



Manual of Standards - Units of Measurement to be used in Air and Ground Operations

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AMENDMENT RECORDS

The amendments listed below have been incorporated into this copy of the Manual of Standards – Units of Measurement to be used in Air and Ground Operations.

Amendment no.	Version no.	Subject	Source	Sections affected	Entered by (Date)	Approved by (Date)	Effective date
-	1.0	Original version	-	All	AAR (1 July 2010)	Chief Executive (1 July 2010)	1 July 2010
1	1.1	Unit for wind speed	ICAO Annex 5 (incorporating Amendment 17 applicable on 18 Nov 2010)	4.16 in Table 3-4	AAR (1 Nov 2010)	Chief Executive (1 Nov 2010)	18 Nov 2010

FOREWORD

Pursuant to paragraph 88(C) of the Air Navigation Order (ANO), this Manual of Standards – Units of Measurement to be used in Air and Ground Operations is issued by CAAS to specify the use of a standardized system of units of measurement in international civil aviation air and ground operations. This standardized system of units of measurement is based on the International System of Units (SI) and certain non-SI units considered necessary to meet the specialized requirements of international civil aviation. The standards and recommended practices contained in this Manual of Standards shall be applicable to all aspects of international civil aviation air and ground operations in Singapore.

The standards and recommended practices in this Manual are based on those stipulated in Annex 5 (entitled “Units of Measurement to be used in Air and Ground Operations”) to the Convention on International Civil Aviation (as in force and amended from time to time by the Council of the International Civil Aviation Organisation) and other relevant ICAO documents, and with such modifications as may be determined by CAAS to be applicable in Singapore.

Amendments to this Manual of Standards – Units of Measurement to be used in Air and Ground Operations are the responsibility of the Division Head of the CAAS Aerodrome and Air Navigation Services Regulation Division. Readers should forward advice of errors, inconsistencies or suggestions for improvement to this Manual to the addressee stipulated below.

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Chapter 1 Definitions

1.1 Definitions

1.1.1 When the following terms are used in the standards and recommended practices concerning the units of measurement to be used in all aspects of international civil aviation air and ground operations in Singapore, they have the following meanings:

Ampere (A)

The ampere is that constant electric current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length.

Becquerel (Bq)

The activity of a radionuclide having one spontaneous nuclear transition per second.

Candela (cd)

The luminous intensity, in the perpendicular direction, of a surface of 1/600 000 square metre of black body at the temperature of freezing platinum under a pressure of 101 325 newtons per square metre.

Celsius temperature ($t^{\circ}\text{C}$)

The Celsius temperature is equal to the difference $t^{\circ}\text{C} = T - T_0$ between two thermodynamic temperatures T and T_0 where T_0 equals 273.15 kelvin.

Coulomb (C)

The quantity of electricity transported in 1 second by a current of 1 ampere.

Degree Celsius ($^{\circ}\text{C}$)

The special name for the unit kelvin for use in stating values of Celsius temperature.

Farad (F)

The capacitance of a capacitor between the plates of which there appears a difference of potential of 1 volt when it is charged by a quantity of electricity equal to 1 coulomb.

Foot (ft)

The length equal to 0.304 8 metre exactly.

Gray (Gy)

The energy imparted by ionizing radiation to a mass of matter corresponding to 1 joule per kilogram.

Henry (H)

The inductance of a closed circuit in which an electromotive force of 1 volt is produced when the electric current in the circuit varies uniformly at a rate of 1 ampere per second.

Hertz (Hz)

The frequency of a periodic phenomenon of which the period is 1 second.

Human performance

Human capabilities and limitations which have an impact on the safety and efficiency of aeronautical operations.

Joule (J)

The work done when the point of application of a force of 1 newton is displaced a distance of 1 metre in the direction of the force.

Kelvin (K)

A unit of thermodynamic temperature which is the fraction $1/273.16$ of the thermodynamic temperature of the triple point of water.

Kilogram (kg)

The unit of mass equal to the mass of the international prototype of the kilogram.

Knot (kt)

The speed equal to 1 nautical mile per hour.

