Statute mile measurement unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/2510B58E-EE89-4CBF-B514-28E0EC7EFFAB/1.1
System of units	U.S. Customary Measurement System
Measurement unit symbol	mi
Quantity measured	Length quantity Length of path quantity Length of position vector quantity
Definition	1 mi := 1,760 yd = 5,280 ft = 1,609.344 m
Remarks	Not to be confused with U.S. Survey mile

6.4.18 Yard of Length

Table 228 - Defining elements for yard of length unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Yard of length unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/71962C8F-D922-43B4-9026-AA3BC8093941/1.1
System of units	U.S. Customary Measurement System
Measurement unit symbol	yd
Quantity measured	Length quantity Length of path quantity Length of position vector quantity
Definition	1 yd := 3 ft = 36 in = 0.9144 m
Remarks	

6.5 Off-System Measurement Units

6.5.1 Inches Mercury (60 °F)

Table 229 - Defining elements for inches mercury unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Inches mercury (60 °F) unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/69B56C63-AF5B-47BB-A149-01FB09F51984/1.1
System of units	Off-system
Measurement unit symbol	inHg (60 °F)
Quantity measured	Pressure quantity
Definition	1 inHg (60 °F) ≈ 0.24884 kPa
Remarks	

6.5.2 Revolutions per Minute

Table 230 - Defining elements for revolutions per minute unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Revolutions per minute unit
Version	1.0
Definition URI	https://www.sae.org/AS6969/1e6f1d34-7e7b-4ee5-91e6-8e709b2bdf5b/1.0
System of units	Off-system
Measurement unit symbol	r/min
Quantity measured	Rotational frequency quantity
Definition	60 r/min := 1 s^{-1}
Remarks	r/min is the international symbol defined in ISO 80000-3. The alternative symbol in English is RPM.

6.5.3 Year

Table 231 - Defining elements for year unit

DEFINING ELEMENT	DESCRIPTION
Measurement unit name/identifier	Year unit
Version	1.1
Definition URI	https://www.sae.org/AS6969/0D223588-0E01-4BCF-A96C-3C41845263DD/1.1
System of units	Off-system
Measurement unit symbol	a
Quantity measured	Time duration quantity
Definition	$a := \begin{cases} 365\ \mathrm{d} \\ 366\ \mathrm{d} \end{cases}$
Remarks	Not to be confused with a tropical year, where one tropical year is the period duration between two successive passages of the Sun through the mean vernal equinox.

7. TIME REFERENCE SYSTEMS

7.1 Time Reference Systems

A time reference system (TRS) is analogous to a coordinate datum in a spatial reference system. As there are no components of time (there is only one time axis), a separate time coordinate system is not required. The extensible list of available TRS subtypes is:

a. International Atomic Time (TAI)

b. Earth rotation

c. Coordinated Universal Time (UTC)

d. Global system clock

e. Local system clock

A local system clock TRS would be defined in a quantity domain or system specification.

Table 232 - Defining elements of a time reference system

DEFINING ELEMENT	DESCRIPTION
TRS name	Unique name/identifier of TRS
Version	Version number of table
Definition URI	Namespace and universally unique identifier. UUID conformant to RFC4122 standard.
TRS subtype	TRS subtypes from the extensible list above
Description and scope	
Authoritative reference (if any)	The standard, convention or interface where the TRS is defined.
Epoch	The description of TRS epoch and initial time value.
Realization epoch	The time after which the TRS definition is valid
TRS validity	The time frame in which the TRS is valid.
Remarks	Other information concerning the TRS

7.1.1 International Atomic Time (TAI)

Table 233 - Defining elements of TAI time reference system

DEFINING ELEMENT	DESCRIPTION
TRS name	International Atomic Time (TAI) TRS
Version	1.1
Definition URI	https://www.sae.org/AS6969/AAEF6ACB-7A8B-444C-BE0E-488FD92EC814/1.1
TRS subtype	International Atomic Time (TAI)
Description and scope	TAI is a stable and continuous temporal reference whose unit of duration is the SI second. It does not, therefore, keep in step with the slightly irregular rotation of the Earth.
Authoritative reference (if any)	The TAI timescale is calculated by the International Bureau of Weights and Measures (BIPM, France).
Epoch	
Realization epoch	TAI was synchronized with Universal Time (UT) at the beginning of 1958.
TRS validity	
Remarks	TAI is the weighted average of participating atomic clocks adjusted for the gravity at mean sea level.

7.1.2 Universal Time (UT1)

Table 234 - Defining elements of UT1 time reference system

DEFINING ELEMENT	DESCRIPTION
TRS name	Universal Time (UT1) TRS
Version	1.1
Definition URI	https://www.sae.org/AS6969/1FD71A8E-5074-4374-A77A-7DBC86232156/1.1
TRS subtype	Earth rotation
Description and scope	Conceptually, UT1 is the mean solar time at the Earth's Prime Meridian. It is used in determining the required leap second adjustments to Coordinated Universal Time (UTC). The difference between UT1 and UTC is known as DUT1.
Authoritative reference (if any)	UT1 is monitored by the International Earth Rotation and Reference Systems Service (IERS).
Epoch	
Realization epoch	
TRS validity	
Remarks	UT0 is Universal Time observed at a site assuming fixed coordinates in the International Terrestrial Reference Frame. UT1 corrects UT0 for the wondering of the polar axis (called polar motion).

7.1.3 Coordinated Universal Time (UTC)

Table 235 - Defining elements of UTC time reference system

DEFINING ELEMENT	DESCRIPTION
TRS name	Coordinated Universal Time (UTC) TRS
Version	1.1
Definition URI	https://www.sae.org/AS6969/6B38F8EA-F6A7-46E7-B612-26EB1BAC8A06/1.1
TRS subtype	Coordinated Universal Time (UTC)
Description and scope	UTC is the international standard on which civil time is based. Its unit of duration is the SI second, in step with TAI. However, UTC is occasionally adjusted with leap seconds to keep DUT1 less than 0.9 seconds.
Authoritative reference (if any)	UTC is maintained by the International Bureau of Weights and Measures (BIPM). The UTC system is defined by ITU-R TF.460-5, Standard-frequency and time-signal emissions.
Epoch	
Realization epoch	
TRS validity	
Remarks	

7.1.4 Global Positioning System (GPS) Time (GPST)

Table 236 - Defining elements of GPST time reference system

DEFINING ELEMENT	DESCRIPTION
TRS name	Global Positioning System (GPS) Time (GPST) TRS
Version	1.1
Definition URI	https://www.sae.org/AS6969/5CB5EDD6-54FA-4073-8133-B50F65E11AF6/1.1
TRS subtype	Global system clock
Description and scope	GPST is a continuous time scale (no leap seconds) maintained by the GPS Control segment. GPST is synchronized with TAI via UTC (USNO).
Authoritative reference (if any)	IS-GPS-200G
Epoch	1980-01-06T00:00Z
Realization epoch	1980-01-06T00:00Z
TRS validity	
Remarks	At the epoch, TAI-UTC was 19 seconds. GPST is specified to be synchronized with UTC (USNO) at the 1 microsecond level, but actually kept within 25 ns.

7.1.5 Galileo System Time (GST)

Table 237 - Defining elements of GST time reference system

DEFINING ELEMENT	DESCRIPTION
TRS name	Galileo System Time (GST) TRS
Version	1.1
Definition URI	https://www.sae.org/AS6969/136E0CFD-55FB-45F7-A7FA-E689624177C3/1.1
TRS subtype	Global system clock
Description and scope	GST is a continuous time scale and maintained by the Galileo Central Segment. It is synchronized with TAI.
Authoritative reference (if any)	Galileo OS SIS ICD
Epoch	1999-08-22T00:00Z
Realization epoch	1999-08-22T00:00Z
TRS validity	
Remarks	GST is synchronized with TAI with a nominal offset below 50 ns.

7.1.6 GLONASS Time (GLONASST)

Table 238 - Defining elements of GLONASST time reference system

DEFINING ELEMENT	DESCRIPTION
TRS name	GLONASS Time (GLONASST) TRS
Version	1.1
Definition URI	https://www.sae.org/AS6969/F430CA11-1B96-4B8A-BC9A-1782C2D17F9B/1.1
TRS subtype	Global system clock
Description and scope	GLONASST is generated by the GLONASS Central Synchronizer. It is synchronized with UTC (SU) plus 3 hours (i.e., Moscow time zone).
Authoritative reference (if any)	GLONASS ICD L1, L2
Epoch	
Realization epoch	
TRS validity	
Remarks	Synchronization with UTC is specified to not exceed 1 millisecond, but typically better that 1 microsecond.

8. SPATIAL REFERENCE SYSTEMS

8.1 Coordinate Datums

The defining elements of a coordinate datum (CD) are provided in Table 239.

Table 239 - Defining elements of a coordinate datum

DEFINING ELEMENT	DESCRIPTION
CD name	Unique name/identifier of CD
Version	Version number of table
Definition URI	Namespace and universally unique identifier. UUID conformant to RFC4122 standard.
CD subtype	CD subtypes from the extensible list above
Description and scope	
Authoritative reference (if any)	The standard or convention in where the coordinate datum is defined.
Anchor definition	The description of the datum position and direction relative to a physical object of interest.
Realization epoch	The time after which the datum definition is valid
Datum validity	The area of region or time frame in which the datum is valid.
Remarks	Other information concerning the CD

There are four subtypes of coordinate datum. These are Terrestrial Reference Frame (TRF), Earth-fixed Local Reference Frame (LRF), Vehicle-Carried LRF, and Engineering Body. CDs of the TRF subtype are anchored to Earth's center of mass, pole and meridian. CDs of the LRF subtype are earth-stationary at the time of interest even when the LRF origin is vehicle-carried. The CDs of the Engineering Body subtype share the inertial state of the Engineering Body to which they are anchored.

The taxonomy of CDs is shown below:

a. Terrestrial Reference Frame (TRF)

   1. WGS 84 (G1762) CD

b. Earth-fixed Local Reference Frame (LRF)

   1. WGS 84 (G1762) Earth-fixed Local Tangent Plane (LTP) CD

   2. Earth-fixed Vehicle Pose CD

c. Vehicle-carried LRF

   1. WGS 84 (G1762) Vehicle-carried LTP (Freefall) CD

   2. WGS 84 (G1762) Vehicle-carried LTP CD

   3. Vehicle-carried Pose CD

d. Engineering Body

   1. Vehicle Body CD

NOTE: Consider a vehicle's inertal navigation system. It may report its position vector referenced to a TRF or Earth-fixed LRF, its velocity vector referenced to its vehicle-carried LRF, and its experienced body accelleration vector referenced to its Engineering Body.

