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Sections:

- Common Properties and Conversions
- Thermodynamics
- Heat Transfer
- Fluid Mechanics
- Mechanics of Materials
- Failure Theories
- Motor Equations/Electrical

Common Properties/Conversions:

Common conversions:

$7.48gal = 1ft^3$

$1gal = 8.35lb$

$1stoke = 100cst = 929\,ft^2/s$

$778\,ft \cdot lbs = 1btu$

$1cm = 0.3937in = 3.281 \times 10^{-2}$

$1m = 39.37in = 3.281ft$

$1m^2 = 10.76ft^2 = 1550in^2$

$1m^3 = 35.31ft^3 = 6.102 \times 10^4 in^3$

12000 btu/hr=1 ton

$1MW = 3.412 \times 10^6 \frac{btu}{hr}$

$1kW = 3412.14 \frac{btu}{hr}$

Common Constants:

Gravitational Constant

$$g_c = 32.2 \frac{lb_m ft}{lb_f s^2}$$

Specific Heat (constant pressure):

$$C_{p(air)} = 0.24 \frac{btu}{lbm \cdot F}$$

$$C_{p(water)} = 1.0 \frac{btu}{lbm \cdot F}$$

Specific Heat (constant volume):

$$C_{v(air)} = 0.171 \frac{btu}{lbm \cdot F}$$

	cm	METER	km	in	ft	mile
1 centimeter =	1	10^{-2}	10^{-5}	0.3937	3.281×10^{-2}	6.214×10^{-6}
1 METER =	100	1	10^{-3}	39.37	3.281	6.214×10^{-4}
1 kilometer =	10^{5}	1000	1	3.937×10^{4}	3281	0.6214
1 inch =	2.540	2.540×10^{-2}	2.540×10^{-5}	1	8.333×10^{-2}	1.578×10^{-5}
1 foot =	30.48	0.3048	3.048×10^{-4}	12	1	1.894×10^{-4}
1 statute mile =	1.609×10^{5}	1609	1.609	6.336×10^{4}	5280	1

	METER^2	cm^2	ft^2	in^2	circ mil
1 SQUARE METER =	1	10^{4}	10.76	1550	1.974×10^{9}
1 square cm =	10^{-4}	1	1.076×10^{-3}	0.1550	1.974×10^{5}
1 square foot =	9.290×10^{-2}	929.0	1	144	1.833×10^{8}
1 square inch =	6.452×10^{-4}	6.452	6.944×10^{-3}	1	1.273×10^{6}
1 circular mil =	5.067×10^{-10}	5.067×10^{-6}	5.454×10^{-3}	7.854×10^{-7}	1

	METER^3	cm^3	liter	ft^3	in^3
1 CUBIC METER =	1	10^{6}	1000	35.31	6.102×10^{4}
1 cubic cm =	10^{-6}	1	1.000×10^{-3}	3.531×10^{-8}	6.102×10^{-2}
1 liter =	1.000×10^{-3}	1000	1	3.531×10^{-2}	61.02
1 cubic foot =	2.832×10^{-2}	2.832×10^{4}	28.32	1	1728
1 cubic inch =	1.639×10^{-5}	16.39	1.639×10^{-2}	5.787×10^{-4}	1

	gm	**KGM**	slug	amu	oz	lb	ton
1 gram =	1	0.001	6.852×10^{-5}	6.024×10^{23}	3.527×10^{-2}	2.205×10^{-3}	1.102×10^{-6}
1 **KILOGRAM** =	1000	1	6.852×10^{-2}	6.024×10^{26}	35.27	2.205	1.102×10^{-3}
1 slug =	1.459×10^{4}	14.59	1	8.789×10^{27}	514.8	32.17	1.609×10^{-2}
1 amu =	1.660×10^{-24}	1.660×10^{-27}	1.137×10^{-28}	1	5.855×10^{-26}	3.660×10^{-27}	1.829×10^{-30}
1 ounce (avoirdupois) =	28.35	2.835×10^{-2}	1.943×10^{-3}	1.708×10^{25}	1	6.250×10^{-2}	3.125×10^{-5}
1 pound (avoirdupois) =	453.6	0.4536	3.108×10^{-2}	2.732×10^{26}	16	1	0.0005
1 ton =	9.072×10^{-5}	907.2	62.16	5.465×10^{29}	3.200×10^{4}	2000	1

NOTE FOR TABLE F: Portion of table enclosed in heavy lines must be used with caution because those units are not properly mass units but weight equivalents which depend on standard terrestrial acceleration due to gravity, i.e. g.

