UNITS

Consistent Units

The programs of the PAM-CSM family are dynamic programs and require the model (geometry, loading, material data, velocities, accelerations …) to be specified in "consistent units". Some examples of consistent units are:

basic units			derived units		
LENGTH	MASS	TIME	FORCE	STRESS	ENERGY
cm	g	s	dyn=g cm/s^2	dyn/cm^2	dyn cm=erg
m	kg	s	N=kg m/s^2	N/m^2=Pa	N m=J
cm	100 kg	s	N=100 kg cm/s^2	N/cm^2=10^{-1}bar	cm
mm	ton	s	N=ton mm/s^2	N/mm^2=MPa	N mm
mm	kg	ms	kN=kg mm/ms^2	kN/mm^2=GPa	kN mm
mm	dton	s	kgf=9.81 ton mm/s^2	kgf/mm^2	kgf mm
cm	g	µs	10^7 N=g cm/µs^2	10^7 N/cm^2=Mbar	10^7 N cm
ft	slug	s	lbf (or pf) = slug ft/s^2	lbf/ft^2 (or pf/ft^2)	lbf ft (or pf ft),
mm	kg/G	ms	10^3 kgf=metric ton-f	9.81 GPa	9.81 kN mm

where the given symbols have the following meaning:

length units	mass units	time units
m=meter	g=gram	s=second
cm=centimeter=10^{-2} m	kg=kilogram= 10^3 g	ms=millisecond=10^{-3} s
mm=millimeter=10^{-3} m	ton=10^3 kg=10^6 g	µs=microsecond=10^{-6} s
ft=foot=12 in=30.48 cm	dton=9.81 ton	
in=inch=2.54 cm	slug=14.594 kg	
	lbm=pound mass=0.45359 kg,	
	Kg/G=9.81 kg	

force units	stress units	energy units
dyn=10^{-5} N	Pa=pascal=N/m^2	erg=dyn cm
N=Newton	bar=daN/cm^2	J=joule=N m
daN=decanewton=10 N	MPa=megapascal=10^6 Pa	lbf ft=1.35581 Nm (J)
kN=kilonewton=10^3 N	GPa=gigapascal=10^9 Pa	
lbf=pound force(or pf)=4.4482 N	Mbar=megabar=10^6 bar	
kgf=kilogram-force=9.81 N	lbf/ft^2=pf/ft^2=47.88 N/m^2	
metric ton-f (ton-force)= 10^3 kgf	lbf/in^2=psi=0.68947 N/cm^2	

The units of physical parameters, such as:

- distance
- areas
- inertia moments
- forces
- line loads
- surface load (pressure)
- material moduli
- mass densities
- displacements
- velocities
- acceleration
- energies
- work
- stresses
- etc.

must be given and will be output by the program in terms of the chosen set of consistent units. The acceleration of gravity is equal to 9.81 m/s^2 (32.2 ft/s^2).

Unit Specifications

Where appropriate, the units of the input variables are listed in tables given in the input sections of the manual. In these tables, units are indicated either as "basic units", as "derived units" or as "units of functions".

Basic units are expressed as

- length for length units
- mass for mass units
- angle for angle units
- time for time units
- temperature for thermal units

Derived units are surrounded by brackets, [ ], and are ultimately expressed in terms of the basic units. Examples are given by

- [force]=mass length/$time^2$
- [stress]=[force]/[area]=mass/(length $time^2$)
- [area]=$length^2$
- [volume]=$length^3$
- etc.

For example, read "[force]" as "units of force" or "force units".

Units of functions are given as units of their ordinate values vs units of their abscissa values, for example, [force] vs time, or mass vs time. This can be expressed as

[function] = [ordinate values] vs [abscissa values].

The function ordinate and abscissa values can be multiplied by a scale factor. Then the units of the function ordinates and abscissae are given by the product of the units of their input values times the units of their scale factors, which can be expressed as

[ordinate or abscissa values] = [input values] [scale factor].

In many cases the scale factors are supplied unitless and the input values are assigned the units of the function ordinates or abscissae, i.e.,

[input values] =[ordinate or abscissa values]

[scale factor] =none.

In some cases the user may wish to specify normalized, unitless, input ordinate or abscissa values and assign the units to their scale factors, i.e.,

[input values] =none

[scale factor] =[ordinate or abscissa values].

It is up to the user to keep the assignment of units as clear as possible in all cases. Refer to the Auxiliaries Section for the treatment of function shifts.

Basic Units Conversion Factors

The basic units for length, angle, mass, time and temperature can be expressed in several types of basic units, e.g., length units in meters (m), centimeters (cm), millimeters (mm), etc. The conversion factors for the used types of length, angle, time, thermal and mass units are listed in the following tables.

Length unit types are given by meter (m), centimeter (cm), millimeter (mm), foot (ft) and inch (in). They convert as follows.

