CONTENTS

Engineering Data

Sphere:

Surface Area, $A = 4\pi r^2 = \pi d^2$

Volume, $V = 4/3\pi r^3 = \dfrac{\pi d^3}{6}$

Cone and Pyramid:

Volume, V = 1/3 (area of base) (altitude)

Simpson's Rules:

First Rule: $\Sigma = 1/3\ h\ [y_1 + 4y_2 + 2y_3 + 4y_4 + 2y_5 ------ y_n]$

(odd number of ordinates)

Second Rule: $\Sigma = 3/8\ h\ [y_1 + 3y_2 + 3y_3 + 2y_4 + 3y_5 + 3y_6 + 2y_7 ------ y_n]$

(even number of ordinates)

Factors

$(x+y)^2 = x^2 + 2xy + y^2$

$(x-y)^2 = x^2 - 2xy + y^2$

$x^2 - y^2 = (x-y)(x+y)$

$(x+y)^3 = x^3 + 3x^2y + 3xy^2 + y^2$

$x^3 + y^3 = (x+y)(x^2 - xy + y^2)$

$(x-y)^3 = x^3 - 3x^2y + 3xy^2 - y^3$

$x^3 - y^3 = (x-y)(x^2 + xy + y^2)$

Quadratic Equations

If $ax^2 + bx + c = 0$, *then* $x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

Sum of roots $= -\dfrac{b}{a}$ Product of roots $= \dfrac{c}{a}$

Also

if $[b^2 - 4ac]$ is negative / zero / positive then roots are imaginary / real and equal / real and unequ

SI UNIT PREFIXES Amount	Multiples and Submultiples	Prefixes	Symbols
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	deka	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

*Most commonly used.

RELATIVE DENSITY OF VARIOUS SUBSTANCES
(ratio between density of substance and density of pure water)

Water (fresh)	1·00	Mica	2·9
Water (sea average)	1·03	Nickel	8·6
Aluminium	2·56	Oil (linseed)	0·94
Antimony	6·70	„ (olive)	0·92
Bismuth	9·80	„ (petroleum)	0·76–0·86
Brass	8·40	„ (turpentine)	0·87
Brick	2·1	Paraffin	0·86
Calcium	1·58	Platinum	21·5
Carbon (diamond)	3·4	Sand (dry)	1·42
Carbon (graphite)	2·3	Silicon	2·3
Carbon (charcoal)	1·8	Silver	10·57
Chromium	6·5	Slate	2·1–2·8
Clay	1·9	Sodium	0·97
Coal	1·36–1·4	Steel (mild)	7·86
Cobalt	8·6	Sulphur	2·07
Copper	8·77	Tin	7·3
Cork	0·24	Tungsten	19·1
Glass (crown)	2·5	Wood (ash)	0·75
Glass (flint)	3·5	„ (beech)	0·7–0·8
Gold	19·3	„ (ebony)	1·1–1·2
Iron (cast)	7·21	„ (elm)	0·66
Iron (wrought)	7·78	„ (lignum-vitae)	1·3
Lead	11·4	„ (oak)	0·7–1·0
Magnesium	1·74	„ (pine)	0·56
Manganese	8·0	„ (teak)	0·8
Mercury	13·6	Zinc	7·0

SPECIFIC HEAT OF LIQUIDS
$kJ(kg\ K)^{-1}$

Alcohol	2·515	Olive Oil	1·96
Ammonia (liquid)	3·98	Petroleum	2·17
Benzol	1·75	Petrol	1·255
Carbonic Acid (liquid)	3·14	Turpentine	1·88
Mercury	0·138	Water	4·187

SPECIFIC HEAT AND LINEAR EXPANSION OF SOLIDS

	Specific Heat $kJ(kg\ K)^{-1}$	Mean Expansion per °C $\times 10^{-6}$		Specific Heat $kJ(kg\ K)^{-1}$	Mean Expansion per °C $\times 10^{-6}$
Aluminium	0·8876	23	Iron (cast)	0·5443	11
Antimony	0·2009	12	Iron (wrought)	0·4732	12
Bismuth	0·1256	13·5	Lead	0·1298	27·9
Brass	0·3936	18·9	Nickel	0·4563	12·8
Carbon	0·8373	7·92	Platinum	0·1340	8·8
Cobalt	0·4312	12·22	Silicon	0·7076	
Copper	0·3978	16·7	Silver	0·2345	18·7
Glass	0·8290	9	Steel (mild)	0·4857	12
Gold	0·1298	14·4	Tin	0·2345	21·6
Ice	2·110	50	Zinc	0·3894	28·8

MELTING POINT OF VARIOUS SUBSTANCES

Substance	Melting Point °C	Lat. Heat of Fusion kJ/kg	Substance	Melting Point °C	Lat. Heat of Fusion kJ/kg
Aluminium	660	380	Nickel	1453	19
Antimony	630	168	Platinum	1769	114
Bismuth	260	53	Silver	961	104
Brass	80–1000	—	Sulphur	113	39
Chromium	1800	—	Tallow	43	—
Cobalt	1492	—	Tantalum	2996	172
Copper	1083	180	Tin	232	60
Gold	1063	68	Tungsten	3380	—
Glass	1100	—	Zinc	419	100
Ice	0	336	Solder (com.) (2 tin to 1 lead)	171	—
Iron (cast)	1535	109			
Iron (wrought)	1538	266	Fusible Metal	50	—
Lead	327	23	(5 tin, 3 lead		
Manganese	1260	—	5 Bismuth	—	—
Mercury	−39	12	3 Mercury)		

PERFECT GASES

At normal atmospheric conditions, and over a limited range of temperature and pressure, the gases listed may be assumed to behave as perfect gases. That is, they may be assumed to have the equation of state $pv = RT$, and to have constant specific heats.

Molar (universal) gas constant: $\bar{R} = MR = 8.3143$ kJ/kmol K.

Molar volume of a perfect gas: 1 kmol of any perfect gas occupies a volume of approximately 22.4 m³ at s.t.p. (0 °C and 1 atm).

Gas	Molar mass kg/kmol	Gas constant kJ(kg K)⁻¹	Specific heat capacity kJ(kg K)⁻¹		c_p/c_v
			c_p	c_v	
Air	29.0	0.287	1.01	0.72	1.40
Atmospheric nitrogen †	28.15	0.295	1.03	0.74	1.40
N_2	28	0.297	1.04	0.74	1.40
O_2	32	0.260	0.92	0.66	1.40
A	40	0.208	0.52	0.31	1.67
H_2	2*	4.12	14.20	10.08	1.41
He	4	2.08	5.19	3.11	1.67
CO	28	0.297	1.04	0.74	1.40
CO_2	44	0.189	0.82	0.63	1.31
SO_2	64	0.130	0.61	0.48	1.26
CH_4	16	0.520	2.23	1.71	1.31
C_2H_6	30	0.277	1.75	1.47	1.19
C_3H_6	42	0.198	1.52	1.32	1.15

* A more exact value is 2.016.

† Air contains 0.93 % of argon (A) and traces of other gases; these and the nitrogen together are called *atmospheric nitrogen*.

Real gases are not perfect gases, and the rounded values for R, c_p, c_v and c_p/c_v listed above do not exactly satisfy the relationships between these quantities that would obtain for perfect gases.