Litre (L)

A unit of volume restricted to the measurement of liquids and gases which is equal to 1 cubic decimetre.

Lumen (lm)

The luminous flux emitted in a solid angle of 1 steradian by a point source having a uniform intensity of 1 candela.

Lux (lx)

The illuminance produced by a luminous flux of 1 lumen uniformly distributed over a surface of 1 square metre.

Metre (m)

The distance travelled by light in a vacuum during $1/299\,792\,458$ of a second.

Mole (mol)

The amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon-12.

Note.- When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles or specified groups of such particles.

Nautical mile (NM)

The length equal to 1 852 metres exactly.

Newton (N)

The force which when applied to a body having a mass of 1 kilogram gives it an acceleration of 1 metre per second squared.

Ohm (Ω)

The electric resistance between two points of a conductor when a constant difference of potential of 1 volt, applied between these two points, produces in this conductor a current of 1 ampere, this conductor not being the source of any electromotive force.

Pascal (Pa)

The pressure or stress of 1 newton per square metre.

Radian (rad)

The plane angle between two radii of a circle which cut off on the circumference an arc equal in length to the radius.

Second (s)

The 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 caesium-133 atom.

Siemens (S)

The electric conductance of a conductor in which a current of 1 ampere is produced by an electric potential difference of 1 volt.

Sievert (Sv)

The unit of radiation dose equivalent corresponding to 1 joule per kilogram.

Steradian (sr)

The solid angle which, having its vertex in the centre of a sphere, cuts off an area of the surface of the sphere equal to that of a square with sides of length equal to the radius of the sphere.

Tesla (T)

The magnetic flux density given by a magnetic flux of 1 weber per square metre.

Tonne (t)

The mass equal to 1 000 kilograms.

Volt (V)

The unit of electric potential difference and electromotive force which is the difference of electric potential between two points of a conductor carrying a constant current of 1 ampere, when the power dissipated between these points is equal to 1 watt.

Watt (W)

The power which gives rise to the production of energy at the rate of 1 joule per second.

Weber (Wb)

The magnetic flux which, linking a circuit of one turn, produces in it an electromotive force of 1 volt as it is reduced to zero at a uniform rate in 1 second.

Chapter 2 Applicability

- 2.1 This Manual of Standards – Units of Measurement to be used in Air and Ground Operations (hereafter referred to as the “Manual”) shall be applicable to all aspects of international civil aviation air and ground operations in Singapore.
- 2.2 This Manual is based on the ICAO Annex 5 – Units of Measurement to be used in Air and Ground Operations.
- 2.3 Where there is a difference between a standard in this Manual and that of the above-mentioned ICAO documents, the standard in this Manual shall prevail.
- 2.4 Differences, where they exist, between the standards in this Manual and those contained in the relevant ICAO Annexes shall be published in section GEN 1.7 of the Singapore AIP and also notified to ICAO.
- 2.5 In this Manual, standards are preceded by the word “shall”, whereas recommended practices are preceded by the word “should”. All operators involved in international civil aviation air and ground operations in Singapore shall comply with all standards set out in this manual at all times and should endeavour to comply with all recommended practices.
- 2.6 In addition to the Manual of Standards, the following may also be issued as and when required:
 - (a) Safety Directive – this directive is a mandatory requirement to be complied by all operators involved in international civil aviation air and ground operations in Singapore. It is published for purposes of immediate promulgation of local standards and recommended practices in response to, but not limited to, amendments to ICAO Annexes. The Safety Directives will be incorporated into subsequent amendment of this Manual.
 - (b) Safety Publication – this advisory circular is published for purposes of promulgating supplementary guidance materials to the standards and recommended practices in this Manual. The publications are intended to provide recommendations and guidance to illustrate a means, but not necessarily the only means, of complying with this Manual. Safety Publications may explain certain regulatory requirements by providing interpretive and explanatory materials.

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- (c) Information Circular – this is published for purposes of bringing to the attention of educational materials related to aviation safety. The publications could be initiated as a result of ICAO State letters which do not require immediate changes to local regulations, new safety initiatives or international best practices. All operators involved in international civil aviation air and ground operations in Singapore are encouraged to review and adopt the material if practicable. Where appropriate, the material in the publications may be incorporated into subsequent amendments of this Manual.

