coreform IGA
for Abaqus

Consistent unit systems

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1 Consistent unit systems

Neither Abaqus nor Coreform IGA for Abaqus prescribes units. They operate on the numerical values provided by the analyst, so every input and every interpreted result must belong to one self-consistent unit system. A length in millimeters, for example, cannot be combined with a modulus in pascals unless the modulus is first converted to the corresponding force-per-square-millimeter unit.

This chapter uses M for mass, L for length, T for time, and Θ for thermodynamic temperature. A dimensionless quantity is written 1. The defining units for mechanics tables identify the independent units used to construct the remaining quantities; this is deliberately narrower than the formal list of base units in a standards document. The derived units tables show a common coherent expression for each derived quantity.

Energy and moment have the same dimensionality, ML^2T^{-2}, but use different unit notation to preserve their distinct physical meanings: for example, J for energy and $\mathrm{N\,m}$ for moment.

The BIPM SI Brochure and the NIST Guide to the SI provide the standards basis for the SI definitions and conversions used here.

1.1 SI

For mechanics, the International System of Units provides a coherent meter-kilogram-second system. It is usually the clearest choice when geometry is modeled in meters.

1.1.a Defining units for mechanics

Quantity	Unit	Dimensionality
Mass	kg	M
Length	m	L
Time	s	T
Temperature	K	Θ

1.1.b Derived units

Quantity	Unit	Dimensionality
Area	m^2	L^2
Volume	m^3	L^3
Velocity	$\mathrm{m/s}$	LT^{-1}
Acceleration	$\mathrm{m/s}^2$	LT^{-2}
Frequency	$\mathrm{Hz} = \mathrm{s}^{-1}$	T^{-1}
Force	N	MLT^{-2}
Energy or work	J	ML^2T^{-2}
Moment or torque	$\mathrm{N\,m}$	ML^2T^{-2}
Power	W	ML^2T^{-3}
Pressure or stress	$\mathrm{Pa} = \mathrm{N/m}^2$	$ML^{-1}T^{-2}$
Mass density	$\mathrm{kg/m}^3$	ML^{-3}
Body force per volume	$\mathrm{N/m}^3$	$ML^{-2}T^{-2}$

1.2 CGS

The centimeter-gram-second system is common in some scientific literature. Its named mechanical units include the dyne for force, the erg for energy, and the barye for pressure.

1.2.a Defining units for mechanics

Quantity	Unit	Dimensionality
Mass	g	M
Length	cm	L
Time	s	T
Temperature	K	Θ

1.2.b Derived units

Quantity	Unit	Dimensionality
Area	cm^2	L^2
Volume	cm^3	L^3
Velocity	$\mathrm{cm/s}$	LT^{-1}
Acceleration	$\mathrm{cm/s}^2$	LT^{-2}
Frequency	s^{-1}	T^{-1}
Force	dyn	MLT^{-2}
Energy or work	erg	ML^2T^{-2}
Moment or torque	$\mathrm{dyn\,cm}$	ML^2T^{-2}
Power	$\mathrm{erg/s}$	ML^2T^{-3}
Pressure or stress	$\mathrm{Ba} = \mathrm{dyn/cm}^2$	$ML^{-1}T^{-2}$
Mass density	$\mathrm{g/cm}^3$	ML^{-3}
Body force per volume	$\mathrm{dyn/cm}^3$	$ML^{-2}T^{-2}$

1.3 MMTS

The millimeter-tonne-second system is especially convenient for mechanical finite-element models whose geometry is dimensioned in millimeters:

$$1\,\mathrm{tonne}\,\frac{\mathrm{mm}}{\mathrm{s}^2} = 1\,\mathrm{N}.$$

Consequently, stress is naturally expressed in $\mathrm{N/mm}^2 = \mathrm{MPa}$. Gravitational acceleration near Earth's surface is approximately $9810\,\mathrm{mm/s}^2$.

1.3.a Defining units for mechanics

Quantity	Unit	Dimensionality
Mass	tonne	M

Quantity	Unit	Dimensionality
Length	mm	L
Time	s	T
Temperature	K	Θ

1.3.b Derived units

Quantity	Unit	Dimensionality
Area	mm^2	L^2
Volume	mm^3	L^3
Velocity	$\mathrm{mm/s}$	LT^{-1}
Acceleration	$\mathrm{mm/s}^2$	LT^{-2}
Frequency	s^{-1}	T^{-1}
Force	N	MLT^{-2}
Energy or work	$\mathrm{mJ} = \mathrm{N\,mm}$	ML^2T^{-2}
Moment or torque	$\mathrm{N\,mm}$	ML^2T^{-2}
Power	$\mathrm{mW} = \mathrm{N\,mm/s}$	ML^2T^{-3}
Pressure or stress	$\mathrm{MPa} = \mathrm{N/mm}^2$	$ML^{-1}T^{-2}$
Mass density	$\mathrm{tonne/mm}^3$	ML^{-3}
Body force per volume	$\mathrm{N/mm}^3$	$ML^{-2}T^{-2}$

1.4 IPS

The coherent inch-pound-second system used here takes the pound-force as the familiar force unit. Its corresponding mass unit is the slinch:

$$1\ \mathrm{slinch} \equiv 1\ \frac{\mathrm{lbf\,s}^2}{\mathrm{in}}.$$

1.4.a Defining units for mechanics

Quantity	Unit	Dimensionality
Mass	slinch	M
Length	in	L
Time	s	T
Temperature	$^\circ\mathrm{R}$	Θ