Air composition:

Volumetric (and molar): **21.0 % O_2, 79.0 % atmospheric nitrogen.**

Gravimetric: **23.2 % O_2, 76.8 % atmospheric nitrogen.**

A	α	Alpha	N	ν	Nu
B	β	Beta	Ξ	ξ	Xi
Γ	γ	Gamma	O	o	Omicron
Δ	δ	Delta	Π	π	Pi
E	ε	Epsilon	P	ρ	Rho
Z	ζ	Zeta	Σ	σ	Sigma
H	η	Eta	T	τ	Tau
Θ	θ	Theta	Y	υ	Upsilon
I	ι	Iota	Φ	ϕ	Phi
K	κ	Kappa	X	χ	Chi
Λ	λ	Lambda	Ψ	ψ	Psi
M	μ	Mu	Ω	ω	Omega

expansion for common liquids

Liquid	Per °C
Alcohol, methyl	122×10^{-5}
Gasoline	108×10^{-5}
Glycerin	53×10^{-5}
Mercury	18.2×10^{-5}
Petroleum	89.9×10^{-5}
Sulfuric acid	58×10^{-5}
Turpentine	94×10^{-5}
Water (at 20°C)	20.7×10^{-5}

OBSERVABLE	SYMBOL	DIMENSION	MKSC UNIT
Length, position	$\mathbf{r}, x, \ell, \ldots$	L	meter (m)
Time	t, τ	T	second (sec)
Mass	m	M	kilogram (kg)
Area	A, S	L^2	m^2
Volume	V	L^3	m^3
Density	ρ	ML^{-3}	kg/m^3
Frequency	ν, f	T^{-1}	Hertz (Hz) = sec^{-1}
Angle	θ, ϕ	—	radian (rad)
Solid angle	Ω	—	steradian (sr)
Velocity	$\mathbf{v}, v, w$	LT^{-1}	m/sec
Acceleration	$\mathbf{a}$	LT^{-2}	m/sec^2
Angular frequency	ω	T^{-1}	rad/sec
Angular acceleration	α	T^{-2}	rad/sec^2
Force	$\mathbf{F}$	MLT^{-2}	newton (N) = $kg\text{-}m/sec^2$
Energy, work	E, W, U, T	ML^2T^{-2}	Joule (J) = N-m
Power	P	ML^2T^{-3}	watt (W) = J/sec
Momentum	$\mathbf{p}$	MLT^{-1}	kg-m/sec
Angular momentum	$\mathbf{L}, \mathbf{J}$	ML^2T^{-2}	$kg\text{-}m^2/sec^2$
Moment of inertia	I	ML^2	$kg\text{-}m^2$
Torque	$\boldsymbol{\tau}$	ML^2T^{-2}	N-m
Pressure	P	$ML^{-1}T^{-2}$	$N/m^2 = kg/m\text{-}sec^2$ = Pa
Temperature	T	—	degree Kelvin (°K)
Heat	Q	ML^2T^{-2}	J
Entropy	S	$ML^2T^{-2}/°K$	J/°K
Electric charge	Q, q	C	coulomb (coul)
Charge density	ρ, ρ_e	CL^{-3}	$coul/m^3$
Surface charge density	σ	CL^{-2}	$coul/m^2$
Current	I	CT^{-1}	ampere (A) = coul/sec
Current density	$\mathbf{j}$	$CL^{-2}T^{-1}$	A/m^2
Electrostatic potential	V	$ML^2T^{-2}C^{-1}$	volt (V) = J/coul
Electric field	$\mathbf{E}$	$MLT^{-2}C^{-1}$	V/m = N/coul
Polarization	$\mathbf{P}$	CL^{-2}	$coul/m^2$
Resistance	R	$ML^2T^{-3}C^{-2}$	ohm (Ω) = V/A
Resistivity	ρ	$ML^3T^{-3}C^{-2}$	Ω-m
Dielectric constant	K	—	—
Electric dipole moment	$\mathbf{p}$	CL	coul-m
Magnetic field	$\mathbf{B}$	$MT^{-1}C^{-1}$	tesla (T) = $V\text{-}sec/m^2$
Magnetic flux	ϕ	$ML^2T^{-1}C^{-1}$	weber (Wb) = V-sec
Magnetic dipole moment	$\mathbf{m}$	CL^2T^{-1}	$A\text{-}m^2$
Magnetization	$\mathbf{M}$	$CL^{-1}T^{-1}$	A/m
Magnetizing field	$\mathbf{H}$	$CL^{-1}T^{-1}$	A/m
Capacitance	C	$C^2M^{-1}L^{-2}T$	farad (F) = coul/V
Inductance	L	$ML^2T^{-2}C^{-2}$	henry (H) = V-sec/A = Ω-sec

STRENGTH AND PROPERTIES OF VARIOUS METALS

Metal	Tensile Strength MPa	Compressive Strength MPa	Shear Strength MPa	Modulus of Elasticity GPa	Modulus of Rigidity GPa	Mass Density kg/m^3
Aluminium (cast)	80	—	80	58	22·5	2574
(rolled)	124	78	93	70	26·3	2712
Brass (cast)	170	78	124	62	23·2	8384
,, (wire)	310	—	—	87	34	8384
Bronze (phosphor)	390	620	370	95	35·5	8578
(manganese)	465	—	—	95	35·5	—
Copper (cast)	140	390	170	85	32·5	8772
(rolled)	220	390	186	104	38·5	8772
(wire) unannealed	400	—	—	116	46	8772
(wire) annealed	280	—	—	108	43·3	8772
Gunmetal	220	620	186	78	34	8606
Iron (cast)	125	700	155	124	40·2	7194
(wrought)	360	340	280	193	77	7775
Lead	24	46	—	5	1·85	11 400
Muntz Metal	340	360	—	93	34	8190
Steel (mild)	460	465	340	207	82	7830
(tool)	800	800	695	224	85	7830
(castings)	390	—	—	185	70	7830
Tin	30	93	28	39	13·9	7305
Zinc	23	230	93	85	32·5	7000

SYMBOLS AND ATOMIC WEIGHTS OF ELEMENTS

Aluminium	Al	27·1	Manganese	Mn	54·9
Antimony	Sb	120·2	Mercury	Hg	200·6
Bismuth	Bi	208·0	Nickel	Ni	58·7
Calcium	Ca	40·0	Nitrogen	N	14·0
Carbon	C	12·0	Oxygen	O	16·0
Chlorine	Cl	35·5	Phosphorus	P	31·0
Chromium	Cr	52·0	Platinum	Pt	195·2
Cobalt	Co	58·9	Potassium	K	39·1
Copper	Cu	63·5	Silicon	Si	28·3
Gold	Au	197·2	Silver	Ag	107·8
Helium	He	4·0	Sodium	Na	23·0
Hydrogen	H	1·0	Sulphur	S	32·0
Iron	Fe	55·8	Tin	Sn	118·7
Lead	Pb	207·2	Tungsten	W	184·0
Magnesium	Mg	24·3	Zinc	Zn	65·3

THEORY OF MACHINES

Uniform Velocity and Acceleration

Linear	*Angular*
$v_2 = v_1 + at$	$\omega_2 = \omega_1 + \alpha t$
$v_2^2 = v_1^2 + 2as$	$\omega_2^2 = \omega_1^2 + 2\alpha\theta$
$s = \dfrac{v_1 + v_2}{2}\, t$	$\theta = \dfrac{\omega_1 + \omega_2}{2}\, t$
$s = v_1 t + \frac{1}{2}at^2$	$\theta = \omega_1 t + \frac{1}{2}\alpha t^2$

s =	Linear Distance	m	θ =	Angular Displacement	radians
v =	Linear Velocity	m/s	ω =	Angular Velocity	rad/s
a =	Linear Acceleration	m/s^2	α =	Angular Acceleration	rad/s^2
t =	Time	s	t =	Time	s

Suffixes 1 and 2 refer to initial and final conditions respectively.

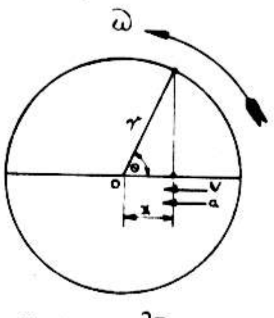
Relationship between linear and angular quantities

$$s = \theta r$$
$$v = \omega r$$
$$a = \alpha r$$

Motion of a point travelling on a circular path

$$\text{Centripetal acceleration} = \omega^2 r = \frac{v^2}{r}$$

Circle Diagram



$v = \omega r \sin\theta = \omega\sqrt{r^2 - x^2}$

$a = \omega^2 r \cos\theta = \omega^2 x$

x = Displacement from mean position.

r = Amplitude or motion.