	$slug/ft^3$	**KGM/M^3**	gm/cm^3	lb/ft^3	lb/in^3
1 slug per ft^3 =	1	515.4	0.5154	32.17	1.862×10^{-2}
1 **KILOGRAM** per **METER**^{3} =	1.940×10^{-3}	1	0.001	6.243×10^{-2}	3.613×10^{-5}
1 gm per cm^3 =	1.940	1000	1	62.43	3.613×10^{-2}
1 pound per ft^3 =	3.108×10^{-2}	16.02	1.602×10^{-2}	1	5.787×10^{-4}
1 pound per in^3 =	53.71	2.768×10^{4}	27.68	1728	1

NOTE FOR TABLE G: Portion of table enclosed in heavy lines must be used with caution because those units are not mass-density units but weight-density units which depend on g.

	yr	day	hr	min	SECOND
1 year =	1	365.2	8.766×10^3	5.259×10^3	3.156×10^7
1 day =	2.738×10^{-3}	1	24	1440	8.640×10^4
1 hour =	1.141×10^{-4}	4.167×10^{-2}	1	60	3600
1 minute =	1.901×10^{-6}	6.944×10^{-4}	1.667×10^{-2}	1	60
1 **SECOND** =	3.169×10^{-8}	1.157×10^{-5}	2.778×10^{-4}	1.667×10^{-2}	1

	ft/sec	km/hr	METER/SEC	miles/hr	cm/sec	knot
1 foot per second =	1	1.097	0.3408	0.6818	30.48	0.5925
1 kilometer per hour =	0.9113	1	0.2778	0.6214	27.78	0.5400
1 **METER** per **SECOND** =	3.281	3.600	1	2.237	100	1.944
1 mile per hour =	1.467	1.609	0.4770	1	44.70	0.8689
1 centimeter per sec =	3.281×10^{-2}	3.600×10^{-2}	0.0100	2.237×10^{-2}	1	1.944×10^{-2}
1 knot =	1.688	1.852	0.5144	1.151	51.44	1

1 knot = 1 nautical mile/hr

1 mile/min = 88 ft/sec
= 60 miles/hr

	dyne	NT	lb	pdl	gf	kgf
1 dyne =	1	10^{-5}	2.248×10^{-6}	7.233×10^{-5}	1.020×10^{-3}	1.020×10^{-6}
1 **NEWTON** =	10^5	1	0.2248	7.233	102.0	0.1020
1 pound =	4.480×10^5	4.448	1	32.17	453.6	0.4536
1 poundal =	1.383×10^4	0.1383	3.108×10^{-2}	1	14.10	1.410×10^{-2}
1 gram-force =	980.7	9.807×10^{-3}	2.205×10^{-3}	7.093×10^{-2}	1	0.001
1 kilogram-force =	9.807×10^5	9.807	2.205	70.93	1000	1

NOTE FOR TABLE J: Portion of table enclosed in heavy lines must be used with caution because those units are not force units but weight equivalents of mass which depend on g.

1 kgf = 9.80665 newton   1 lb = 32.17398 poundal

	atm	dyne/cm^2	inch of water	cm Hg	NT/METER^2	lb/in^2	lb/ft^2
1 atmosphere =	1	1.013×10^6	406.8	76	1.013×10^5	14.70	2116
1 dyne per cm^2 =	9.869×10^{-7}	1	4.015×10^{-4}	7.501×10^{-5}	0.100	1.450×10^{-5}	2.089×10^{-3}
1 inch of water at $4^{\circ}C$[a] =	2.458×10^{-3}	2.491	1	0.1868	249.1	3.613×10^{-2}	5.202
1 centimeter of mercury at $0^{\circ}C$[a] =	1.316×10^{-2}	1.333×10^4	5.353	1	1333	0.1934	27.85
1 **NEWTON** per **METER**^{2} =	9.869×10^{-6}	10	4.015×10^{-3}	7.501×10^{-4}	1	1.450×10^{-4}	2.089×10^{-2}
1 pound per in^2 =	6.805×10^{-2}	6.895×10^4	27.68	5.171	6.895×10^3	1	144
1 pound per ft^2 =	4.725×10^{-4}	478.8	0.1922	3.591×10^{-2}	47.88	6.944×10^{-3}	1