NOTE: The speed of a body will be earth-relative when referenced against a TRF or LRF and body-relative when referenced referenced to an Engineering Body. For example, an earth-stationary body will have zero speed when referenced to a TRF or LRF and non-zero speed when referenced to a moving Engineering Body.

Body: A body is an entity that has observable position and extension (i.e., it occupies a Cartesian space).

NOTE: Additional engineering body subtypes are permitted within a quantity domain.

8.1.1 WGS 84 (G1762) Coordinate Datum

Table 240 - Defining elements of WGS 84 (G1762) coordinate datum

DEFINING ELEMENT	DESCRIPTION
CD name	WGS84G1762 CD
Version	1.1
Definition URI	https://www.sae.org/AS6969/8A63E02C-F0AF-4F5D-B545-E69C9619682E/1.1
CD subtype	Terrestrial reference frame
Description and scope	WGS 84 (G1762) is the sixth update to the realization of the WGS 84 Reference Frame.
Authoritative reference (if any)	NGA.STND.0036_1.0.0_WGS84
Anchor definition	As defined by NGA.STND.0036_1.0.0_WGS84. The origin is the Earth's center of mass. The Z_e-axis is in the direction of the IERS Reference Pole (IRP). The X_e-axis is the intersection of the IERS Reference Meridian (IRM) and the plane passing through the origin and normal to the Z_e-axis. The Y_e-axis completes the right-handed orthogonal axis system.
Realization epoch	Datum epoch 2005.0. Realization implementation date 16 Oct 2013.
Datum validity	Global positioning
Remarks	Previous realizations were designated WGS 84 (G1674), WGS 84 (G1150), WGS 84 (G873), WGS 84 (G730) and WGS 84.

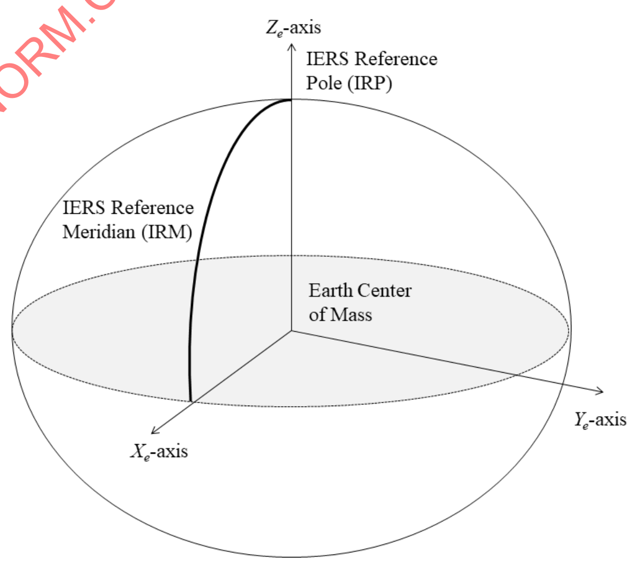


Figure 8 - WGS 84 reference frame

8.1.2 Vehicle Body Coordinate Datum

Vehicle: A vehicle is an artificial (i.e., man-made) body that can change its position through changes in its kinematic state. The term applies to both manned (inhabited) vehicles and unmanned (uninhabited) vehicles. Various kinds of vehicle are defined according to the medium through which they move and their means of propulsion.

Air vehicle: An air vehicle is any vehicle whose medium of movement is air. The term includes, but is not limited to, airplanes, airships, helicopters, gliders, and guided missiles.

Ground vehicle: A ground vehicle is any vehicle whose medium of movement is the ground surface or through the ground. The term includes, but is not limited to, wheeled vehicles, tracked vehicles, and boring vehicles.

Aquatic vehicle: An aquatic vehicle is any vehicle whose medium of movement is the water surface or through the water body. The term includes, but is not limited to, boats and ships, submersibles, torpedoes, and self-propelled mines.

Table 241 - Defining elements of vehicle body coordinate datum

DEFINING ELEMENT	DESCRIPTION
CD name	VehicleBody CD
Version	1.1
Definition URI	https://www.sae.org/AS6969/A0C787FB-F4C3-4DD2-BE6E-9294B29CBA33/1.1
CD subtype	Engineering body
Description and scope	Defines the forward (aft), right (left), and body down (body up) directions of the vehicle structure as well as the point of origin. See Figure 9.
Authoritative reference (if any)	Vehicle documentation
Anchor definition	The anchor definition is based on the fuselage reference line, which is on the symmetrical plane. The origin lies on the fuselage reference line. The forward-axis (+X) is in the direction of the fuselage reference line towards forward travel. The right-axis (+Y) passes through the origin and is normal to the symmetrical plane in the direction of right when facing forwards. The body-down axis (+Z) completes the right-handed axis system.
Realization epoch	Any
Datum validity	Vector measurements referenced to the vehicle body axis system.
Remarks	Engineering considerations will determine the fuselage reference line and the location of the origin on that line. The origin shares the same inertial state as the vehicle. The orientation of the vertical axis towards body-down ensures that a rotation about the vertical axis towards the right is properly clockwise.

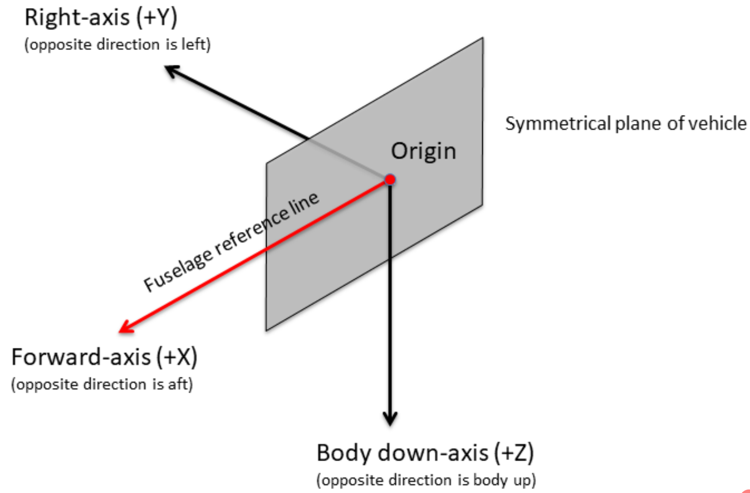


Figure 9 - Vehicle body coordinate datum

NOTE: Figures 10 through 12 show the vehicle body CD applied to an airplane, boat, and wheeled vehicle respectively.

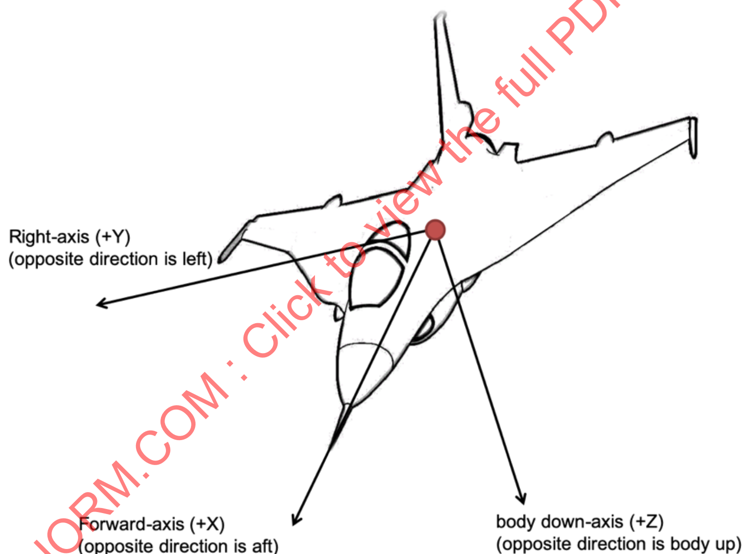


Figure 10 - Vehicle body CD applied to aircraft

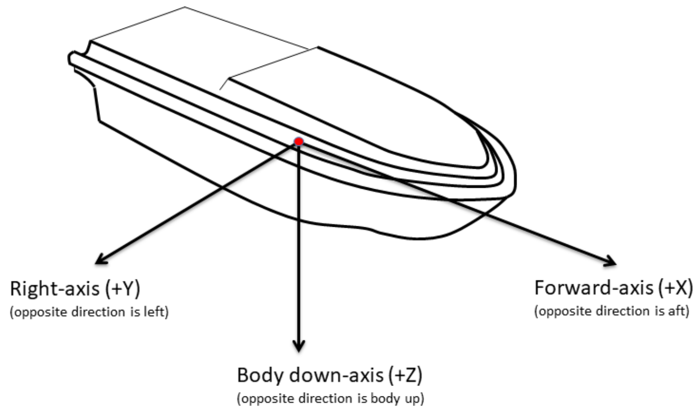


Figure 11 - Vehicle body CD applied to vessel (i.e., boat or ship)

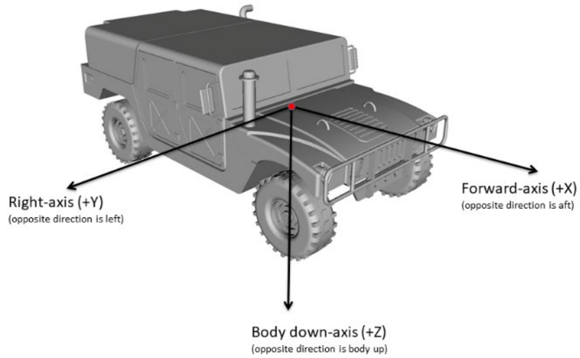


Figure 12 - Vehicle body CD applied to wheeled vehicle

8.1.3 WGS 84 (G1762) Earth-Fixed LTP Coordinate Datum

Table 242 - Defining elements of WGS 84 (G1762) earth-fixed LTP coordinate datum

DEFINING ELEMENT	DESCRIPTION
CD name	WGS84G1762EarthFixedLTP CD
Version	1.1
Definition URI	https://www.sae.org/AS6969/C532A571-F190-4FB9-BD2C-2B3E251330D1/1.1
CD subtype	Earth-fixed LTP
Description and scope	This CD is defined by the position differential of a given geodetic ellipsoidal CRS. In this case the WGS 84 (G1762) Geodetic Ellipsoidal CRS. It is used for local positioning of entities relative to an arbitrarily chosen Earth-fixed point.
Authoritative reference (if any)	The WSG 84 (G1762) Geodetic Ellipsoid is defined by NGA.STND.0036_1.0.0_WGS84.
Anchor definition	The origin is a specified earth-fixed position $\vec{r} = (\lambda_g, \varphi_g, h_g)$. The east-axis (+X) is in the direction of the unit vector $\vec{e}_\lambda$ at $\vec{r} = (\lambda_g, \varphi_g, h_g)$. The north-axis (+Y) is in the direction of the unit vector $\vec{e}_\varphi$ at $\vec{r} = (\lambda_g, \varphi_g, h_g)$. The up-axis (+Z) completes the right-handed axis system and is in the direction of the unit vector $\vec{e}_h$ at $\vec{r} = (\lambda_g, \varphi_g, h_g)$.
Realization epoch	Tied to the realization epoch of the chosen geodetic ellipsoidal CRS. In this case 2005.0, implemented on 16 October 2013.
Datum validity	Global
Remarks	