ω = Uniform Angular Velocity of the point travelling on the circumference of the circle.

$$\text{Periodic time} = \frac{2\pi}{\omega}$$

$$\text{Frequency} = \frac{1}{\text{periodic time}}$$

$$\text{Periodic time} = 2\pi\sqrt{\frac{\text{displacement}}{\text{acceleration}}}$$

Dynamics

Fundamental force equation $F = ma$

Fundamental torque equation $T = J\alpha$ where $J = mk^2$

Linear momentum $= mv$

Angular momentum $= J\omega$

Impulse = Force × Time
= Mass × Change of velocity
= Change of momentum

Impulse torque = Torque × Time
= Mass moment of inertia × Change of angular velocity
= Change of angular momentum

Coefficient of restitution between two bodies colliding $= \dfrac{\text{Relative velocity between bodies after impact}}{\text{Relative velocity between bodies before impact}}$

Kinetic energy of translation $= \frac{1}{2}mv^2$

Kinetic energy of rotation $= \frac{1}{2}J\omega^2 = \frac{1}{2}mk^2\omega^2$

Work done by a force $= \int F.ds$
$= Fs$ if force is constant

Work done by a torque $= \int Td\theta$
$= T\theta$ if torque is constant

Power developed by a force $= Fdv$
$= Fv$ if force and velocity are constant

Power developed by a torque $= T.d\omega$
$= T\omega$ if torque and angular velocity are constant

Centrifugal force $= m\omega^2 r = \dfrac{mv^2}{r}$

F = unbalanced acceleration force (newtons N)
T = unbalanced accelerating torque (Nm)
m = mass (kg)
a = linear acceleration (m/s^2)
α = angular acceleration (rad/s^2)
J = mass moment inertia about axis of rotation ($kg.m^2$)
$= mk^2$
k = radius of gyration about axis of rotation (m)
s = linear displacement (m)
θ = angular displacement (radians)
v = linear velocity (m/s)
ω = angular velocity (rad/s)

Energy units in joules(J) Power units in watts (W)

Gyroscopic Torque

$$T = J\omega\Omega = mk^2\omega\Omega$$

J = mass moment of inertia of wheel
ω = angular velocity of wheel
Ω = angular velocity of precession

Friction

$F = \mu N$ where $\mu = \dfrac{F}{N} = \tan\phi$

F = friction force
N = reaction normal to surface
μ = coefficient of friction
ϕ = friction angle

Inclined Plane

Force parallel to plane $= W \sin\theta$ (without friction)

$= \dfrac{W \sin(\theta+\phi)}{\cos\phi}$ (with friction)

Force parallel to base $= W \tan\theta$ (without friction)

$= W \tan(\theta+\phi)$ (with friction)

Force at angle to α plane $= \dfrac{W \sin\theta}{\cos\alpha}$ (without friction)

$= \dfrac{W \sin(\theta+\phi)}{\cos(\alpha-\phi)}$ (with friction)

where W = weight of body on plane
θ = angle of plane
ϕ = friction angle
Force = force to move body up plane.

Threads (With Friction)

Square

$$\eta = \frac{\tan\theta}{\tan(\theta+\phi)}$$

$$\eta_{max} = \frac{1-\sin\phi}{1+\sin\phi}$$

θ = thread angle
ϕ = friction angle

Single Plate Clutch

Torque transmitted $= \frac{2}{3}\mu W\left(\dfrac{R_1^3 - R_2^3}{R_1^2 - R_2^2}\right)$ Uniform pressure theory

Torque transmitted $= \mu W R_m$ Uniform wear theory

For multi-plate clutch with n pairs of contact surfaces torque transmitted will be n times the above.

Cone Clutch

Torque transmitted $\dfrac{\mu W}{\sin\theta}\left(\dfrac{R_1^3 - R_2^3}{R_1^2 - R_2^2}\right)$ Uniform pressure theory

Torque transmitted $= \dfrac{\mu W R_m}{\sin\theta}$ Uniform wear theory

Unless otherwise stated use uniform pressure theory for bearings, uniform wear theory for clutches.

R_m = mean radius
W = Axial load
θ = Semi apex angle.

Centrifugal Clutch

Torque transmitted $= n\mu R(F-P)$
n = Number of shoes
R = Inside radius of rim
F = Centrifugal force on each shoe
P = Force exerted on each shoe by retaining spring.

Belt Drives

Flat Belts. $\dfrac{T_1 - T_c}{T_2 - T_c} = e^{\mu\theta}$

T_1 = Tension on tight side of belt (N) $T_1 - T_c$ = Effective tension tight side.

T_2 = Tension on slack side of belt (N) $T_2 - T_c$ = Effective tension slack side.

T_c = Centrifugal tension (N)
$T_c = mv^2$
m = mass per unit length of belt (kg/m)
v = linear velocity of belt (m/s)

Power transmitted $= (T_1 - T_2)v$

Maximum power transmitted when $T_c = \dfrac{T_1}{3}$

Initial tension $T_o = \dfrac{T_1 + T_2}{2}$

STRENGTH OF MATERIALS

A = Area
$A\bar{x}$ = 1st moment of area
D, d = diameter
E = Young's Modulus of Elasticity
F = Shearing force
G = Modulus of Rigidity or Shear
h = Height, distance
I = 2nd moment of area
J = Polar 2nd moment of area
K = Bulk Modulus
L = Length
M = Bending moment
P = Force
p = Pressure, compressive stress
R, r = Radius
T = Torque
U = Strain energy
W = Load, weight

Δ = Deflection
ε = Direct strain
θ = Twist, angle
γ = Shear strain
ρ = Density
σ = Direst stress
τ = Shear stress
ν = Poisson's Ratio
ω = Angular velocity

Stress, Strain and Modulii

$$\text{Modulus of Elasticity } (E) = \frac{\text{direct stress } (\sigma)}{\text{direct strain } (\varepsilon)} = \frac{\frac{\text{load}}{\text{area}}}{\frac{\text{extension}}{\text{original length}}}$$

$$\text{Poisson's Ratio } \nu = \frac{\text{lateral strain}}{\text{linear strain}}$$

$$\text{General expression for strain } \varepsilon_x = \frac{\sigma_x}{E} - \frac{\nu\sigma_y}{E} - \frac{\nu\sigma_z}{E}$$

$$\text{Modulus of Rigidity } (G) = \frac{\text{shear stress } (\tau)}{\text{shear strain } (\gamma)}$$

$$\text{Bulk Modulus } (K) = \frac{\text{fluid press } (p)}{\text{volumetric strain } (\varepsilon_v)}$$

$$G = \frac{E}{2(1+\nu)}$$

$$K = \frac{E}{3(1-2\nu)}$$

$$\text{Principal Stress} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\frac{(\sigma_x - \sigma_y)^2}{2} + \tau^2}$$

$$\text{Angle of Principal planes: } \tan 2\theta = \frac{2\tau}{\sigma_x - \sigma_y}$$

$$\text{Maximum Shear Stress} = \sqrt{\frac{(\sigma_x - \sigma_y)}{2}^2 + \tau^2}$$

$$\text{Principal Strains} = \frac{\varepsilon_x + \varepsilon_y}{2} \pm \sqrt{\frac{(\varepsilon_x - \varepsilon_y)^2}{2} + \frac{\gamma^2}{4}}$$