Chapter 3 Standard Application of Units of Measurement

3.1 SI Units

3.1.1 The International System of Units developed and maintained by the General Conference of Weights and Measures (CGPM) shall, subject to the provisions of paragraphs 3.2 and 3.3, be used as the standard system of units of measurement for all aspects of international civil aviation air and ground operations in Singapore.

3.1.2 The prefixes and symbols listed in Table 3-1 shall be used to form names and symbols of the decimal multiples and sub-multiples of SI units.

Note 1.- As used herein the term SI unit is meant to include base units and derived units as well as their multiples and sub-multiples.

Note 2.- See Attachment B of ICAO Annex 5 for guidance on the general application of prefixes.

Table 3-1: SI unit prefixes

Multiplication factor		Prefix	Symbol
1 000 000 000 000 000 000	=	10^{18}	exa E
1 000 000 000 000 000	=	10^{15}	peta P
1 000 000 000 000	=	10^{12}	tera T
1 000 000 000	=	10^9	giga G
1 000 000	=	10^6	mega M
1 000	=	10^3	kilo k
100	=	10^2	hecto h
10	=	10^1	deca da
0.1	=	10^{-1}	deci d
0.01	=	10^{-2}	centi c
0.001	=	10^{-3}	milli m
0.000 001	=	10^{-6}	micro μ
0.000 000 001	=	10^{-9}	nano n
0.000 000 000 001	=	10^{-12}	pico p
0.000 000 000 000 001	=	10^{-15}	femto f
0.000 000 000 000 000 001	=	10^{-18}	atto a

3.2 Non-SI Units

3.2.1 The non-SI units listed in Table 3-2 shall be used either in lieu of, or in addition to, the SI units as the units of measurement but only as specified in Table 3-4.

3.2.2 The non-SI units listed in Table 3-3 shall be permitted for temporary use as the units of measurement but only for those specific quantities listed in table 3-4.

Note.- It is intended that the use of the non-SI units listed in Table 3-3 and applied as indicated in Table 3-4 will eventually be discontinued in accordance with individual unit termination dates established by the ICAO Council. Termination dates, when established, will be given in Chapter 4.

3.3 Application of specific units

3.3.1 The application of units of measurements for certain quantities used in international civil aviation air and ground operations in Singapore shall be in accordance with Table 3-4.

3.3.2 Means and provisions for design, procedures and training should be established for operations in environments involving the use of standard and non-SI units of measurement, or the transition between environments using different units, with due consideration to human performance.

Note.- Guidance material on human performance can be found in the Human Factors Training Manual (ICAO Doc 9683) and Circular 238 (ICAO Human Factors Digest No. 6 - Ergonomics).

Table 3-2: Non-SI units for use with the SI

Specific quantities in Table 3-4 related to	Unit	Symbol	Definition (in terms of SI units)
mass	tonne	t	1 t = 10 ³ kg
plane angle	degree	°	1 ° = (π/180) rad
	minute	'	1' = (1/60) ^o = (π/10 800) rad
	second	"	1" = (1/60)' = (π/648 000) rad
temperature	degree Celsius	°C	1 unit °C = 1 unit K ^{a)}
time	minute	min	1 min = 60 s
	hour	h	1 h = 60 min = 3 600 s
	day	d	1 d = 24 h = 86 400 s
	week, month, year	--	
volume	litre	L	1 L = 1 dm ³ = 10 ⁻³ m ³

a) See Table 3-5 for conversion.

Table 3-3: Non-SI units permitted for temporary use with the SI

<i>Specific quantities in Table 3-4 related to</i>			<i>Definition (in terms of SI units)</i>
	<i>Unit</i>	<i>Symbol</i>	
distance (long)	nautical mile	NM	1 NM = 1 852 m
distance (vertical) ^{a)}	foot	ft	1 ft = 0.304 8 m
speed	knot	kt	1 kt = 0.514 444 m/s

a) altitude, elevation, height, vertical speed.