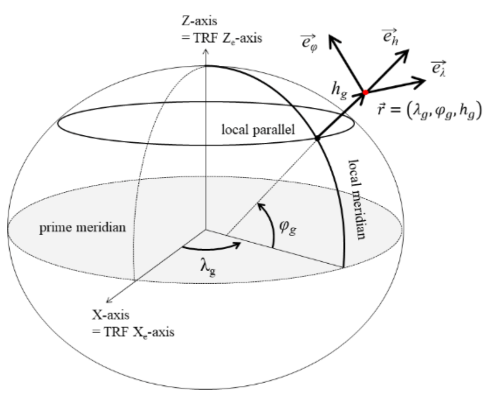


Figure 13 - Earth-fixed LTP coordinate datum

8.1.4 Earth-Fixed Vehicle Pose Coordinate Datum

Table 243 - Defining elements of earth-fixed vehicle pose coordinate datum

DEFINING ELEMENT	DESCRIPTION
CD name	EarthFixedVehiclePose CD
Version	1.0
Definition URI	https://www.sae.org/AS6969/532653ba-651d-42d1-b40d-e3efdad6a316/1.0
CD subtype	Earth-fixed local reference frame
Description and scope	Used for local positioning of entities relative to a vehicle body CD at some arbitrarily chosen Earth-fixed point and time.
Authoritative reference (if any)	Vehicle documentation
Anchor definition	The Earth-fixed local reference frame is determined by a **VehicleBody** CD at some arbitrarily chosen time t_0. For example, at the start of a mission or task. The LRF forward-axis (+X), right-axis (+Y), and body-down axis (+Z) are earth-fixed and equal to the corresponding **VehicleBody** CD axes at time t_0. The Earth-fixed position of the LRF origin is equal to the Earth position of the origin of a **VehicleBody** CD at time t_0.
Realization epoch	Determined by mission or task
Datum validity	Vector measurements over a given realization epoch referenced to the arbitrary vehicle pose when it was at the start of its mission or task
Remarks	

8.1.5 WGS 84 (G1762) Vehicle-Carried LTP (freefall) Coordinate Datum

Table 244 - Defining elements of WGS 84 (G1762) vehicle-carried (freefall) LTP coordinate datum

DEFINING ELEMENT	DESCRIPTION
CD name	WGS84G1762VehicleCarriedLTPFreefall CD
Version	1.1
Definition URI	https://www.sae.org/AS6969/F6F01027-9156-48F5-96B6-4B43B711543D/1.1
CD subtype	Vehicle-carried local reference frame
Description and scope	This CD is defined by the position differential of a given geodetic ellipsoidal CRS. In this case the WGS 84 (G1762) Geodetic Ellipsoidal CRS. It is used as a reference for modeling aerospace vehicle dynamics relative to the local tangent plane and freefall observer.
Authoritative reference (if any)	The WSG 84 (G1762) Geodetic Ellipsoid is defined by NGA.STND.0036_1.0.0_WGS84.
Anchor definition	The origin is a free-fall observer that is momentarily at rest in the experienced gravitation field at the same position as the origin of the engineering body coordinate datum at the time of interest. The east-axis (+X) is in the direction of the unit vector $\vec{e}_\lambda$ at $\vec{r} = (\lambda_g, \varphi_g, h_g)$. The north-axis (+Y) is in the direction of the unit vector $\vec{e}_\varphi$ at $\vec{r} = (\lambda_g, \varphi_g, h_g)$. The up-axis (+Z) completes the right-handed axis system and is in the direction of the unit vector $\vec{e}_h$ at $\vec{r} = (\lambda_g, \varphi_g, h_g)$.
Realization epoch	Tied to the realization epoch of the chosen geodetic ellipsoidal CRS. In this case 2005.0, implemented on 16 October 2013.
Datum validity	Global
Remarks	This CD differs from its non-freefall counterpart (WGS84G1762VehicleCarriedLTP CD) in that the origin is a freefall observer.

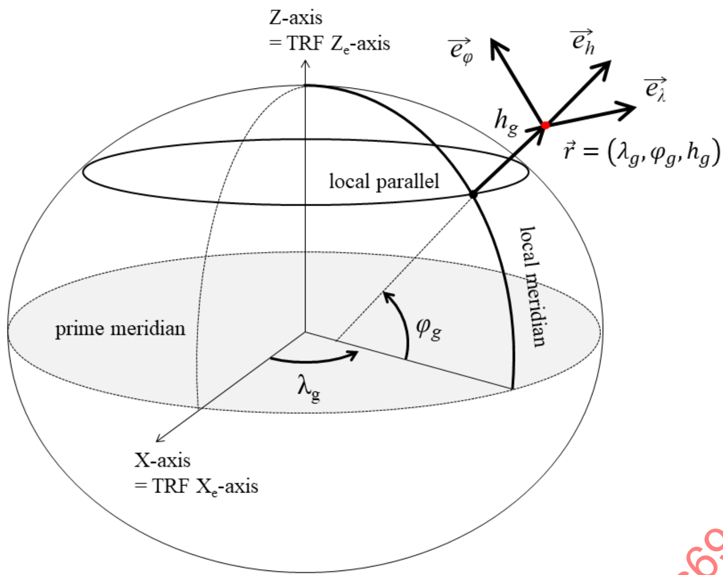


Figure 14 - Vehicle-carried LTP coordinate datum

8.1.6 WGS 84 (G1762) Vehicle-Carried LTP Coordinate Datum

Table 245 - Defining elements of WGS 84 (G1762) vehicle-carried LTP coordinate datum

DEFINING ELEMENT	DESCRIPTION
CD name	WGS84G1762VehicleCarriedLTP CD
Version	1.0
Definition URI	https://www.sae.org/AS6969/82c27814-df45-457e-a49b-764098be26bf/1.0
CD subtype	Vehicle-carried local reference frame
Description and scope	This CD is defined by the position differential of a given geodetic ellipsoidal CRS. In this case the WGS 84 (G1762) Geodetic Ellipsoidal CRS. It is used as a reference for modeling vehicle dynamics relative to the local tangent plane.
Authoritative reference (if any)	The WSG 84 (G1762) Geodetic Ellipsoid is defined by NGA.STND.0036_1.0.0_WGS84.
Anchor definition	The origin is an observer that is momentarily at rest at the same position as the origin of the engineering body coordinate datum at the time of interest. The east-axis (+X) is in the direction of the unit vector $\vec{e}_\lambda$ at $\vec{r} = (\lambda_g, \varphi_g, h_g)$. The north-axis (+Y) is in the direction of the unit vector $\vec{e}_\varphi$ at $\vec{r} = (\lambda_g, \varphi_g, h_g)$. The up-axis (+Z) completes the right-handed axis system and is in the direction of the unit vector $\vec{e}_h$ at $\vec{r} = (\lambda_g, \varphi_g, h_g)$.
Realization epoch	Tied to the realization epoch of the chosen geodetic ellipsoidal CRS. In this case 2005.0, implemented on 16 October 2013.
Datum validity	Global.
Remarks	This CD differs from its freefall counterpart (WGS84G1762VehicleCarriedLTPFreefall CD) in that the origin has zero acceleration.

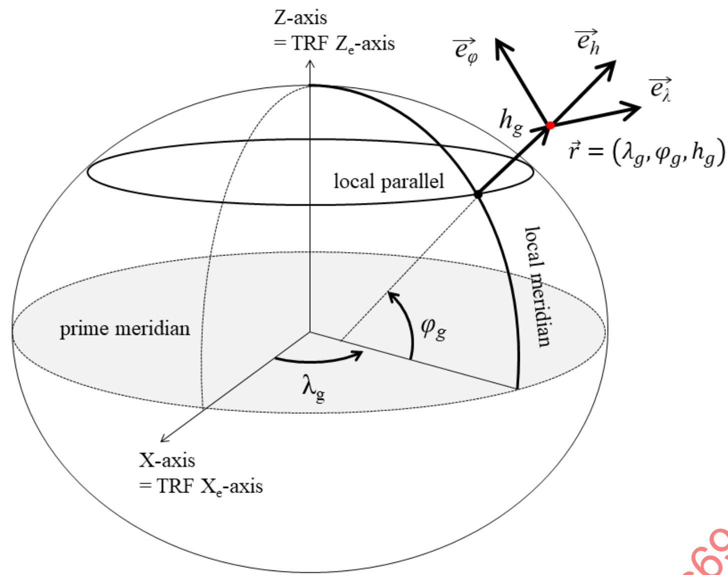


Figure 15 - Vehicle-carried LTP coordinate datum

8.1.7 Vehicle-Carried Pose Coordinate Datum

Table 246 - Defining elements of vehicle-carried pose coordinate datum

DEFINING ELEMENT	DESCRIPTION
CD name	VehicleCarriedPose CD
Version	1.0
Definition URI	https://www.sae.org/AS6969/55781bd7-7c5e-406b-ade3-2640ddcadf3b/1.0
CD subtype	Vehicle-carried local reference frame
Description and scope	Used for as a reference for modeling vehicle dynamics and target engagement relative to a vehicle pose. For example, the velocity of a vehicle relative to its own axes.
Authoritative reference (if any)	Vehicle documentation
Anchor definition	The origin is an observer that is momentarily at rest at the same position as the origin of the engineering body coordinate datum at the time of interest. The forward-axis (+X), right-axis (+Y), and body-down axis (+Z) equal to the corresponding **VehicleBody** CD axes at the time of interest.
Realization epoch	Any
Datum validity	Vector measurements referenced to the vehicle pose at the time of interest
Remarks	This local reference frame is not intended to vehicles in flight.

8.2 Coordinate Systems

The attributes of a coordinate system are enumerated in Table 247.