Strain Energy

Direct stress $U = \frac{\sigma^2}{2E} \times \text{volume}$

Shear stress $U = \frac{\tau^2}{2G} \times \text{volume}$

Beams and Bending

$$\frac{M}{I} = \frac{\sigma}{y} = \frac{E}{R}$$

M = Bending moment
I = Second moment of area
σ = Stress
y = Distance from neutral axis.
E = Modulus of elasticity
R = Radius of curvature

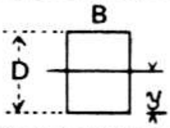
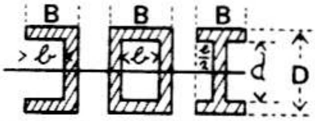
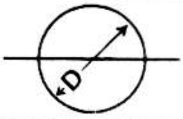
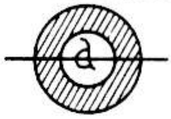
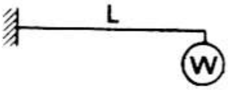
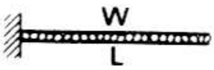
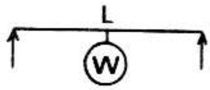
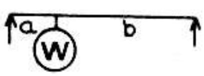
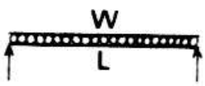
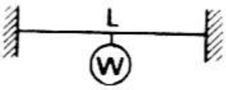
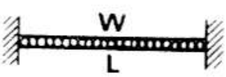
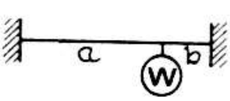
Section	I	y	$\frac{I}{y}$
	$\frac{BD^3}{12}$	$\frac{D}{2}$	$\frac{BD^2}{6}$
	$\frac{BD^3 - bd^3}{12}$	$\frac{D}{2}$	$\frac{BD^3 - bd^3}{6D}$
	$\frac{\pi}{64} D^4$	$\frac{D}{2}$	$\frac{\pi}{32} D^3$
	$\frac{\pi}{64}(D^4 - d^4)$	$\frac{D}{2}$	$\frac{\pi}{32}\left(\frac{D^4 - d^4}{D}\right)$

TABLE OF BENDING MOMENTS AND DEFLECTIONS

Load Diagram	Bending Moment	Deflection
	WL (at wall)	$\frac{WL^3}{3EI}$ (at free end)
	$\frac{WL}{2}$ (at wall)	$\frac{WL^3}{8EI}$ (at free end)
	$\frac{WL}{4}$ (at centre)	$\frac{WL^3}{48EI}$ (at centre)
	$\frac{Wab}{a+b}$ (at load)	$\frac{Wa}{3LEI}\left\{\frac{b(2a+b)}{3}\right\}^{\frac{3}{2}}$ at $\left\{\frac{b(2a+b)}{3}\right\}^{\frac{1}{2}}$ from right
	$\frac{WL}{8}$ (at centre)	$\frac{5WL^3}{384EI}$ (at centre)
	$\frac{WL}{8}$ at centre and ends	$\frac{WL^3}{192EI}$ (at centre)
	$\frac{WL}{12}$ (at the ends) $\frac{WL}{24}$ (at the centre)	$\frac{WL^3}{384EI}$ (at centre)
	$\frac{Wab^2}{L^2}$ (at 'a' end) $\frac{Wba^2}{L^2}$ (at 'b' end)	$\frac{\frac{2}{3}Wa^3b^2}{(3a+b)^2EI}$ (maximum where a is greater than b)

Torsion

general formula $\frac{T}{J} = \frac{\tau}{r} = \frac{G\theta}{l}$

power transmitted $= T\omega = \frac{2\pi NT}{60}$ watts

N = rev/min
T = [N m]

twist on solid tapered shaft $= \frac{32Tl}{3\pi G}\left(\frac{D_1^2 + D_1D_2 + D_2^2}{D_1^3 D_2^3}\right)$

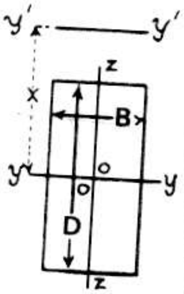
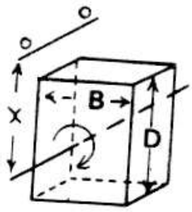
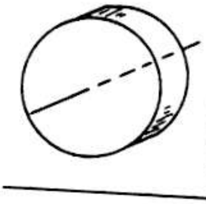
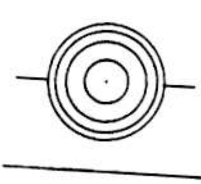
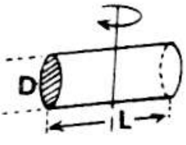
where
D_1 = small diameter
D_2 = large diameter
l = length

Equivalent Bending Moment or Equivalent Torque on a Shaft

$M_E = \frac{M + \sqrt{M^2 + T^2}}{2}$ Principal Stress

$T_E = \sqrt{M^2 + T^2}$ Maximum Shear Stress

Moments of Inertia and k^2

Sketch	Description	Second Moments	(Radius of Gyration)^2
	Rectangle about axis yy	$\frac{BD^3}{12}$	$\frac{D^2}{12}$
	Rectangle about axis zz	$\frac{DB^3}{12}$	$\frac{B^2}{12}$
	Rectangle about axis 00	Area $\times k^2 = BD\left[\frac{D^2+B^2}{12}\right]$	$\frac{D^2+B^2}{12}$
	Rectangle about external axis x from C of G	$BD\left[\frac{D^2}{12}+x^2\right]$	$\left(\frac{D^2}{12}+x^2\right)$
	For rectangular solids $(k)^2$ remains the same but Vol is substituted for Area in expression for I:		
	Rectangular solid rotating about external axis 00 which is x from C of G	Vol $\frac{D^2}{12}+\frac{B^2}{12}+x^2$	$\frac{D^2+B^2}{12}+x^2$
	Circle about a diameter	$\frac{\pi}{64}D^4$	$\frac{D^2}{16} = \frac{R^2}{4}$
	Circle about its centre	$\frac{\pi}{32}D^4$	$\frac{D^2}{8} = \frac{R^2}{2}$
	Cylinder about its axis	Vol $\left[\frac{D^2}{8}\right]$	$\frac{D^2}{8} = \frac{R^2}{2}$
	Sphere rotating about a diameter	Vol $\left[\frac{D^2}{10}\right]$	$\frac{D^2}{10} = \frac{2}{5}R^2$
	Cylinder about an axis at right angles to axis but through the C of G	Vol $\left[\frac{D^2}{16}+\frac{L^2}{12}\right]$	$\frac{D^2}{16}+\frac{L^2}{12}$

ENGINEERING THERMODYNAMICS

Symbols Used

T = Thermodynamic temperature (K)
θ = Temperature value (C)
T_f = Saturation temperature
P, p = Pressure
V, v = Volume
m = Mass
ρ = Density (mass/unit volume)
W = Work energy
P = Power
η = Efficiency
n = Amount of substance (moles or kilomoles)
Vo = Molar volume
C = Vapour velocity
Q = Quantity of heat, Qs = Sensible heat
H = Enthalpy, h = specific enthalpy (enthalpy per unit mass)
U = Internal energy (molecular), u = specific internal energy
E = Total internal energy including kinetic energy (K.E.) and/or P.E.
e = Specific total internal energy
h_f = Specific liquid enthalpy
h_{fg} = Specific enthalpy of evaporation
h_g = Specific enthalpy of dry saturated vapour
c = Specific heat capacity
cp = Specific heat at constant pressure
cv = Specific heat at constant volume
R = Specific gas constant
S = Entropy, s = specific entropy
x = Dryness fraction
R_o = Universal gas constant
ϕ = Heat flow rate
λ = Thermal conductivity
α = Coefficient, linear expansion
β = Coefficient, cubical expansion.