Table 3-4: Standard application of specific units of measurement

<i>Ref. No.</i>	<i>Quantity</i>	<i>Unit (symbol)</i>
1. Direction/Space/Time		
1.1	altitude	m or ft
1.2	area	m ²
1.3	distance (long) ^{a)}	km or NM
1.4	distance (short)	m
1.5	elevation	m or ft
1.6	endurance	h and min
1.7	height	m or ft
1.8	latitude	° ' "
1.9	length	m
1.10	longitude	° ' "
1.11	plane angle (when required, decimal subdivisions of the degree shall be used)	°
1.12	runway length	m
1.13	runway visual range	m
1.14	tank capacities (aircraft) ^{b)}	L
1.15	time	s min h d week month year
1.16	visibility ^{c)}	km
1.17	volume	m ³
1.18	wind direction (wind directions other than for a landing and take-off shall be expressed in degrees true; for landing and take-off wind directions shall be expressed in degrees magnetic)	°

<i>Ref. No.</i>	<i>Quantity</i>	<i>Unit (symbol)</i>
2. Mass-related		
2.1	air density	kg/m ³
2.2	area density	kg/m ²
2.3	cargo capacity	kg
2.4	cargo density	kg/m ³
2.5	density (mass density)	kg/m ³
2.6	fuel capacity (gravimetric)	kg
2.7	gas density	kg/m ³
2.8	gross mass or payload	kg
		t
2.9	hoisting provisions	kg
2.10	linear density	kg/m
2.11	liquid density	kg/m ³
2.12	mass	kg
2.13	moment of inertia	kg · m ²
2.14	moment of momentum	kg · m ² /s
2.15	momentum	kg · m/s
3. Force-related		
3.1	air pressure (general)	kPa
3.2	altimeter setting	hPa
3.3	atmospheric pressure	hPa
3.4	bending moment	kN · m
3.5	force	N
3.6	fuel supply pressure	kPa
3.7	hydraulic pressure	kPa
3.8	modulus of elasticity	MPa
3.9	pressure	kPa
3.10	stress	MPa
3.11	surface tension	mN/m
3.12	thrust	kN
3.13	torque	N · m
3.14	vacuum	Pa
4. Mechanics		
4.1	airspeed ^{d)}	km/h or kt
4.2	angular acceleration	rad/s ²
4.3	angular velocity	rad/s
4.4	energy or work	J
4.5	equivalent shaft power	kW
4.6	frequency	Hz
4.7	ground speed	km/h or kt

<i>Ref. No.</i>	<i>Quantity</i>	<i>Unit (symbol)</i>
4.8	impact	J/m ²
4.9	kinetic energy absorbed by brakes	MJ
4.10	linear acceleration	m/s ²
4.11	power	kW
4.12	rate of trim	°/s
4.13	shaft power	kW
4.14	velocity	m/s
4.15	vertical speed	m/s or ft/min
4.16	wind speed ^{e)}	m/s or kt
5. Flow		
5.1	engine airflow	kg/s
5.2	engine waterflow	kg/h
5.3	fuel consumption (specific)	
	piston engines	kg/(kW · h)
	turbo-shaft engines	kg/(kW · h)
	jet engines	kg/(kN · h)
5.4	fuel flow	kg/h
5.5	fuel tank filling rate (gravimetric)	kg/min
5.6	gas flow	kg/s
5.7	liquid flow (gravimetric)	g/s
5.8	liquid flow (volumetric)	L/s
5.9	mass flow	kg/s
5.10	oil consumption	
	gas turbine	kg/h
	piston engines (specific)	g/(kW · h)
5.11	oil flow	g/s
5.12	pump capacity	L/min
5.13	ventilation airflow	m ³ /min
5.14	viscosity (dynamic)	Pa · s
5.15	viscosity (kinematic)	m ² /s
6. Thermodynamics		
6.1	coefficient of heat transfer	W/(m ² · K)
6.2	heat flow per unit area	J/m ²
6.3	heat flow rate	W
6.4	humidity (absolute)	g/kg
6.5	coefficient of linear expansion	°C ⁻¹
6.6	quantity of heat	J
6.7	temperature	°C