Table 247 - Defining elements of a coordinate system

DEFINING ELEMENT	DESCRIPTION
Basic Attributes	
CS name/identifier	Unique name/identifier of CS
Version	Version number of table
Definition URI	Namespace and universally unique identifier. UUID conformant to RFC4122 standard.
Description	Provide figure reference.
Remarks	Other information concerning the CS
Quantity Vector	
Quantity tuple	The ordered list of coordinates
Quantity coordinates	Identification of each coordinate in quantity tuple
Quantity components	Component equation for quantity vector
Unit vectors of position differential	
Position vector differential	
Position Vector and Time Derivatives (Extensible)	
Position tuple	
Position coordinates	
Position components	
Unit vectors of position differential	
Position vector differential	

8.2.1 Cartesian

Table 248 - Defining elements of a Cartesian coordinate system

DEFINING ELEMENT	DESCRIPTION
Basic Attributes:	
CS name	Cartesian CS
Version	1.1
Definition URI	https://www.sae.org/AS6969/BE5DE424-4DB3-4189-9C69-30ABD37364AD/1.1
Description	See Figure 16
Remarks	
Quantity Vector	
Quantity tuple	$\vec{q} = (q_x, q_y, q_z)$
Quantity coordinates	q_x is Cartesian component in direction of x-*axis* q_y is Cartesian component in direction of y-*axis* q_z is Cartesian component in direction of z-*axis*
Quantity components	$\vec{q} = q_x\vec{e}_x + q_y\vec{e}_y + q_z\vec{e}_z$
Unit vectors of quantity differential	$\vec{e}_x, \vec{e}_y, \vec{e}_z$
Quantity vector differential	$d\vec{q} = dq_x\vec{e}_x + dq_y\vec{e}_y + dq_z\vec{e}_z$
Position Vector and Time Derivatives	
Position tuple	$\vec{r} = (x, y, z)$
Position coordinates	x is Cartesian component in direction of x-*axis* y is Cartesian component in direction of y-*axis* z is Cartesian component in direction of z-*axis*
Position components	$\vec{r} = x\vec{e}_x + y\vec{e}_y + z\vec{e}_z$
Unit vectors of position differential	$\vec{e}_x, \vec{e}_y, \vec{e}_z$
Position vector differential	$d\vec{r} = dx\vec{e}_x + dy\vec{e}_y + dz\vec{e}_z$
Velocity tuple	$\vec{v} = (v_x, v_y, v_z)$
Velocity equation	$v_x = \frac{dx}{dt}, v_y = \frac{dy}{dt}, v_z = \frac{dz}{dt}$
Velocity vector	$\vec{v} = v_x\,\vec{e}_x + v_y\,\vec{e}_y + v_z\,\vec{e}_z$
Acceleration tuple	$\vec{a} = (a_x, a_y, a_z)$
Acceleration equation	$a_x = \frac{dv_x}{dt}, a_y = \frac{dv_y}{dt}, a_z = \frac{dv_z}{dt}$
Acceleration vector	$\vec{a} = a_x\,\vec{e}_x + a_y\,\vec{e}_y + a_z\,\vec{e}_z$

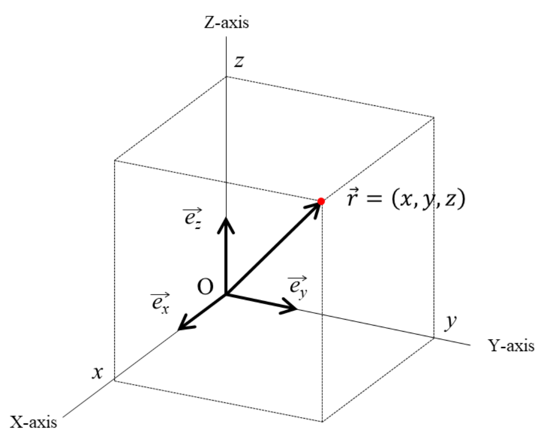


Figure 16 - Cartesian coordinate system (Euclidean space)

8.2.2 2D Cartesian

Table 249 - Defining elements of a 2D Cartesian coordinate system

DEFINING ELEMENT	DESCRIPTION
Basic Attributes:	
CS name	2DCartesian CS
Version	1.1
Definition URI	https://www.sae.org/AS6969/5C5F70D6-33B2-4E65-9BC1-11142A9C1501/1.1
Description	See Figure 17
Remarks	
Quantity Vector	
Quantity tuple	$\vec{q} = (q_x, q_y)$
Quantity coordinates	q_x is Cartesian component in direction of x-*axis* q_y is Cartesian component in direction of y-*axis*
Quantity components	$\vec{q} = q_x\vec{e}_x + q_y\vec{e}_y$
Unit vectors of quantity differential	$\vec{e}_x, \vec{e}_y$
Quantity vector differential	$d\vec{q} = dq_x\vec{e}_x + dq_y\vec{e}_y$
Position Vector and Time Derivatives	
Position tuple	$\vec{r} = (x, y)$
Position coordinates	x is Cartesian component in direction of x-*axis* y is Cartesian component in direction of y-*axis*
Position components	$\vec{r} = x\vec{e}_x + y\vec{e}_y$
Unit vectors of position differential	$\vec{e}_x, \vec{e}_y$
Position vector differential	$d\vec{r} = dx\vec{e}_x + dy\vec{e}_y$
Velocity tuple	$\vec{v} = (v_x, v_y)$
Velocity equation	$v_x = \frac{dx}{dt}, v_y = \frac{dy}{dt}$
Velocity vector	$\vec{v} = v_x\,\vec{e}_x + v_y\,\vec{e}_y$
Acceleration tuple	$\vec{a} = (a_x, a_y)$
Acceleration equation	$a_x = \frac{dv_x}{dt}, a_y = \frac{dv_y}{dt}$
Acceleration vector	$\vec{a} = a_x\,\vec{e}_x + a_y\,\vec{e}_y$

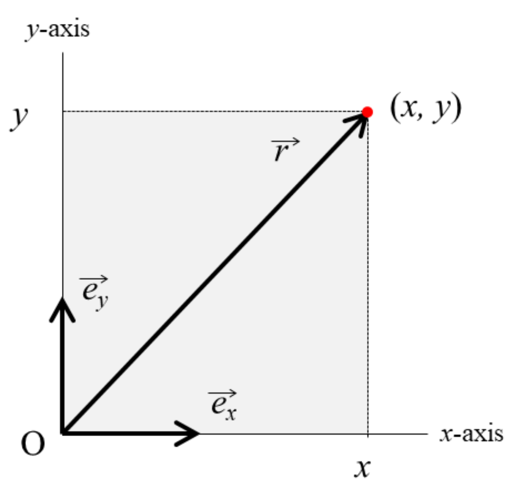


Figure 17 - 2DCartesian coordinate system (Euclidean space)

8.2.3 1D Cartesian

Table 250 - Defining elements of a 1D Cartesian coordinate system

DEFINING ELEMENT	DESCRIPTION
Basic Attributes:	
CS name	1DCartesian CS
Version	1.1
Definition URI	https://www.sae.org/AS6969/F70485B0-D176-4396-999F-D9913724A845/1.1
Description	See Figure 18
Remarks	
Quantity Vector	
Quantity tuple	$\vec{q} = (q_x)$
Quantity coordinates	q_x is Cartesian component in direction of x-*axis*
Quantity components	$\vec{q} = q_x \vec{e}_x$
Unit vectors of quantity differential	$\vec{e}_x$
Quantity vector differential	$d\vec{q} = dq_x \vec{e}_x$
Position Vector and Time Derivatives	
Position tuple	$\vec{r} = (x)$
Position coordinates	x is Cartesian component in direction of x-*axis*
Position components	$\vec{r} = x\vec{e}_x$
Unit vectors of position differential	$\vec{e}_x$
Position vector differential	$d\vec{r} = dx\vec{e}_x$
Velocity tuple	$\vec{v} = (v_x)$
Velocity equation	$v_x = \frac{dx}{dt}$
Velocity vector	$\vec{v} = v_x \vec{e}_x$
Acceleration tuple	$\vec{a} = (a_x)$
Acceleration equation	$a_x = \frac{dv_x}{dt}$
Acceleration vector	$\vec{a} = a_x \vec{e}_x$

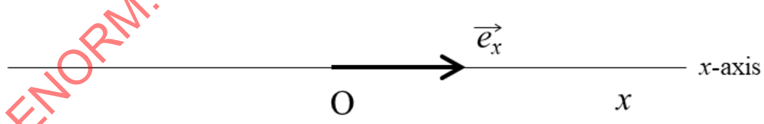


Figure 18 - 1DCartesian coordinate system (Euclidean space)

8.2.4 Cylindrical

Table 251 - Defining elements of a cylindrical coordinate system

DEFINING ELEMENT	DESCRIPTION
Basic Attributes	
CS name	Cylindrical CS
Version	1.1
Description	See Figure 19
Definition URI	https://www.sae.org/AS6969/A18FD8E4-90E7-40E3-8F06-5BD616C9E8B8/1.1
Remarks	
Quantity Vector	
Quantity tuple	$\vec{q} = (q_\rho, \lambda, q_z)$
Quantity coordinates	q_ρ is the magnitude perpendicular to the z-axis λ plane angle of rotation about z-axis q_z is Cartesian component in direction of z-axis
Quantity components	$\vec{q} = q_\rho \vec{e}_\rho + q_z \vec{e}_z$
Unit vectors of position differential	$\vec{e}_\rho, \vec{e}_\lambda, \vec{e}_z$
Position vector differential	$d\vec{q} = dq_\rho \vec{e}_\rho + q_\rho \, d\lambda \, \vec{e}_\lambda + dq_z \, \vec{e}_z$
Position Vector and Time Derivatives	
Position tuple	$\vec{r} = (\rho, \lambda, z)$
Position coordinates	ρ is radius of cylinder λ plane angle of rotation about z-axis z is Cartesian component of length of vector r in direction of z-axis
Position components	$\vec{r} = \rho \vec{e}_\rho + z \vec{e}_z$
Unit vectors of position differential	$\vec{e}_\rho, \vec{e}_\lambda, \vec{e}_z$
Position vector differential	$d\vec{r} = d\rho \, \vec{e}_\rho + \rho \, d\lambda \, \vec{e}_\lambda + dz \, \vec{e}_z$
Velocity tuple	$\vec{v} = (v_\rho, v_\lambda, v_z)$
Velocity vector	$\vec{v} = v_p \vec{e}_\rho + v_\lambda \, \vec{e}_\lambda + v_z \vec{e}_z$
Velocity quantity equation	$v_\rho = \frac{d\rho}{dt}, v_\lambda = \rho \, \frac{d\lambda}{dt}, v_z = \frac{dz}{dt}$
Acceleration tuple	$\vec{a} = (a_\rho, a_\lambda, a_z)$
Acceleration vector	$\vec{a} = a_\rho \, \vec{e}_\rho + a_\lambda \, \vec{e}_\lambda + a_z \vec{e}_z$
Acceleration quantity equation	$a_\rho = \frac{dv_\rho}{dt}, a_y = \frac{dv_\lambda}{dt}, a_z = \frac{dv_z}{dt}$
Angular velocity	ω_λ
Angular velocity equation	$\omega_\lambda = \frac{d\lambda}{dt}$
Angular acceleration	α_λ
Angular acceleration equation	$\alpha_\lambda = \frac{\omega_\lambda}{dt}$

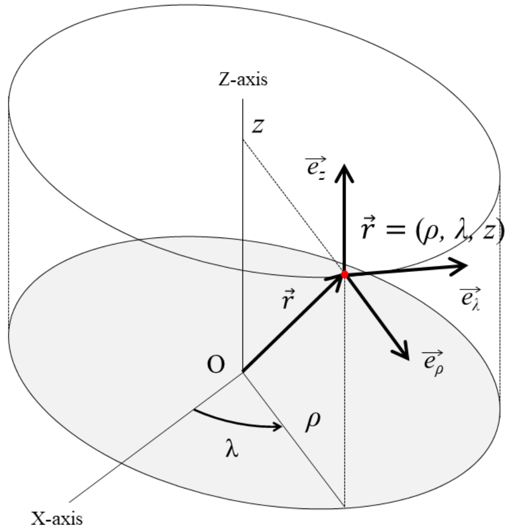


Figure 19 - Cylindrical coordinate system (Euclidean space)

8.2.5 Polar

The polar CS is a two-dimensional projection of the cylindrical coordinate system.