RELATIONSHIPS BETWEEN TEMPERATURE AND VOLUME, AND TEMPERATURE AND PRESSURE,

when $pV^n = C$

$$\frac{T_1}{T_2} = \left\{\frac{V_2}{V_1}\right\}^{n-1} = \left\{\frac{p_1}{p_2}\right\}^{\frac{n-1}{n}}$$

Work Formulae

(i) $PV = Constant$

$$W = PV \log_e \frac{V_2}{V_1}$$

(ii) $PV^n = Constant$

$$W = \frac{(P_1V_1 - P_2V_2)}{n-1}$$

(iii) $P = Constant$

$$W = P(V_2 - V_1)$$

The perfect gas

The characteristic equation of state

$$pv = RT$$

or for m kg, occupying V m³,

$$pV = mRT$$

Universal Gas Equation

$$PV = nR_oT$$

$R_o = MR = 8{\cdot}3143$ kJ/kg mol. K
M = mass of one mol. in kg
n = number of mols

General

The efficiency of any heat engine cycle is given by

$$\eta = \frac{Q_1 - Q_2}{Q_1}$$

where Q_1 is the sum of the heat flows to the cycle and Q_2 the sum of the heat flows from the cycle.

Carnot

$$\eta = \frac{T_1 - T_2}{T_1}$$

for any reversible cycle working between one heat source and one heat sink.

Constant Volume Air Standard Cycle (A.S.E.)

$$\eta = 1 - \frac{1}{r_v^{\gamma-1}}$$

r_v = volume compression ratio.

Constant Pressure Cycle (JOULE)

$$\eta = 1 - \frac{T_4 - T_3}{T_3 - T_2} = 1 - \frac{1}{r_v^{\gamma-1}}$$

r_v = volume compression ratio

T_1 = temperature at beginning of compression.

Diesel Cycle

$$\eta = 1 - \frac{1}{\gamma}\left[\frac{T_4 - T_1}{T_3 - T_2}\right]$$

$$= 1 - \frac{1}{r_v^{\gamma-1}}\left[\frac{r_c^{\gamma} - 1}{\gamma(r_c - 1)}\right]$$

r_v = volume compression ratio

$r_c = \frac{T_3}{T_2}$

T_1 = temperature at beginning of compression.

Dual Cycle

$$\eta = 1 - \frac{1}{r_v^{\gamma-1}} \cdot \frac{r_p r_c^{\gamma} - 1}{(r_p - 1) + \gamma r_p (r_c - 1)}$$

r_v = vol. compression

$r_c = \frac{V_4}{V_3}$ ratio

$r_p = \frac{p_3}{p_2}$

v_1 = beginning of compression

Heat Transfer

(i) **Conduction**

for steady heat flow through a flat surface of one material,

$$Q = \frac{kA(t_1 - t_2)}{x}$$

steady flow through a flat composite wall,

$$Q = \frac{A(t_1 - t_n)}{\Sigma \frac{x}{k}}$$

(always carefully note the units in which a 'k' value is given)

t_1 are surface temperatures of the wall or plate.

A = surface area m^2

x = thickness (m)

k = conductivity coefficient (Watts/m °C_o)

through a thick cylinder,

$$Q = \frac{2\pi lk(t - t_2)}{\log_e \frac{r_2}{r}}$$

l = length (m)

r = inner radius

r_2 = outer radius (m)

through a composite thick cylinder,

$$Q = \frac{l(t - t_0)}{\sum \left[\frac{\log_e \frac{r^{n+1}}{r^n}}{2\pi k_n}\right]}$$

t = inner temperature

t_o = outer temperature

r^{n+k} and r^n are the radii of any included cylinder and k_n its conductivity coefficient.

The overall heat transfer coefficient is U.

(ii) **Convection**

$$\frac{1}{U} = \frac{1}{h_1} + \frac{1}{k/x} + \frac{1}{h_2}$$

$$Q = UA(t_1 - t_4) = h_1 A(t_1 - t_2) = h_2 A(t_3 - t_4) = kA\frac{(t_2 - t_3)}{x}$$

t_1 = temperature of hot fluid
t_2 = temperature of tube wall on hot fluid side

t_3 = temperature of tube wall on cool side
t_4 = temperature of cool fluid

Heat Exchangers

In these the overall temperature difference across the wall varies and a mean temperature difference is used in the Q equation.

mean temperature difference for parallel flow and contra flow exchangers

$$= \frac{\Delta t_1 - \Delta t_0}{\log_e \left(\frac{\Delta t_1}{\Delta t_0}\right)}$$

Δt_1 = temp. difference at inlet end of hot fluid.
Δt_0 = temp. difference at outlet end of hot fluid.

Radiation

Stefan-Boltzmann Law

for 'black' body $q_b = \sigma T^4$

q_b = energy emitted per unit area per unit time, for black body
σ = Stefan-Boltzmann constant
T = absolute temperature (k)

for 'grey' body $\varepsilon = \dfrac{q}{q_b}$

$$q = \varepsilon q_b = \varepsilon \sigma T^4$$

q = energy emitted (or radiated) per unit area per unit time for 'grey' body

$$\varepsilon = \alpha$$

ε = emissivity, being unity for black body and less than unity for any real body

for 'grey' body of surface area A and at absolute temperature T_1, and surroundings at absolute temperature t_2, we have

α = ratio of energy absorbed by a real body to energy absorbed by a 'black' body

$A = m^2$

q radiated $= \varepsilon A \sigma T_1^4$
q absorbed $= \alpha A \sigma T_2^4$
nett q $= \varepsilon A \sigma T_1^4 - \alpha A \sigma T_2^4$
$= \varepsilon A \sigma (T_1^4 - T_2^4)$
$= 56 \cdot 7 \times 10^{-12} \varepsilon A (T_1^4 - T_2^4)$ kJ/s

Substance	Thermal conductivity $W(m\ K)^{-1}$
Pure copper	386
Pure aluminium	229
Duralumin	164
Cast iron	52
Mild steel	48·5
Lead	34·6
Concrete	0·85 to 1·4
Building brick	0·35 to 0·7
Wood (oak)	0·15 to 0·2
Rubber	0·15
Cork board	0·043

Typical Values of ε

Copper, polished	0·02
Copper, dull	0·56
Steel, polished	0·07
Steel, dull	0·8
White paint	0·96
Lamp black	0·96

Pressure at Depth h from Free Surface
Pressure $= h\rho g$ N/m^2
where h = depth to point considered in metres
ρ = fluid density in kg/m^3
$g = 9{\cdot}81$ m/s^2
Total Pressure Load $= \bar{h}a\rho g$ Newtons on immersed area
where a is area considered in m^2
and $\bar{h}$ is depth from free surface to centroid of figure in metres.

Centre of Pressure

$$\text{Depth to C of P from free surface} = \frac{\text{2nd moment of area about surface}}{\text{1st moment of area about surface}}$$

Common Cases
Rectangle, depth D, top edge in surface: C of P at $\frac{2}{3}D$ depth
Circle, diameter D, top edge in surface: C of P at $\frac{5}{8}D$ depth
Triangle, vertical depth H, side in surface: C of P at $\frac{1}{2}H$ depth
Triangle, vertical depth H, corner in surface: C of P at $\frac{3}{4}H$ depth.

Energy Equation
Expressed per unit *Weight* of fluid flowing.

$$H = Z + \frac{P}{\rho g} + \frac{v^2}{2g} + \text{losses}$$

where H = total head in metres
Z = height above datum level in metres
P = pressure in N/m^2
ρ = fluid density in kg/m^3
v = fluid velocity in m/s
$g = 9{\cdot}81$ m/s^2
loss may be due to any or all of the following:
loss due to enlargement $= \dfrac{(v_1 - v_2)^2}{2g}$
loss due to contraction $= \dfrac{kv^2}{2g}$ usually taken as $\dfrac{0{\cdot}5v^2}{2g}$
loss due to friction hf $= \dfrac{4fLv^2}{2gd}$
where f is a constant, depending on the type of flow and the pipe finish, d is the pipe diameter and L the length of pipe considered in metres.