1.4.b Derived units

Quantity	Unit	Dimensionality
Area	in^2	L^2
Volume	in^3	L^3
Velocity	$\mathrm{in/s}$	LT^{-1}
Acceleration	$\mathrm{in/s^2}$	LT^{-2}
Frequency	$\mathrm{s^{-1}}$	T^{-1}
Force	lbf	MLT^{-2}
Energy or work	$\mathrm{lbf\ in}$	ML^2T^{-2}
Moment or torque	$\mathrm{lbf\ in}$	ML^2T^{-2}
Power	$\mathrm{lbf\ in/s}$	ML^2T^{-3}
Pressure or stress	$\mathrm{psi} = \mathrm{lbf/in^2}$	$ML^{-1}T^{-2}$
Mass density	$\mathrm{slinch/in^3}$	ML^{-3}
Body force per volume	$\mathrm{lbf/in^3}$	$ML^{-2}T^{-2}$

1.5 FPS

The coherent foot-pound-second system likewise uses pound-force for force, but its mass unit is the slug:

$$1\ \mathrm{slug} \equiv 1\ \frac{\mathrm{lbf\ s^2}}{\mathrm{ft}}, \qquad 1\ \mathrm{slinch} = 12\ \mathrm{slug}.$$

1.5.a Defining units for mechanics

Quantity	Unit	Dimensionality
Mass	slug	M
Length	ft	L
Time	s	T
Temperature	$^\circ\mathrm{R}$	Θ

1.5.b Derived units

Quantity	Unit	Dimensionality
Area	ft^2	L^2
Volume	ft^3	L^3

Quantity	Unit	Dimensionality
Velocity	$\mathrm{ft/s}$	LT^{-1}
Acceleration	$\mathrm{ft/s^2}$	LT^{-2}
Frequency	$\mathrm{s^{-1}}$	T^{-1}
Force	lbf	MLT^{-2}
Energy or work	$\mathrm{ft\,lbf}$	ML^2T^{-2}
Moment or torque	$\mathrm{lbf\,ft}$	ML^2T^{-2}
Power	$\mathrm{ft\,lbf/s}$	ML^2T^{-3}
Pressure or stress	$\mathrm{psf} = \mathrm{lbf/ft^2}$	$ML^{-1}T^{-2}$
Mass density	$\mathrm{slug/ft^3}$	ML^{-3}
Body force per volume	$\mathrm{lbf/ft^3}$	$ML^{-2}T^{-2}$

1.6 Common mistakes

1.6.a On the pound

A common error—perhaps the most common error made by new analysts—is entering density incorrectly in the IPS unit system. This likely stems from confusion about what "lb" means: is it weight, mass, or force? The situation is not helped by the many names inherited by the Imperial and United States customary systems. In contrast to metric systems, their unit names were adopted from many sources. In the pre-industrial era, several conveyed useful pragmatic information.[1]

Common names for weights, forces, and masses include pound (lb), poundal (pdl), pound-force (lbf), pound-mass (lbm), short and long ton, slug, and slinch. Whenever one of these terms appears, take extra care to determine its dimensionality and convert it into the selected coherent unit system. The NIST definition of pound-force, for example, explicitly relates it to the force produced by standard gravity on one avoirdupois pound.

The first example starts with a density expressed using the FPS mass unit and converts the mass unit from slugs to slinches:

[1]For instance, an *acre* was approximately the area a team of oxen could plow in a day, and a *ton of refrigeration* was based on the heat-transfer rate required to melt a short ton (2000 lb) of ice at its freezing point in 24 hours.

$$
\begin{aligned}
\rho &= 0.00898\,\frac{\text{slug}}{\text{in}^3},\\
1\ \text{slug} &\equiv \frac{1\ \text{lbf}}{1\ \text{ft/s}^2},\\
1\ \text{slinch} &\equiv \frac{1\ \text{lbf}}{1\ \text{in/s}^2},\\
\rho &= 0.00898\,\frac{\text{slug}}{\text{in}^3}\left(\frac{1\ \text{ft}}{12\ \text{in}}\right)\\
&= 0.000748\,\frac{\text{lbf s}^2}{\text{in}^4}\\
&= 0.000748\,\frac{\text{slinch}}{\text{in}^3}.
\end{aligned}
$$

The second example begins with the familiar tabulated steel density $0.289\ \text{lbm/in}^3$. Using standard gravitational acceleration rounded to $32.2\ \text{ft/s}^2$ gives the coherent mass equivalence

$$
1\ \text{lbm} \equiv \frac{1\ \text{lbf}}{32.2\ \text{ft/s}^2} = \frac{1\ \text{lbf s}^2}{32.2\ \text{ft}}.
$$

The complete conversion is therefore

$$
\begin{aligned}
\rho &= 0.289\,\frac{\text{lbm}}{\text{in}^3}\left(\frac{1\ \text{lbf s}^2}{32.2\ \text{lbm ft}}\right)\left(\frac{1\ \text{ft}}{12\ \text{in}}\right)\\
&= 0.000748\,\frac{\text{lbf s}^2}{\text{in}^4}\\
&= 0.000748\,\frac{\text{slinch}}{\text{in}^3}.
\end{aligned}
$$

The number 0.289 is not itself wrong; the mistake is entering it as though lbm/in^3 were already the coherent IPS mass-density unit. If a load is specified as weight density instead, write and convert it explicitly as force per volume, lbf/in^3, rather than silently treating it as mass density.