Table 252 - Defining elements of a polar coordinate system

DEFINING ELEMENT	DESCRIPTION
Basic Attributes	
CS name	Polar CS
Version	1.1
Definition URI	https://www.sae.org/AS6969/464DABC1-D6C8-4EF3-8950-8903FBB699D3/1.1
Description	See Figure 20
Remarks	A cylindrical CS in which the coordinate z is not specified or has no meaning.
Quantity Vector	
Quantity tuple	$\vec{q} = (q_\rho, \lambda)$
Quantity coordinates	q_ρ is magnitude in direction of radius ρ λ plane angle of rotation about axis
Quantity components	$\vec{q} = q_\rho \vec{e}_\rho$
Unit vectors of quantity differential	$\vec{e}_\rho, \vec{e}_\lambda$
Quantity vector differential	$d\vec{q} = dq_\rho\, \vec{e}_\rho + q_\rho\, d\lambda\, \vec{e}_\lambda$
Position Vector and Time Derivatives	
Position tuple	$\vec{r} = (\rho, \lambda)$
Position quantities	ρ is radius of circle λ plane angle of rotation about axis
Position vector	$\vec{r} = \rho \vec{e}_\rho$
Unit vectors of position differential	$\vec{e}_\rho, \vec{e}_\lambda$
Position vector differential	$d\vec{r} = d\rho\, \vec{e}_\rho + \rho\, d\lambda\, \vec{e}_\lambda$
Velocity tuple	$\vec{v} = (v_\rho, v_\lambda)$
Velocity vector	$\vec{v} = v_\rho \vec{e}_\rho + v_\lambda\, \vec{e}_\lambda$
Velocity quantity equations	$v_\rho = \frac{d\rho}{dt}, v_\lambda = \rho\, \frac{d\lambda}{dt}$

Acceleration tuple	$\vec{a} = (a_\rho, a_\lambda)$
Acceleration vector	$\vec{a} = a_\rho\, \vec{e}_\rho + a_\lambda\, \vec{e}_\lambda$
Acceleration quantity equations	$a_\rho = \frac{dv_\rho}{dt}, a_y = \frac{dv_\lambda}{dt}$
Angular velocity	ω_λ
Angular velocity equation	$\omega_\lambda = \frac{d\lambda}{dt}$
Angular acceleration	α_λ
Angular acceleration equation	$\alpha_\lambda = \frac{\omega_\lambda}{dt}$

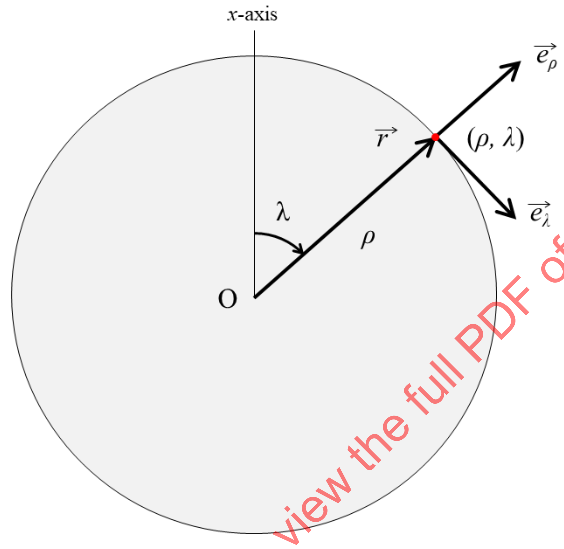


Figure 20 - Polar coordinate system (Euclidean space)

8.2.6 Spherical

Table 253 - Defining elements of a spherical coordinate system

DEFINING ELEMENT	DESCRIPTION
Basic Attributes	
CS name	Spherical CS
Version	1.1
Definition URI	https://www.sae.org/AS6969/D16F25B6-DF85-4B61-863F-B08A02FEB804/1.1
Description	See Figure 21
Remarks	
Quantity Vector	
Quantity tuple	$\vec{q} = (q, \vartheta, \lambda)$
Quantity coordinates	q is magnitude (in direction of q) ϑ is plane angle of deflection from z-axis λ plane angle of rotation about z-axis
Quantity components	$\vec{q} = q\vec{e}_q$
Unit vectors of position differential	$\vec{e}_q, \vec{e}_\vartheta, \vec{e}_\lambda$
Position vector differential	$d\vec{q} = dq\, \vec{e}_q + q\, d\vartheta\, \vec{e}_\vartheta + q\, \sin\vartheta\, d\lambda\, \vec{e}_\lambda$

Position Vector and Time Derivatives	
Position tuple	$\vec{r} = (r, \vartheta, \lambda)$
Position coordinates	r is radius of sphere ϑ is plane angle of deflection from z-axis λ plane angle of rotation about z-axis
Position components	$\vec{r} = r\vec{e}_r$
Unit vectors of position differential	$\vec{e}_r, \vec{e}_\vartheta, \vec{e}_\lambda$
Position vector differential	$d\vec{r} = dr\ \vec{e}_r + r\ d\vartheta\ \vec{e}_\vartheta + r\ \sin\vartheta\ d\lambda\ \vec{e}_\lambda$
Velocity tuple	$\vec{v} = (v_r, v_\vartheta, v_\lambda)$
Velocity vector	$\vec{v} = v_r\vec{e}_r + v_\vartheta\ \vec{e}_\vartheta + v_\lambda\ \vec{e}_\lambda$
Velocity quantity equation	$v_r = \frac{dr}{dt}, v_\vartheta = r\ \frac{d\vartheta}{dt}, v_\lambda = r\ \sin\vartheta\ \frac{d\lambda}{dt}$
Acceleration tuple	$\vec{a} = (a_r, a_\vartheta, a_\lambda)$
Acceleration vector	$\vec{a} = a_r\ \vec{e}_r + a_\vartheta\ \vec{e}_\vartheta + a_\lambda\ \vec{e}_\lambda$
Acceleration quantity equations	$a_r = \frac{dv_r}{dt}\ a_\vartheta = \frac{dv_\vartheta}{dt}, a_y = \frac{dv_\lambda}{dt}$
Angular velocities	$\omega_\lambda, \omega_\vartheta$
Angular velocity equations	$\omega_\lambda = \frac{d\lambda}{dt}, \omega_\vartheta = \frac{d\vartheta}{dt}$
Angular accelerations	$\alpha_\lambda, a_\vartheta$
Angular acceleration equations	$\alpha_\lambda = \frac{\omega_\lambda}{dt}, a_\vartheta = \frac{w_\vartheta}{dt}$

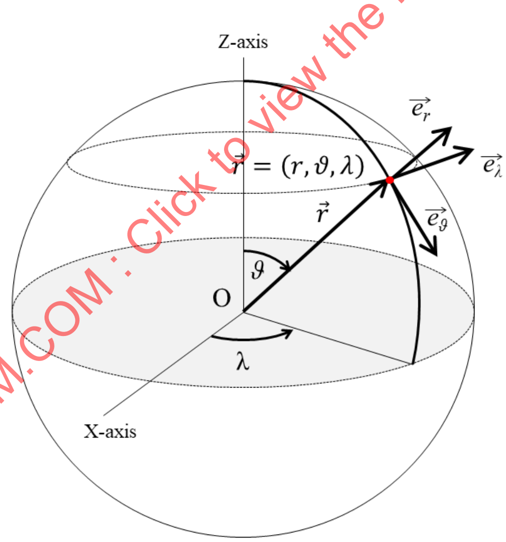


Figure 21 - Spherical coordinate system (Euclidean space)

8.2.7 2D Spherical

Table 254 - Defining elements of a 2D spherical coordinate system

DEFINING ELEMENT	DESCRIPTION
Basic Attributes	
CS name	2DSpherical CS
Version	1.1
Definition URI	https://www.sae.org/AS6969/903BAAA0-D71A-488E-92D4-72A256F99F71/1.1
Description	See Figure 22
Remarks	Spherical CS in which the quantity magnitude is not specified - only its direction. Consequently, there is not a complete specification of the position vector or its differential.
Quantity Vector	
Quantity tuple	(ϑ, λ)
Quantity coordinates	ϑ is plane angle of deflection from z-axis λ plane angle of rotation about z-axis
Quantity components	none
Unit vectors of position differential	none
Position vector differential	none
Position Vector and Time Derivatives	
Position tuple	(ϑ, λ)
Position coordinates	ϑ is plane angle of deflection from z-axis λ plane angle of rotation about z-axis
Position components	none
Unit vectors of position differential	none
Position vector differential	none
Angular velocities	$\omega_\lambda, \omega_\vartheta$
Angular velocity equations	$\omega_\lambda = \frac{d\lambda}{dt}, \omega_\vartheta = \frac{d\vartheta}{dt}$
Angular accelerations	$\alpha_\lambda, a_\vartheta$
Angular acceleration equations	$\alpha_\lambda = \frac{\omega_\lambda}{dt}, a_\vartheta = \frac{w_\vartheta}{dt}$

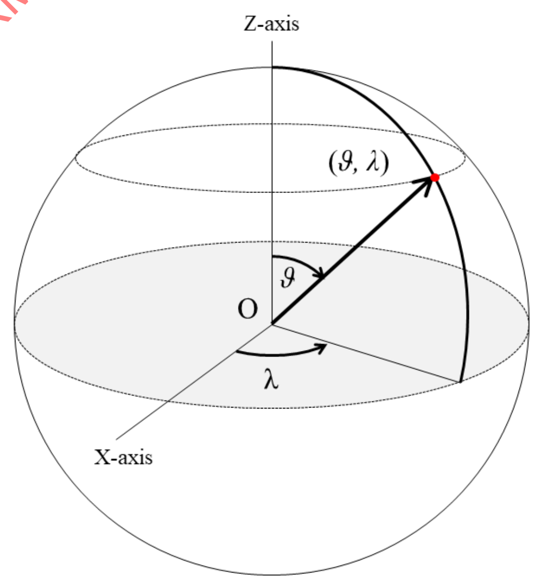


Figure 22 - 2DSpherical coordinate system (Euclidean space)