Orifices
Theoretical velocity of flow from an orifice $= \sqrt{2gh}$ m/s
where h is depth to centre of orifice
Actual velocity of flow $= C_v\sqrt{2gh}$ m/s
small round orifices $C_v \simeq 0{\cdot}97$
Area of jet at Vena Contracta $= C_a \times$ Area Orifice
average value of C_a for small round orifices $= 0{\cdot}64$
Quantity flowing from an orifice $= C_d \times$ Area Orifice $\times \sqrt{2gh}$
where,
area orifice is in m^2
h is in m
C_d is the coefficient of discharge $= C_v \times C_a$

Velocity of a Pressure Wave or Sound in a Liquid

$$\alpha = \frac{k}{\rho}$$

where k is the coefficient of compressibility of the liquid in N/m^2
ρ is the liquid density kg/m^3
$\alpha \simeq 1430$ m/s for water.

ELECTROTECHNOLOGY

Electrical Quantity	*Symbol*	*Unit*	*Unit Abbreviation*
Admittance	Y	siemens	S
Angular velocity	ω	radian per second	rad/s
Capacitance	C	farad	F
		microfarad	μF
Charge or Quantity of electricity	Q	coulomb	C
Conductance	G	siemens	S
Conductivity	σ	siemens per metre	S/m
Current			
Steady or r.m.s. value	I	ampere	A
		milliampere	mA
		microampere	μA
Instantaneous value	i		
Maximum value	I_m		
Current density	J	ampere per metre²	A/m²
Difference of potential			
Steady or r.m.s. value	V	volt	V
		millivolt	mV
		kilovolt	kV
Instantaneous value	v		
Maximum value	V_m		
Electric force (Electric field strength)	E	volt per metre	V/m
Electric flux	ψ	coulomb	C
Electric flux density	D	coulomb per square metre	C/m²
Electromotive force			
Steady or r.m.s. value	E	volt	V
Instantaneous value	e		
Maximum value	E_m		
Energy	W	joule	J
		watt-hour	Wh
		kilowatt-hour	kWh
		electronvolt	eV
Frequency	f	hertz	Hz
		kilohertz	kHz
		megahertz	MHz
Impedance	Z	ohm	Ω
Inductance, self	L	henry (plural, henrys)	H
Inductance, mutual	M	henry (plural, henrys)	H
Magnetizing force (Magnetic field strength)	H	ampere per metre	A/m
Magnetic flux	ϕ	weber	Wb
Magnetic flux density	B	tesla	T
Magnetomotive force	F	ampere	A
Permeability of free space	μ_0	henry per metre	H/m
Permeability, relative	μ_r		
Permeability, absolute	μ	henry per metre	H/m
Permittivity of free space	ε_0	farad per metre	F/m
Permittivity, relative (Di-electric constant)	ε_r		
Permittivity, absolute	ε	farad per metre	F/m
Power	P	watt	W
		kilowatt	kW
		megawatt	MW
Reactance	X	ohm	Ω
Reactive voltampere		var	VAr
Reluctance	S	ampere per weber	A/Wb
Resistance	R	ohm	Ω
		microhm	μΩ
		megohm	MΩ
Resistivity	ρ	ohm-metre	Ωm
		microhm-metre	μΩ m
		ohm-centimetre	Ω cm
Susceptance	B	siemens	S
Voltampere		voltampere	VA
		kilovoltampere	kVA

ELECTRICAL CIRCUITS

Simple D.C. Circuit (steady conditions)

(a) **Steady Conditions**

Ohm's Law $I = \frac{V}{R}$

Power in circuit $= IV = I^2 R = \frac{V^2}{R}$ watts

Energy in time t $= Vt$ joules

For resistances in series $R = R_1 + R_2 + R_3 + \ldots$

For resistances in parallel $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$

that is $G = G_1 + G_2 + G_3 + \ldots$

Resistivity $R = \frac{\rho l}{a}$

Temperature effects $R = R_0(1 + \alpha t)$

Induced e.m.f. $= -L\frac{di}{dt}$ volts.

(b) **Inductive Conditions** (e.g. switching)

i (rising) $= I\left(1 - e^{\frac{-Rt}{L}}\right) = I\left(1 - e^{\frac{-t}{T}}\right)$

i (decaying) $= Ie^{\frac{-Rt}{L}}$

Time constant $T = \frac{L}{R}$ seconds

Energy stored in magnetic field $= \frac{1}{2}LI^2$ joules.

Simple a.c. Circuit

$$e = E \sin \theta = 2\pi \text{ BAN } n \sin \theta \text{ volts}$$

Average current $= \frac{\Sigma i}{\text{number of ordinates}} = 0{\cdot}637\ I_m$ if sinusoidal

r.m.s. current $= \sqrt{\frac{\Sigma i^2}{\text{number of ordinates}}} = 0{\cdot}707\ I_m$, if sinusoidal

form factor $= \frac{\text{r.m.s. value}}{\text{average value}} = 1{\cdot}11$, if sinusoidal.

Circuit Laws

(a) **Pure Resistance Current**

$I = \frac{V}{R}$ current and voltage are in phase

(b) **Pure Inductive Current**

$I = \frac{V}{2\pi fL} = \frac{V}{X_L}$ current lags applied voltage by 90° ($\phi = 90°$)

(c) **Pure Capacitive Current**

$I = 2\pi fCV$ current leads applied voltage by 90° ($\phi = 90°$)

$= \frac{V}{\frac{1}{2\pi fC}} = \frac{V}{X_C}$

(d) **RLC Series Circuit**

$I = \frac{V}{Z}$ where $Z = \sqrt{\left[R^2 + \left(2\pi fL - \frac{1}{2\pi fC}\right)^2\right]}$

$= \sqrt{[R^2 + (X_L - X_C)^2]}$

for resonance, $X = X_C$, $f = \frac{1}{2\pi\sqrt{LC}}$

(e) **RLC Parallel Circuit** $C = \frac{L}{R^2 + (2\pi fL)^2}$

$f = \frac{1}{2\pi\sqrt{LC}}$ provided $R \ll 2\pi fL$

and, impedance at resonance $= \frac{L}{CR}$

NAVAL ARCHITECTURE

Notation

Z = chosen ordinate in integration rules
d = draught, or distance
∇ = displacement volume
Δ = ship mass
W = ship weight
w = weight (general)
v = volume of emerged/immersed wedge
S = wetted surface
A_w = waterplane area
B = centre of buoyancy (also beam)
L = ship length (general)
M = metacentre
G = centre of ship mass
BM = metacentric radius
GM = metacentric height
GZ = righting lever
G_1G_2 = movement of G
I_f = second moment of area of waterplane about a transverse axis through centroid
i = second moment of area of a free liquid surface about a longitudinal axis through its centroid
ρ = density
MCT 1 cm = moment to change trim one cm
R_f = frictional resistance

R_r = residual resistance
R_t = total resistance
V = hull speed
g = acceleration due to gravity (also centroids of immersed/ emerged wedges)
f = Froude friction factors
R_n $= \frac{VL}{\nu}$ (Reynolds number) non-dimensional
F_n $= \frac{V}{\sqrt{Lg}}$ (Froude's number) non-dimensional
T = thrust
t = thrust deduction factor
a = augment of resistance factor
w_f = Froude wake fraction
w_t = Taylor wake fraction
P_D = delivered power
P_E = effective power
P_T = thrust power
η_O = open water propeller efficiency
η_B = behind hull propeller efficiency
η_r $= \frac{\eta_B}{\eta_O}$ = relative rotative efficiency
η_H = hull efficiency
QPC = quasi propulsive coefficient
P = propeller pitch
N = revolutions per minute

n = revolutions per second
V_a = speed of advance of propeller
s = propeller slip ratio
D = propeller diameter
Q = propeller torque

TONNE PER CENTIMETRE IMMERSION : $\text{TPC} = \frac{A_w \times \rho}{100}$

Transverse Stability

Morrish Formula
for approximate position of centre of buoyancy B

from waterline $= \frac{1}{3}\left(\frac{d}{2} + \frac{\nabla}{A}\right)$

from keel, $KB = \frac{1}{3}\left(\frac{5d}{2} - \frac{\nabla}{A}\right)$

Metacentric Radius

$$BM = \frac{I_t}{\nabla}$$

Moment of Statical Stability

$= W \times GZ$ or $\triangle g GZ$

for small angles $GZ = GM \sin\theta = GM\,\theta_c$

for large angles $GZ = \frac{v \times hh}{\nabla} - BG \sin\theta$

where $v \times hh$ = horizontal transfer moment of wedges.