Table (a): Conversion factors for length units

	m	cm	mm	ft	in
meter (m)	1	100	1000	3.281	39.37
centimeter (cm)	.01	1	10	.03281	.3937
millimeter (mm)	.001	.1	1	.003281	.03937
foot (ft)	.3048	30.48	304.8	1	12
inch (in)	.0254	2.54	25.4	.08333	1

Angular unit types are given by degrees (deg) or radians (rad). They convert as follows.

Table (b): Conversion factors for angular units

	deg	rad
degrees deg	1	0.0174533
radians rad	57.2958	1

Time unit types are given by second (s), millisecond (ms) and microsecond (μs). They convert as follows.

Table (c): Conversion factors for time units

	s	ms	μs
second	1	10^{3}	10^{6}
millisecond	10^{-3}	1	10^{3}
microsecond	10^{-6}	10^{-3}	1

Thermal unit types are given by temperature expressed in degrees Kelvin (K), Celsius (C) and Fahrenheit (F). They convert as follows.

Table (d): Conversion factors for thermal units

	K	C	F
Kelvin (K)	1	C+273.15	.5556(F+459.67)
Celsius (C)	K-273.15	1	.5556(F-32)
Fahrenheit (F)	1.8K-459.67	1.8C+32	1

Mass unit types are given by grams (g), kilograms (kg), 100 kilograms (100 kg), metric tons (ton), dton (9.81 ton), pound mass (lbm) (sometimes called "avoirdupoids pound"), slugs (slug) and pound force-second squared/inch (lbf s^2/in). They convert as follows.

Table (e): Conversion factors for mass units

	g	kg	100 kg	ton	lbm	slug	lbf s^2/in
gram (g)	1	10^{-3}	10^{-5}	10^{-6}	$2.2046x10^{-3}$	$6.8522x10^{-5}$	$5.710x10^{-6}$
kilogram (kg)	10^3	1	10^{-2}	10^{-3}	2.2046	$6.8522x10^{-2}$	$5.710x10^{-3}$
100 kilogram (100 kg)	10^5	10^2	1	10^{-1}	220.46	6.8522	.5710
metric ton (ton)	10^6	10^3	10	1	2204.6	68.522	5.710
pound mass (lbm)	453.59	.45359	$4.5359x10^{-3}$	$4.5359x 10^{-4}$	1	$3.1081x10^{-2}$	$2.589x10^{-3}$
slug (slug)	14 594	14.594	.14594	$14.594x 10^{-3}$	32.174	1	.0833
lbf s^2/in (lbf s^2/in)	175 126	175 126	1.75126	.175126	386.09	12	1

Derived Units

Some units that are derived from the basic units of ***length***, ***angle***, ***mass***, ***mole***, ***temperature*** and ***time*** units are listed below.

Table (f) shows the general unit name and the derivation to be used for converting units.

Table (f): List of [derived] and basic units

Name	Derivation
[acceleration]	length/time^2
angle	basic unit
[angular velocity]	angle/time
[area]	length^2
[bending inertia]	length^4
[elongation rate]	length/time
[energy]	[force] length = mass length^2/time^2
[energy per unit mass]	[energy]/mass = length^2/time^2
[energy per unit volume]	[energy]/[volume] = mass/(length time^2)
[enthalpy]	[energy] = mass length^2/time^2
[entropy]	[energy per unit mass]/temperature (Kelvin)= length^2/(time^2 temperature (K))
[force]	mass length/time^2
[force moment]	[force] length = mass length^2/time^2
[gas constant R]	[energy]/(mass temperature) = length^2/(time^2 temperature)
[gas constant R_u]*	[energy]/(mole temperature) = mass length^2/(time^2 temperature)
[molecular gas weight]**	mass/mole
[inertia moment]	mass length^2
length	basic unit
mass	basic unit
[mass density]	mass/length^2
[mass (flow) rate]	mass/time
*mole**	basic unit

Name	Derivation
[moment]	[force] length = mass length^2/time^2
[momentum]	mass [velocity] = mass length/time
[momentum rate]	[momentum]/time = mass length/time^2
none	unitless (no conversion necessary for this value)
[pressure]	[force]/length^2 = mass/(length time^2)
[strain rate]	1/time
[stress]	[force]/length^2 = mass/(length time^2)
[surface rate]	length^2/time
temperature	basic unit
time	basic unit
[velocity]	length/time
[volume]	length^3
[volume (flow) rate]	length^3/time

* *one mole of a gas contains 6.023 x 10^{23} gas molecules*

** *the molecular weight of N_2 gas is 28.014 g/mole*

The reader is invited to consult the above table to obtain the expressions of [derived] units in terms of ***basic*** units, when the tables of the units of the input variables that are provided in the input sections contain derived units.