8.2.8 Spherical (RAE)

Table 255 - Defining elements of spherical (RAE) coordinate system

DEFINING ELEMENT	DESCRIPTION
Basic Attributes	
CS name	SphericalRAE CS
Version	1.1
Definition URI	https://www.sae.org/AS6969/13BB380F-BB23-4E67-A5BA-48B370A0EB35/1.1
Description	See Figure 23
Remarks	
Quantity Vector	
Quantity tuple	$\vec{q} = (q, \lambda, \varphi)$
Quantity coordinates	q is magnitude (in direction of q) λ is azimuth (plane angle) φ is elevation (plane angle)
Quantity components	$\vec{q} = q\vec{e}_q$
Unit vectors of quantity differential	$\vec{e}_q, \vec{e}_\lambda, \vec{e}_\varphi$
Quantity vector differential	$d\vec{q} = dq\ \vec{e}_r + q\ \cos\ \varphi\ d\lambda\ \vec{e}_\lambda + q\ d\varphi\ \vec{e}_\varphi$
Position Vector and Time Derivatives	
Position tuple	$\vec{r} = (r, \lambda, \varphi)$
Position coordinates	r is range (length of position vector) λ is azimuth (plane angle) φ is elevation (plane angle)
Position components	$\vec{r} = r\vec{e}_r$
Unit vectors of position differential	$\vec{e}_r, \vec{e}_\lambda, \vec{e}_\varphi$
Position vector differential	$d\vec{r} = dr\ \vec{e}_r + r\ \cos\ \varphi\ d\lambda\ \vec{e}_\lambda + r\ d\varphi\ \vec{e}_\varphi$
Velocity tuple	$\vec{v} = (v_r, v_\lambda, v_\varphi)$
Velocity vector	$\vec{v} = v_r\vec{e}_r + v_\lambda\ \vec{e}_\lambda + v_\varphi\ \vec{e}_\varphi$
Velocity quantity equation	$v_r = \frac{dr}{dt}, v_\lambda = r\ \cos\vartheta\ \frac{d\lambda}{dt}, v_\vartheta = r\ \frac{d\varphi}{dt},$
Acceleration tuple	$\vec{a} = (a_r, a_\lambda, a_\varphi)$
Acceleration vector	$\vec{a} = a_r\ \vec{e}_r + a_\lambda\ \vec{e}_\lambda + a_\varphi\ \vec{e}_\varphi$
Acceleration quantity equation	$a_r = \frac{dv_r}{dt}, a_y = \frac{dv_\lambda}{dt}, a_\varphi = \frac{dv_\vartheta}{dt},$
Angular velocities	$\omega_\lambda, \omega_\varphi$
Angular velocity equations	$\omega_\lambda = \frac{d\lambda}{dt}, \omega_\varphi = \frac{d\varphi}{dt}$
Angular accelerations	$\alpha_\lambda, a_\varphi$
Angular acceleration equations	$\alpha_\lambda = \frac{\omega_\lambda}{dt}, a_\varphi = \frac{w_\varphi}{dt}$

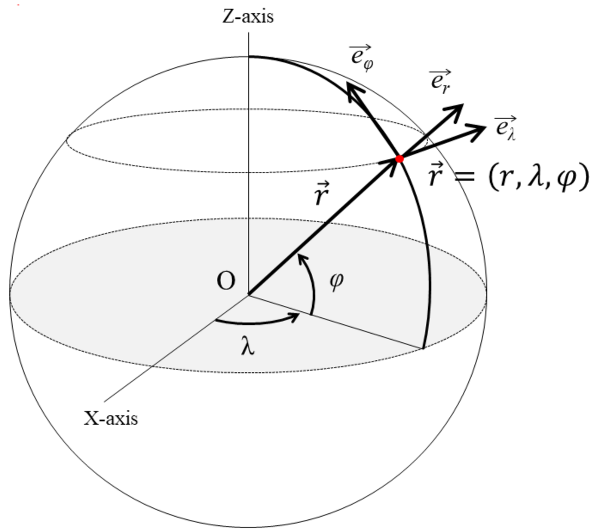


Figure 23 - SphericalRAE coordinate system (Euclidean space)

8.2.9 2D Spherical (RAE)

Table 256 - Defining elements of 2D spherical (RAE) coordinate system

DEFINING ELEMENT	DESCRIPTION
Basic Attributes	
CS name	2DSphericalRAE CS
Version	1.1
atAS6969 UUID	https://www.sae.org/AS6969/6710E6EC-9396-42D5-A746-AADFDFE6BBE9/1.1
Description	See Figure 24
Remarks	Spherical (RAE) CS in which magnitude is not specified - only direction. Consequently, there is not a complete specification of the quantity vector or its differential.
Quantity Vector	
Quantity tuple	$\vec{r} = (\lambda, \varphi)$
Quantity coordinates	λ is azimuth (plane angle) φ is elevation (plane angle)
Quantity components	none
Unit vectors of quantity differential	none
Quantity vector differential	none
Position Vector and Time Derivatives	
Position tuple	$\vec{r} = (\lambda, \varphi)$
Position coordinates	λ is azimuth (plane angle) φ is elevation (plane angle)
Position components	none
Unit vectors of position differential	none
Position vector differential	none
Angular velocities	$\omega_\lambda, \omega_\varphi$
Angular velocity equations	$\omega_\lambda = \frac{d\lambda}{dt}, \omega_\varphi = \frac{d\varphi}{dt}$
Angular accelerations	$\alpha_\lambda, a_\varphi$
Angular acceleration equations	$\alpha_\lambda = \frac{\omega_\lambda}{dt}, a_\varphi = \frac{w_\varphi}{dt}$

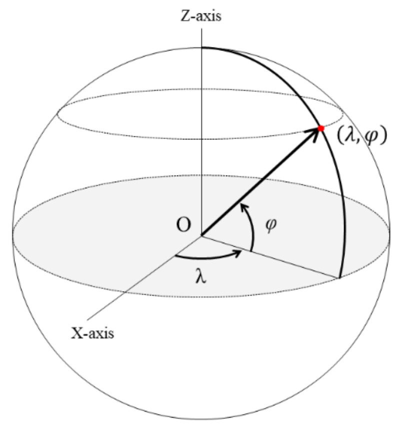


Figure 24 - 2DSphericalRAE coordinate system (Euclidean space)

8.2.10 WGS 84 Ellipsoidal

Table 257 - Defining elements of WGS 84 ellipsoidal coordinate system

DEFINING ELEMENT	DESCRIPTION
Basic Attributes	
CS name	WGS84Ellipsoidal CS
Version	1.1
Definition URI	https://www.sae.org/AS6969/7EC8B9B4-7DB2-4197-A5BC-33814C3C9DD5/1.1
Description	See Figure 25
Remarks	See note. a_e = 6,378,137.0 meters $1/f_e$ = 298.257223563, leading to e_e= 0.018181919
Quantity Vector	
Not used for general quantities	
Position Vector and Time Derivatives	
Position tuple	$\vec{r} = (\lambda, \varphi, h)$
Position quantities	λ is longitude φ is ellipsoidal latitude h is ellipsoidal height
Position vector	$\vec{r} = \ h\vec{e}_h$
Unit vectors of position differential	$\vec{e}_\lambda, \vec{e}_\varphi, \vec{e}_h$
Position vector differential	$d\vec{h} = (\rho + h)\cos\ \varphi\ d\lambda\ \vec{e}_\lambda + (\varrho + h)\ d\varphi\ \vec{e}_\varphi + dh\ \vec{e}_h$ The radius of curvature ρ of the local parallel at ellipsoidal latitude φ is given by: $\rho = \frac{a_e}{\sqrt{1 - e_e^2 \sin^2\varphi}}$ The radius of curvature ϱ of the local meridian at ellipsoidal latitude φ is given by: $\varrho = \frac{a_e(1 - e_e^2)}{(1 - e_e^2 \sin^2\varphi)^{3/2}}$
Velocity tuple	$\vec{v} = (v_\lambda,\ v_\varphi,\ v_h)$
Velocity vector	$\vec{v} = \ v_\lambda\ \vec{e}_\lambda + v_\varphi\ \vec{e}_\varphi + v_h\ \vec{e}_h$
Velocity quantity equations	$v_\lambda = (\rho + h)\cos\varphi\frac{d\lambda}{dt},\ v_\varphi = (\varrho + h)\frac{d\varphi}{dt},\ v_h = \frac{dh}{dt}$
Acceleration tuple	$\vec{a} = (a_\lambda,\ a_\varphi,\ a_h)$
Acceleration vector	$\vec{a} = \ a_\lambda\ \vec{e}_\lambda + a_\varphi\ \vec{e}_\varphi + a_h\ \vec{e}_h$
Acceleration quantity equations	$a_\lambda = \frac{dv_\lambda}{dt},\ a_\varphi = \frac{dv_\varphi}{dt},\ a_h = \frac{dv_h}{dt}$

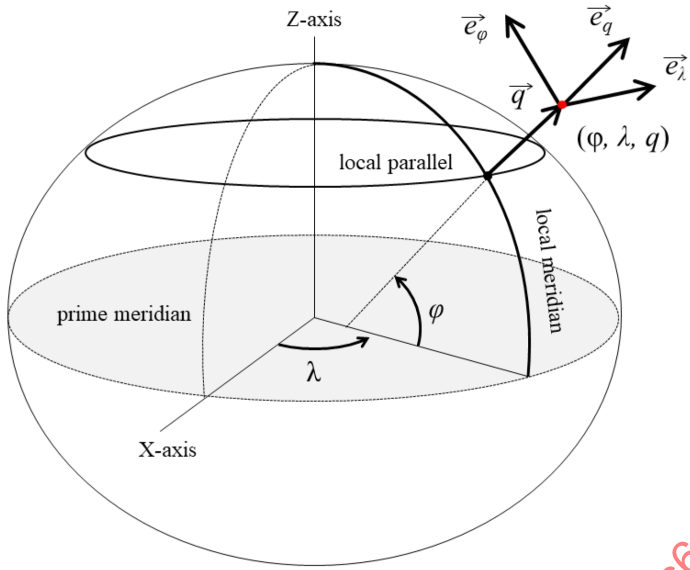


Figure 25 - WGS84 Ellipsoidal coordinate system (Euclidean space)

NOTE: Defines the coordinate system for geodetic longitude and latitude, and ellipsoidal height. The authoritative reference is National Geospatial-Intelligence Agency (NGA): NGA.STND.0036_1.0.0_WGS84.

NOTE: The WGS 84 Ellipsoidal CS does not depend on the realization of the WGS 84 reference frame.