<i>Ref. No.</i>	<i>Quantity</i>	<i>Unit (symbol)</i>
7. Electricity and magnetism		
7.1	capacitance	F
7.2	conductance	S
7.3	conductivity	S/m
7.4	current density	A/m ²
7.5	electric current	A
7.6	electric field strength	C/m ²
7.7	electric potential	V
7.8	electromotive force	V
7.9	magnetic field strength	A/m
7.10	magnetic flux	Wb
7.11	magnetic flux density	T
7.12	power	W
7.13	quantity of electricity	C
7.14	resistance	Ω
8. Light and related electromagnetic radiations		
8.1	illuminance	lx
8.2	luminance	cd/m ²
8.3	luminous exitance	lm/m ²
8.4	luminous flux	lm
8.5	luminous intensity	cd
8.6	quantity of light	lm · s
8.7	radiant energy	J
8.8	wavelength	m
9. Acoustics		
9.1	frequency	Hz
9.2	mass density	kg/m ³
9.3	noise level	dB ^{f)}
9.4	period, periodic time	s
9.5	sound intensity	W/m ²
9.6	sound power	W
9.7	sound pressure	Pa
9.8	sound level	dB ^{f)}
9.9	static pressure (instantaneous)	Pa
9.10	velocity of sound	m/s
9.11	volume velocity (instantaneous)	m ³ /s
9.12	wavelength	m

Ref. No.	Quantity	Unit (symbol)
10. Nuclear physics and ionizing radiation		
10.1	absorbed dose	Gy
10.2	absorbed dose rate	Gy/s
10.3	activity of radionuclides	Bq
10.4	dose equivalent	Sv
10.5	radiation exposure	C/kg
10.6	exposure rate	C/kg · s
<p>a) As used in navigation, generally in excess of 4 000 m.</p> <p>b) Such as aircraft fuel, hydraulic fluids, water, oil and high pressure oxygen vessels.</p> <p>c) Visibility of less than 5 km may be given in m.</p> <p>d) Airspeed is sometimes reported in flight operations in terms of the ratio MACH number.</p> <p>e) A conversion of 1 kt = 0.5 m/s is used in ICAO Annexes for the representation of wind speed.</p> <p>f) The decibel (dB) is a ratio which may be used as a unit for expressing sound pressure level and sound power level. When used, the reference level must be specified.</p>		

Table 3-5: Temperature conversion formulae

To convert from	to	Use formula
Celsius temperature (t°_C)	Kelvin temperature (t_K)	$t_K = t^{\circ}_C + 273.15$
Fahrenheit temperature (t°_F)	Celsius temperature (t°_C)	$t^{\circ}_C = (t^{\circ}_F - 32)/1.8$
Fahrenheit temperature (t°_F)	Kelvin temperature (t_K)	$t_K = (t^{\circ}_F + 459.67)/1.8$
Kelvin temperature (t_K)	Celsius temperature (t°_C)	$t^{\circ}_C = t_K - 273.15$
Rankine temperature (t°_R)	Kelvin temperature (t_K)	$t_K = t^{\circ}_R / 1.8$

Note.- See Attachment C of ICAO Annex 5 for the list of conversion factors provided to express the definitions of miscellaneous units of measure as numerical multiples of SI units.

Chapter 4 Termination of use of Non-SI Units

Note.- The non-SI units listed in Table 3-3 have been retained temporarily for use as the units because of their widespread use and to avoid potential safety problems which could result from the lack of international coordination concerning the termination of their use. As termination dates are established by the ICAO Council, they will be reflected as Standards contained in this Chapter: It is expected that the establishment of such dates will be well in advance of actual termination. Any special procedures associated with specific unit termination will be circulated separately from this Manual of Standards.

- 4.1 The use in international civil aviation operations of the non-SI units listed in Table 3-3 shall be terminated on the dates listed in Table 4-1.

Table 4-1: Termination dates for non-SI units

<i>Non-SI unit</i>	Termination date
Knot Nautical mile } }	Not established ^{a)}
Foot	Not established ^{b)}

a) No termination date has yet been established for use of nautical mile and knot

b) No termination date has yet been established for use of the foot