Free Surface Effect

$G_1G_2 = \frac{i}{\nabla} \times \frac{\rho_F}{\rho_s}$

ρ_F = density of free liquid
ρ_s = sea density

Inclining Experiment

$GM = \frac{w \times d}{W \tan\theta}$ or $\frac{m \times d}{\triangle \tan\theta}$

w = weight moved
d = distance moved
W = ship weight
θ = angle of heel

Statical Stability Curve
A curve of GZ against θ as ship heels at constant displacement.
correction for movement of $G = G_1G_2 \sin\theta$ along ship centreline
correction for movement of $G = G_1G_2 \cos\theta$ parallel to deck.

Dynamical Stability

$= W\int^{\theta 2} GZ d\theta = W \times$ area under GZ curve up to that angle of heel

$= W^0\left[\frac{v(gh+gh)}{\nabla} - BG(1-\cos\theta)\right]$ where $v(gh+gh)$ is the vertical transfer moment (volume) of the wedges

Longitudinal Stability

$BM_L = \frac{I_F}{\nabla}$

$I_F = I_x - Ad^2$

where d is distance of centre of flotation (centroid) from midships

MCT 1 cm $= \frac{\triangle GM_L}{100L}$ tonne metre

$\triangle$ = tonnes
GM_L = metres
L = metres

Note. BM_L may be used in this formula without serious error.

Resistance

$R_f = fSV^{1.825}$ newtons

$R_T = R_F + R_R$

f = Froude friction factor
$S = m^2$
V = knots (1852 m/h)

Corresponding Speeds Law

$\frac{V}{\sqrt{L}}$ has same value for both hulls.

Law of Comparison

$\frac{R_R}{W}$ has same value for both hulls at corresponding speeds and draughts

$$\therefore \quad \frac{R_{R1}}{R_{R2}} = \frac{W_1}{W_2} = \frac{\triangle_1 g}{\triangle_2 g} = \frac{\rho_1 \nabla_1}{\rho_1 \nabla_2} = \frac{\rho_1}{\rho_2} \times \text{scale}^3$$

Modern Coefficients

$C_T = C_F + C_R$
at corresponding speeds $C_{R(ship)} = C_{R(model)}$

$$C_T = \frac{R_T}{\frac{1}{2}\rho S V^2}$$
$$C_F = \frac{R_F}{\frac{1}{2}\rho S V^2}$$
$$C_R = \frac{R_R}{\frac{1}{2}\rho S V^2}$$

Modern Friction Lines

These are empirical formulae derived from plank experiments. They express C_F in terms of Reynold's number (R_n). One such formulae (ITTC) is:

$$C_F = \frac{0{\cdot}075}{(\log R_n - 2)^2}$$

Note a correction factor ΔC_f is added when using these plank formulae to calculate C_F for a ship—to allow for scale, roughness and form effects.

Propulsion

(true) $s = \frac{PN - V_a}{PN}$
(apparent) $s = \frac{PN - V_s}{PN}$
use consistent units.

$$P_{E(KW)} = R_{(KN)} V_{(m/s)}$$
$$P_{T(KW)} = T_{(KN)} V_{a(m/s)}$$
$$P_{D(KW)} = 2\pi N(\text{rev/s}) Q(\text{KN m})$$
$$w_f = \frac{V_s - V_a}{V_a} \qquad w_t = \frac{V_s - V_a}{V_s} = \frac{w_f}{1 + w_f}$$
$$T - R_T = tT = aR_T$$

hull efficiency $= \frac{P_E}{P_T} = \frac{R_T V_s}{T V_a} = \frac{1 + w_f}{1 + a} = (1 + w_f)(1 - t)$

propeller efficiency $= \frac{P_T}{P_D}$

relative rotative efficiency $= \frac{\eta_B}{\eta_0}$. (= R.R.E.)

QPC $= \frac{P_E}{P_D}$ = hull efficiency × open water efficiency × RRE

PC = QPC × transmission efficiency $= \frac{P_E}{\text{Engine power}}$

mmonia - NH_3 (Refrigerant 717)

t	p_s (kPa)	v_g	h_f	h_g	s_f	s_g	Superheat $(t-t_s)$ 50 K h	50 K s	100 K h	100 K s
−50	40.89	2·625	−44·4	1373·3	−0·194	6·159	1479·8	6·592	1585·9	6·948
−45	54.54	2·005	−22·3	1381·6	−0·096	6·057	1489·3	6·486	1596·1	6·839
−40	71.77	1·552	0	1390·0	0	5·962	1498·6	6·387	1606·3	6·736
−35	93.22	1·216	22·3	1397·9	0·095	5·872	1507·9	6·293	1616·3	6·639
−30	119.6	0·9633	44·7	1405·6	0·188	5·785	1517·0	6·203	1626·3	6·547
−28	131.7	0·8809	53·6	1408·5	0·224	5·751	1520·7	6·169	1630·3	6·512
−26	144.7	0·8058	62·6	1411·4	0·261	5·718	1524·3	6·135	1634·2	6·477
−24	153.8	0·7389	71·7	1414·3	0·297	5·686	1527·9	6·103	1638·2	6·444
−22	174.0	0·6783	80·8	1417·3	0·333	5·655	1531·4	6·071	1642·2	6·411
−20	190.2	0·6237	89·8	1420·0	0·368	5·623	1534·8	6·039	1646·0	6·379
−18	207.7	0·5743	98·8	1422·7	0·404	5·593	1538·2	6·008	1650·0	6·347
−16	226.5	0·5296	107·9	1425·3	0·440	5·563	1541·7	5·978	1653·8	6·316
−14	246.5	0·4890	117·0	1427·9	0·475	5·533	1545·1	5·948	1657·7	6·286
−12	268.0	0·4521	126·2	1430·5	0·510	5·504	1548·5	5·919	1661·5	6·256
−10	290.8	0·4185	135·4	1433·0	0·544	5·475	1551·7	5·891	1665·3	6·227
− 8	315.3	0·3879	144·5	1435·3	0·579	5·447	1554·9	5·863	1669·0	6·199
− 6	341.3	0·3599	153·6	1437·6	0·613	5·419	1558·2	5·836	1672·8	6·171
− 4	369.1	0·3344	162·8	1439·9	0·647	5·392	1561·4	5·808	1676·4	6·143
− 2	398.3	0·3110	172·0	1442·2	0·681	5·365	1564·6	5·782	1680·1	6·116
0	429.5	0·2895	181·2	1444·4	0·715	5·340	1567·8	5·756	1683·9	6·090
2	462.5	0·2699	190·4	1446·5	0·749	5·314	1570·9	5·731	1687·5	6·065
4	497.5	0·2517	199·7	1448·5	0·782	5·288	1574·0	5·706	1691·2	6·040
6	534.6	0·2351	209·1	1450·6	0·816	5·263	1577·0	5·682	1694·9	6·015
8	573.6	0·2198	218·5	1452·5	0·849	5·238	1580·1	5·658	1698·4	5·991
10	614.9	0·2056	227·8	1454·3	0·881	5·213	1583·1	5·634	1702·2	5·967
12	658.5	0·1926	237·2	1456·1	0·914	5·189	1586·0	5·611	1705·7	5·943
14	704.5	0·1805	246·6	1457·8	0·947	5·165	1588·9	5·588	1709·1	5·920
16	752.9	0·1693	256·0	1459·5	0·979	5·141	1591·7	5·565	1712·5	5·898
18	803.5	0·1590	265·5	1461·1	1·012	5·118	1594·4	5·543	1715·9	5·876
20	857.0	0·1494	275·1	1462·6	1·044	5·095	1597·2	5·521	1719·3	5·854
22	913.4	0·1405	284·6	1463·9	1·076	5·072	1600·0	5·499	1722·8	5·832
24	972.2	0·1322	294·1	1465·2	1·108	5·049	1602·7	5·478	1726·3	5·811
26	1034	0·1245	303·7	1466·5	1·140	5·027	1605·3	5·458	1729·6	5·790
28	1099	0·1173	313·4	1467·8	1·172	5·005	1608·0	5·437	1732·7	5·770
30	1167	0·1106	323·1	1468·9	1·204	4·984	1610·5	5·417	1735·9	5·750
32	1237	0·1044	332·8	1469·9	1·235	4·962	1613·0	5·397	1739·3	5·731
34	1311	0·0986	342·5	1470·8	1·267	4·940	1615·4	5·378	1742·6	5·711
36	1389	0·0931	352·3	1471·8	1·298	4·919	1617·8	5·358	1745·7	5·692
38	1470	0·0880	362·1	1472·6	1·329	4·898	1620·1	5·340	1748·7	5·674
40	1554	0·0833	371·9	1473·3	1·360	4·877	1622·4	5·321	1751·9	5·655
42	1642	0·0788	381·8	1473·8	1·391	4·856	1624·6	5·302	1755·0	5·637
44	1734	0·0746	391·8	1474·2	1·422	4·835	1626·8	5·284	1758·0	5·619
46	1830	0·0706	401·8	1474·5	1·453	4·814	1629·0	5·266	1761·0	5·602
48	1929	0·0670	411·9	1474·7	1·484	4·793	1631·1	5·248	1764·0	5·584
50	2033	0·0635	421·9	1474·7	1·515	4·773	1633·1	5·230	1766·8	5·567