8.2.11 WGS 84 Ellipsoidal Height

Table 258 - Defining elements of WGS 84 ellipsoidal height coordinate system

DEFINING ELEMENT	DESCRIPTION
Basic Attributes	
CS name	WGS84EllipsoidalHeight CS
Version	1.1
Definition URI	https://www.sae.org/AS66969/73977A67-4AB5-4C40-A016-B32EA728B438/1.1
Description	See Figure 25
Remarks	Ellipsoidal height coordinate of WGS 84 Ellipsoidal CS
Quantity Vector	
Not used for general quantities	
Position Vector and Time Derivatives	
Position tuple	(h)
Position coordinates	h is ellipsoidal height
Position components	None
Unit vectors of position differential	None
Position vector differential	None

8.2.12 WGS 84 2D Ellipsoidal

Table 259 - Defining elements of WGS 84 2D ellipsoidal coordinate system

DEFINING ELEMENT	DESCRIPTION
Basic Attributes	
CS name	WGS842DEllipsoidal CS
Version	1.1
Definition URI	https://www.sae.org/AS6969/C46AED15-1ECE-4FD0-90DD-EC62FD5D9248/1.1
Description	See Figure 25
Remarks	WGS 84 Ellipsoidal CS minus ellipsoidal height
Quantity Vector	
Not used for general quantities	
Position Vector and Time Derivatives	
Position tuple	(λ, φ)
Position coordinates	λ is longitude φ is ellipsoidal latitude
Position components	None
Unit vectors of position differential	None
Position vector differential	None

8.3 Coordinate Reference Systems

A given coordinate tuple must reference one (and only one) coordinate reference system (CRS). A single CRS is a single coordinate system (CS) that is related to a spatial object by a single coordinate datum (CD). A compound CRS is a CRS comprising multiple single CRS where each has a unique coordinate datum within the compound CRS.

The attributes of a single coordinate reference system are enumerated in Table 254. The CRS subtype may be from the following extensible list:

a. Anchored to terrestrial reference frame:

    1. Earth-centered, earth-fixed (ECEF)

    2. Geodetic ellipsoid

    3. Geoid

    4. Map projection

b. Anchored to earth-fixed local reference frame (LRF):

    1. Earth-fixed local tangent plane (LTP)

    2. Earth-fixed vehicle pose

c. Anchored to vehicle-carried LRF:

    1. Vehicle-carried LTP (freefall)

    2. Vehicle-carried LTP

    3. Vehicle-carried pose

d. Anchored to engineering body

1. Vehicle body

For each subtype, this data dictionary provides the base CRS and its commonly used derivations. See Table 260, which identifies the single CRS defined herein. The base CRS are identified in bold text.

NOTE: This data dictionary can be extended by a quantity domain. The quantity domain may add additional, CD, CS, and CRS.

NOTE: This data dictionary is not concerned with the components of a data type, which can combine multiple quantities and CRS defined herein for the purposes of a data model.

Table 260 - Common CRS defined

CRS SUBTYPE	CD	CS	CRS	TABLE
ECEF	WGS84G1762	Cartesian	**ECEFCartesian**	274
Geodetic ellipsoid		WGS84Ellipsoidal	**WGS84G1762Ellipsoid**	263
		WGS842DEllipsoidal	WGS84G17622DEllipsoid	264
		WGS84EllipsoidalHeight	WGS84G1762EllipsoidalHeight	265
Geoid			**WGS84EGM2008OrthometricHeight**	266
Earth-fixed LTP	WGS84G1762EarthFixedLTP datum at (λ, φ, h)	Cartesian	**EarthFixedNED**	268
			EarthFixedENU	269
		Cylindrical	EarthFixedCylindrical	272
		SphericalRAE	EarthFixedSphericalRAE	273
Earth-fixed vehicle pose	EarthFixedVehiclePose	Cartesian	**EarthFixedFRD**	270
			EarthFixedFLU	271
Vehicle body	VehicleBody	Cartesian	**VehicleBodyFRD**	275
			VehicleBodyFLU	276
		Spherical	VehicleBodySpherical	277
		SphericalRAE	VehicleBodySphericalRAE	278
Vehicle-carried LTP (freefall)	WGS84G1762VehicleCarriedLTPFlight datum at (λ, φ, h)	Cartesian	**VehicleCarriedNEDFreefall**	279
			VehicleCarriedENUFreefall	280
		Cylindrical	VehicleCarriedCylindricalNEDFreefall	281
		SphericalRAE	VehicleCarriedSphericalRAENEDFreefall	282
Vehicle-carried LTP (non-freefall)	WGS84G1762VehicleCarriedLTPNonFlight datum at (λ, φ, h)	Cartesian	**VehicleCarriedNED**	283
			VehicleCarriedENU	284
		Cylindrical	VehicleCarriedCylindricalNED	285
		SphericalRAE	VehicleCarriedSphericalRAENED	286
Vehicle-carried pose	VehicleCarriedPose	Cartesian	VehicleCarriedFRDNonFlight	287

Currently, one compound CRS is defined, the WGS 84 (EGM2008) geoid. This combines the WGS 84 (G1762) 2D ellipsoidal CRS with the WGS 84 (EGM2008) orthometric height CRS.

NOTE: This data dictionary is not concerned with the components of a data type, which can combine multiple quantities and CRS defined herein for the purposes of a data model.

Table 261 - Defining elements of single coordinate reference system

DEFINING ELEMENT	DESCRIPTION
Basic Attributes	
CRS name	Unique name/identifier of CRS
Version	Version number of table
Definition URI	Namespace and universally unique identifier. UUID conformant to RFC4122 standard.
CRS subtype	CRS subtypes from the extensible list above
CRS derivation (if any)	Unique name/identifier of base CRS from which CRS is derived. Otherwise note the CRS is a base CRS.
CRS scope	Description of usage or limitations of usage for which CRS is valid.
CRS validity	Area, region or time frame in which the CRS is valid
Associated CS	The name and definition URI of CS used by CRS
Associated CD	The name and definition URI of CD used by CRS
CS axis mapping to CD	Associate each CS axis with a CD axis (or its reverse direction).
Associated CO	The names and definition URIs of any associated COs for which the CRS is a source or target.
Quantity Vector	
CRS quantity tuple	Quantity coordinates in CRS and tuple order
Quantity mapping to CS	CRS coordinate to CS coordinate equivalence
Quantity coordinate names	Coordinate name used in data model
(additional attributes as required)	
Position Vector	
CRS position tuple	Position coordinates in CRS and tuple order
Position mapping to CS	CRS coordinate to CS coordinate equivalence
Position coordinate names	Coordinate name used in data model
(additional attributes as required)	
Statistical Quantities	
(additional attributes as required)	
Remarks	Other information concerning the CRS

The attributes of a compound coordinate reference system are enumerated in Table 262. For a compound CRS, there must be a unique direction label for each coordinate.

Table 262 - Defining elements of compound coordinate reference system

DEFINING ELEMENT	DESCRIPTION
CRS name	Unique name/identifier of CRS
Version	Version number of table.
Definition URI	Namespace and Universally Unique Identifier. UUID conformant to RFC4122 standard.
CRS subtype	Compound CRS
CRS scope	Description of usage or limitations of usage for which CRS is valid.
CRS validity	Area, region or time frame in which the CRS is valid
Component CRS	The unique name and definition URI of each CRS from which the compound CRS is composed.
Coordinate tuple	Order of coordinates in CRS
Remarks	Other information concerning the CRS

8.3.1 WGS 84 (G1762) Ellipsoid Coordinate Reference System

Table 263 - Defining elements of WGS 84 (G1762) ellipsoid coordinate reference system

DEFINING ELEMENT	DESCRIPTION
Basic Attributes	
CRS name	**WGS84G1762Ellipsoid** CRS
Version	1.1
Definition URI	https://www.sae.org/AS6969/1B3275EF-942A-49C8-9643-E7D66FD609F2/1.1
CRS subtype	Geodetic ellipsoid
CRS derivation (if any)	Base CRS
CRS scope	Geodetic longitude, latitude, and ellipsoidal height
CRS validity	Global
Associated CS	WGS84Ellipsoidal CS https://www.sae.org/AS6969/7EC8B9B4-7DB2-4197-A5BC-33814C3C9DD5/1.1
Associated CD	WGS84G1762 CD https://www.sae.org/AS6969/8A63E02C-F0AF-4F5D-B545-E69C9619682E/1.1
CS axis mapping to CD	X-axis = WGS 84 (G1762) CD X_e-axis Y-axis = WGS 84 (G1762) CD Y_e-axis Z-axis = WGS 84 (G1762) CD Z_e-axis
Associated CO	
Quantity Vector	
CRS not used for general quantities	
Position Vector and Time Derivatives	
CRS position tuple	$\vec{r} = (\lambda_g, \varphi_g, h_g)$
position mapping to CS	$\lambda_g = \lambda$ $\varphi_g = \varphi$ $h_g = h$
Position coordinate names	λ_g = EarthLongitude φ_g = EarthLatitude h_g = EarthEllipsoidalHeight
Position differential names	$(\rho + h)\cos\varphi\, d\lambda\, \vec{e}_\lambda$= EarthEastDistance ($x_E$) $(\varrho + h)\, d\varphi\, \vec{e}_\varphi$= EarthNorthDistance ($y_N$) $dh\, \vec{e}_h$ = EarthUpDistance (z_U) $-dh\, \vec{e}_h$ = EarthDownDistance (z_D) (see WGS 84 Ellipsoidal CS for definition of ρ, ϱ)
Velocity names	v_λ = EarthEastVelocity (v_E) v_φ = EarthNorthVelocity (v_N) v_h = EarthUpVelocity (v_U) $-v_h$ = EarthDownVelocity (v_D)
Statistical quantities	
Mean position	$E[\vec{r}]$ = MeanEarthPosition
Mean position coordinate names	$E[\lambda_g]$ = MeanEarthLongitude $E[\varphi_g]$ = MeanEarthLatitude $E[h_g]$ = MeanEarthEllipsoidalHeight
Position standard deviation	$\sigma_{\vec{r}}$ = EarthPositionStandardDeviation
Position variance	$var(\vec{r})$ = EarthPositionVariance
Position variance parameters	$var(x_E)$ = VarEarthEastDistance $var(y_N)$ = VarEarthNorthDistance $var(z_U)$ = VarEarthUpDistance $cov(x_E, y_N)$ = CovEarthEastNorthDistance $cov(x_E, z_U)$ = CovEarthEastUpDistance $cov(y_N, z_U)$ = CovEarthNorthUpDistance
Mean velocity	$E[\vec{v}]$ = MeanEarthVelocity

Mean position coordinate names	$E[v_E]$ = MeanEarthEastVelocity $E[v_N]$ = MeanEarthNorthVelocity $E[v_U]$ = MeanEarthUpVelocity
Velocity variance	$var(\vec{v})$ = EarthVeloclityVariance
Velocity variance parameters	$var(v_E)$ = VarEarthEastVelocity $var(v_N)$ = VarEarthNorthVelocity $var(v_U)$ = VarEarthUpVelocity $cov(v_E, v_N)$ = CovEarthEastNorthVelocity $cov(v_E, v_U)$ = CovEarthEastUpVelocity $cov(v_N, v_U)$ = CovEarthNorthUpVelocity
Position-velocity covariance	$cov(\vec{r}, \vec{v})$ = EarthPositionVelocityCovariance
Covariance parameters	$cov(x_E, v_E)$ = CovEarthEastDistanceEastVelocity $cov(x_E, v_N)$ = CovEarthEastDistanceNorthVelocity $cov(x_E, v_U)$ = CovEarthEastDistanceUpVelocity $cov(y_N, v_E)$ = CovEarthNorthDistanceEastVelocity $cov(y_N, v_N)$ = CovEarthNorthDistanceNorthVelocity $cov(y_N, v_U)$ = CovEarthNorthDistanceUpVelocity $cov(z_U, v_E)$ = CovEarthUpDistanceEastVelocity $cov(z_U, v_N)$ = CovEarthUpDistanceNorthVelocity $cov(z_U, v_U)$ = CovEarthUpDistanceUpVelocity
Remarks	1. Strictly speaking, a coordinate transformation is required to re-reference coordinates to or from historical realizations of the WGS 84 reference frame. 2. Version 1.1 of this table added position standard deviation. 3. See Figure 26.

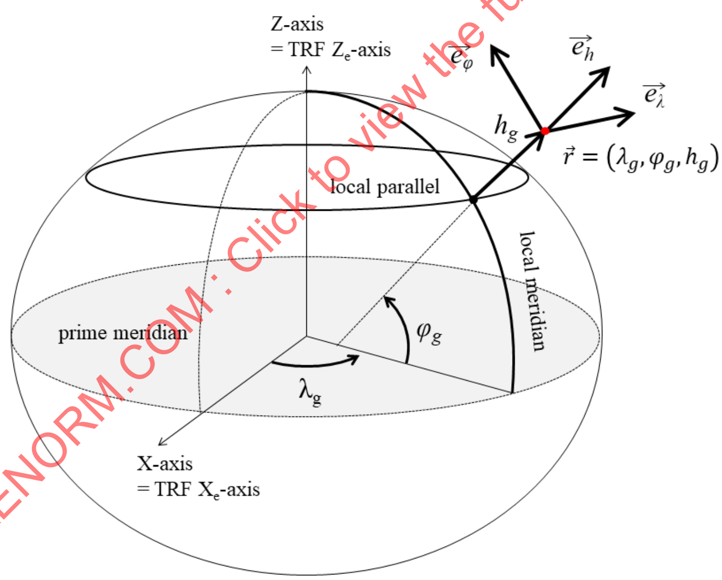


Figure 26 - WGS 84 (G1762) ellipsoid CRS (Euclidean space)

8.3.2 WGS 84 (G1762) 2D Ellipsoid Coordinate Reference System

Table 264 - Defining elements of WGS 84 (G1762) 2D ellipsoid coordinate reference system

DEFINING ELEMENT	DESCRIPTION
Basic Attributes	
CRS name	WGS84G17622DEllipsoid CRS
Version	1.1
Definition URI	https://www.sae.org/AS6969/5C08C45F-8FB6-41FA-A245-7D7968051D2D/1.1
CRS subtype	Geodetic ellipsoid
CRS derivation (if any)	Derived from WGS 84 (G1762) Ellipsoidal CRS with ellipsoidal height omitted
CRS scope	Geodetic longitude and latitude
CRS validity	Global
Associated CS	WGS84Ellipsoidal CS https://www.sae.org/AS6969/7EC8B9B4-7DB2-4197-A5BC-33814C3C9DD5/1.1
Associated CD	WGS84G1762 CD https://www.sae.org/8A63E02C-F0AF-4F5D-B545-E69C9619682E/1.1
CS axis mapping to CD	X-axis = WGS 84 (G1762) CD X_e-axis Y-axis = WGS 84 (G1762) CD Y_e-axis Z-axis = WGS 84 (G1762) CD Z_e-axis
Associated CO	
Quantity Vector	
CRS not used for general quantities	
Position Vector	
CRS position coordinate tuple	$\vec{r} = (\lambda_g, \varphi_g)$
Position mapping to CS	$\lambda_g = \lambda$ $\varphi_g = \varphi$
Position coordinate names	λ_g = EarthLongitude φ_g = EarthLatitude
Position differential names	$(\rho + h) \cos \varphi \, d\lambda \, \vec{e}_\lambda$= EarthEastDistance (x_E) $(\varrho + h) \, d\varphi \, \vec{e}_\varphi$= EarthNorthDistance (y_N) (see WGS 84 Ellipsoidal CS for definition of ρ, ϱ)
Statistical Quantities	
Mean position	$E[\vec{r}]$ = MeanEarthPosition
Mean position coordinate names	$E[\lambda_g]$ = MeanEarthLongitude $E[\varphi_g]$ = MeanEarthLatitude
Position standard deviation	$\sigma_{\vec{r}}$ = EarthPositionStandardDeviation
Position variance	$var(\vec{r})$ = EarthPositionVariance
Position variance parameters	$var(x_E)$ = VarEarthEastDistance $var(y_N)$ = VarEarthNorthDistance $cov(x_E, y_N)$ = CovEarthEastNorthDistance
Confidence ellipse parameters	EarthPositionEllipseProbability EarthPositionEllipseSemiMajorAxis EarthPositionEllipseSemiMinorAxis EarthPositionEllipseSemiMajorAxisRightAzimuth
Remarks	1. Strictly speaking, a coordinate transformation is required to re-reference coordinates to or from historical realizations of the WGS 84 reference frame. 2. Confidence ellipse parameters derived from position variance parameters. 3. Version 1.1 of this table added position standard deviation.

8.3.3 WGS 84 (G1762) Ellipsoidal Height Coordinate Reference System

Table 265 - Defining elements of WGS 84 (G1762) ellipsoidal height coordinate reference system

DEFINING ELEMENT	DESCRIPTION
Basic Attributes	
CRS name	WGS84G1762EllipsoidalHeight CRS
Version	1.1
Definition URI	https://www.sae.org/AS6969/AE0DAEEF-0660-4FE8-A48F-40AB2A660CF5/1.1
CRS subtype	Geodetic ellipsoid
CRS derivation (if any)	Ellipsoidal height coordinate of WGS 84 (G1762) Ellipsoid CRS.
CRS scope	Ellipsoidal height
CRS validity	Global
Associated CS	WGS84EllipsoidalHeight CS UUID: {73977A67-4AB5-4C40-A016-B32EA728B438}
Associated CD	WGS84G1762 CD UUID: {8A63E02C-F0AF-4F5D-B545-E69C9619682E}
CS axis mapping to CD	X-axis = WGS 84 (G1762) CD X_e-axis Y-axis = WGS 84 (G1762) CD Y_e-axis Z-axis = WGS 84 (G1762) CD Z_e-axis
Associated CO	
Quantity Vector	
CRS not used for general quantities	
Position Vector and Time Derivatives	
CRS position tuple	(h_g)
Position mapping to CS	$h_g = h$
Position coordinate names	h_g = EarthEllipsoidalHeight
CRS velocity tuple	(v_{hg})
Position mapping to CS	$v_{hg} = v_h$
Position coordinate names	v_{hg} = EarthEllipsoidalHeightRate
Remarks	Strictly speaking, a coordinate transformation is required to re-reference coordinates to or from historical realizations of the WGS 84 reference frame.

8.3.4 WGS 84 (EGM2008) Orthometric Height Coordinate Reference System

Table 266 - Defining elements of WGS 84 (EGM2008) orthometric height coordinate reference system

DEFINING ELEMENT	DESCRIPTION
Basic Attributes	
CRS name	WGS84EGM2008OrthometricHeight CRS
Version	1.1
Definition URI	https://www.sae.org/AS6969/FCF946E0-3EBF-4D9B-98F3-B0CBF052B576/1.1
CRS subtype	Geoid
CRS derivation (if any)	WGS 84 (G1762) ellipsoidal height CRS adjusted for geoid undulations by the Tide Free Earth Gravitational Model: EGM2008
CRS scope	Orthometric height. Taken as height above mean sea level (MSL)
CRS validity	Global

Associated CS	Ellipsoidal height coordinate of WGS84Ellipsoidal CS https://www.sae.org/7EC8B9B4-7DB2-4197-A5BC-33814C3C9DD5/1.1
Associated CD	WGS84G1762 CD https://www.sae.org/8A63E02C-F0AF-4F5D-B545-E69C9619682E/1.1
CS axis mapping to CD	X-axis = WGS 84 (G1762) CD X_e-axis Y-axis = WGS 84 (G1762) CD Y_e-axis Z-axis = WGS 84 (G1762) CD Z_e-axis
Associated CO	
Quantity Vector	
CRS not used for general quantities	
Position Vector	
CRS position tuple	(H_{geoid})
Position mapping to CS	$H_{geoid} = h_g - N_{geoid}$ Where N is the geoid undulation (the height adjustment to the WGS 84 (G1762) ellipsoidal height) given by EGM2008
Position coordinate names	H = EarthOrthometricHeight
Remarks	This CRS may be combined with a 2D geodetic CRS. Orthometric height is taken as the height above mean sea level (MSL).

8.3.5 WGS 84 (EGM2008) Geoid Coordinate Reference System

Table 267 - Defining elements of WGS 84 (EGM2008) geoid coordinate reference system

DEFINING ELEMENT	DESCRIPTION
CRS name	WGS84EGM2008Geoid CRS
Version	1.1
Definition URI	https://www.sae.org/AS6969/187CEBD6-0773-4008-AE5B-4BABB7E3A3E3/1.1
CRS subtype	Compound CRS
CRS scope	WGS84G1762 Ellipsoid CRS adjusted for geoid undulations according to EGM2008.
CRS validity	Global mapping and surveying
Associated CO	
Quantity Vector	
CRS not used for general quantities	
Position Vector	
CRS position tuple	$\vec{r} = (\lambda_g, \varphi_g, H_{geoid})$
Component CRS	WGS84G17622DEllipsoid CRS https://www.sae.org/AS6969/5C08C45F-8FB6-41FA-A245-7D7968051D2D/1.1 WGS84EGM2008OrthometricHeight CRS https://www.sae.org/AS6969/FCF946E0-3EBF-4D9B-98F3-B0CBF052B576/1.1
Remarks	Other information concerning the CRS