Relative molecular mass = 17·031

Dichlorodifluoromethane - CF_2Cl_2 (Refrigerant 12)

t	p_s (kPa)	v_g	h_f	h_g	s_f	s_g	Superheat $(t-t_s)$ 15 K h	15 K s	30 K h	30 K s
−100	01.18	10·100	−51·84	142·00	−0·2567	0·8628	148·89	0·9019	156·10	0·9428
− 95	01.81	6·585	−47·56	144·22	−0·2323	0·8442	151·23	0·8830	158·55	0·9195
− 90	02.84	4·416	−43·28	146·46	−0·2086	0·8274	153·59	0·8649	161·02	0·9010
− 85	04.24	3·037	−39·00	148·73	−0·1856	0·8122	155·98	0·8493	163·52	0·8851
− 80	06.17	2·138	−34·72	151·02	−0·1631	0·7985	158·39	0·8351	166·04	0·8706
− 75	08.79	1·538	−30·43	153·32	−0·1412	0·7861	160·82	0·8226	168·57	0·8578
− 70	12.27	1·127	−26·13	155·63	−0·1198	0·7749	163·26	0·8110	171·12	0·8459
− 65	16.80	0·8412	−21·81	157·96	−0·0988	0·7649	165·70	0·8008	173·68	0·8355
− 60	22.62	0·6379	−17·49	160·29	−0·0783	0·7558	168·15	0·7915	176·26	0·8259
− 55	29.98	0·4910	−13·14	162·62	−0·0582	0·7475	170·60	0·7830	178·84	0·8172
− 50	39.15	0·3831	− 8·78	164·95	−0·0384	0·7401	173·07	0·7753	181·43	0·8093
− 45	50.44	0·3027	− 4·40	167·28	−0·0190	0·7335	175·54	0·7685	184·01	0·8023
− 40	64.17	0·2419	0	169·60	0	0·7274	178·00	0·7623	186·60	0·7959
− 35	80.71	0·1954	4·42	171·90	0·0187	0·7219	180·45	0·7568	189·18	0·7902
− 30	100.4	0·1594	8·86	174·20	0·0371	0·7170	182·90	0·7517	191·76	0·7851
− 25	123.7	0·1312	13·33	176·48	0·0552	0·7127	185·33	0·7473	194·33	0·7805
− 20	150.9	0·1088	17·82	178·73	0·0731	0·7087	187·75	0·7432	196·89	0·7764
− 15	182.6	0·0910	22·33	180·97	0·0906	0·7051	190·15	0·7397	199·44	0·7728
− 10	219.1	0·0766	26·87	183·19	0·1080	0·7020	192·53	0·7365	201·97	0·7695
− 5	261.0	0·0650	31·45	185·38	0·1251	0·6991	194·90	0·7336	204·49	0·7666
0	308.6	0·0554	36·05	187·53	0·1420	0·6966	197·25	0·7311	206·99	0·7641
5	362.6	0·0475	40·69	189·66	0·1587	0·6943	199·56	0·7289	209·47	0·7618
10	423.3	0·0409	45·37	191·74	0·1752	0·6921	201·85	0·7268	211·92	0·7598
15	491.4	0·0354	50·10	193·78	0·1915	0·6901	204·10	0·7251	214·35	0·7580
20	567.3	0·0308	54·87	195·78	0·2078	0·6885	206·32	0·7235	216·75	0·7565
25	651.6	0·0269	59·70	197·73	0·2239	0·6869	208·50	0·7220	219·11	0·7552
30	744.9	0·0235	64·59	199·62	0·2399	0·6853	210·63	0·7208	221·44	0·7540
35	847.7	0·0206	69·55	201·45	0·2559	0·6839	212·72	0·7196	223·73	0·7529
40	960.7	0·0182	74·59	203·20	0·2718	0·6825	214·76	0·7185	225·98	0·7519
45	1084	0·0160	79·71	204·87	0·2877	0·6811	216·74	0·7175	228·18	0·7511
50	1219	0·0142	84·94	206·45	0·3037	0·6797	218·64	0·7166	230·33	0·7503
55	1366	0·0125	90·27	207·92	0·3197	0·6782	220·48	0·7156	232·42	0·7496
60	1526	0·0111	95·74	209·26	0·3358	0·6765	222·23	0·7146	234·45	0·7490
65	1699	0·00985	101·36	210·46	0·3521	0·6747	223·89	0·7136	236·42	0·7484
70	1886	0·00873	107·15	211·48	0·3686	0·6726	225·45	0·7125	238·32	0·7477
75	2088	0·00772	113·15	212·29	0·3854	0·6702	226·89	0·7113	240·13	0·7470
80	2305	0·00682	119·39	212·83	0·4027	0·6673	228·21	0·7099	241·86	0·7463
85	2538	0·00601	125·93	213·04	0·4204	0·6636	229·39	0·7084	243·50	0·7455
90	2789	0·00526	132·84	212·80	0·4389	0·6591	230·43	0·7067	245·03	0·7445
95	3057	0·00456	140·23	211·94	0·4583	0·6531	231·30	0·7047	246·47	0·7435
100	3344	0·00390	148·32	210·12	0·4793	0·6449	231·93	0·7023	247·80	0·7424
105	3651	0·00324	157·52	206·57	0·5028	0·6325	232·22	0·6994	248·97	0·7412
110	3979	0·00246	169·55	197·99	0·5334	0·6076	232·47	0·6964	250·10	0·7399
112	4115	0·00179	183·43	183·43	0·5690	0·5690	232·80	0·6958	250·58	0·7394

Relative molecular mass = 120·92