	Btu	erg	ft-lb	hp-hr	**JOULES**	cal	kw-hr	ev	Mev	kgm	amu
1 British thermal unit =	1	1.055×10^{10}	777.9	3.929×10^{-4}	1055	252.0	2.930×10^{-4}	6.585×10^{21}	6.585×10^{15}	1.174×10^{-14}	7.074×10^{12}
1 erg =	9.481×10^{-11}	1	7.376×10^{-8}	3.725×10^{-14}	10^{-7}	2.389×10^{-8}	2.778×10^{-14}	6.242×10^{11}	6.242×10^5	1.113×10^{-24}	670.5
1 foot-pound =	1.285×10^{-3}	1.356×10^7	1	5.051×10^{-7}	1.356	0.3239	3.766×10^{-7}	8.464×10^{18}	8.464×10^{12}	1.509×10^{-17}	9.092×10^9
1 horsepower-hour =	2545	2.685×10^{-13}	1.980×10^6	1	2.685×10^6	6.414×10^5	0.7457	1.676×10^{25}	1.676×10^{19}	2.988×10^{-11}	1.800×10^{16}
1 **JOULE** =	9.481×10^{-4}	10^7	0.7376	3.725×10^{-7}	1	0.2389	2.778×10^{-7}	6.242×10^{18}	6.242×10^{12}	1.113×10^{-17}	6.705×10^9
1 calorie =	3.968×10^{-3}	4.186×10^7	3.087	1.559×10^{-6}	4.186	1	1.163×10^{-6}	2.613×10^{19}	2.613×10^{13}	4.659×10^{-17}	2.807×10^{10}
1 kilowatt-hour =	3413	3.6×10^{13}	2.655×10^6	1.341	3.6×10^6	8.601×10^5	1	2.247×10^{25}	2.247×10^{19}	4.007×10^{-11}	2.414×10^{16}
1 electron volt =	1.519×10^{-22}	1.602×10^{-12}	1.182×10^{-19}	5.967×10^{-26}	1.602×10^{-19}	3.827×10^{-20}	4.450×10^{-26}	1	10^{-6}	1.783×10^{-36}	1.074×10^{-9}
1 million electron volts =	1.519×10^{-16}	1.602×10^{-6}	1.182×10^{-13}	5.967×10^{-20}	1.602×10^{-13}	3.827×10^{-14}	4.450×10^{-20}	10^6	1	1.783×10^{-30}	1.074×10^{-3}
1 kilogram =	8.521×10^{-13}	8.987×10^{23}	6.629×10^{16}	3.348×10^{10}	8.987×10^{16}	2.147×10^{16}	2.497×10^{10}	5.610×10^{35}	5.610×10^{29}	1	6.025×10^{26}
1 atomic mass unit =	1.415×10^{-13}	1.492×10^{-3}	1.100×10^{-10}	5.558×10^{-17}	1.492×10^{-10}	3.564×10^{-11}	4.145×10^{-17}	9.310×10^8	931.0	1.660×10^{-27}	1

NOTES FOR TABLE L: The electron volt is the kinetic energy an electron gains from being accelerated through the potential difference of one volt in an electric field. The units enclosed by heavy lines are not properly energy units; they arise from the relativistic mass-energy equivalent formula $E = mc^2$.

	$\frac{cal}{gm}$	$\frac{erg}{gm}$	**$\frac{JOULE}{KGM}$**	$\frac{Btu}{lb_m}$	$\frac{ft - lb_f}{lb_m}$	$\frac{hp - hr}{lb_m}$
1 calorie per gram =	1	4.186×10^7	4.186×10^3	1.800	1.400×10^3	7.072×10^{-4}
1 erg per gram=	2.389×10^{-8}	1	10^{-4}	4.299×10^{-8}	3.346×10^{-5}	1.690×10^{-11}
1 **JOULE** per **KILOGRAM** =	2.389×10^{-4}	10^4	1	4.299×10^{-4}	0.3346	1.690×10^{-7}
1 Btu per pound (mass)=	0.5557	2.326×10^7	2.326×10^3	1	777.9	3.929×10^{-4}
1 foot-pound per pound (mass)=	7.142×10^{-4}	2.990×10^4	2.990	1.285×10^{-3}	1	5.051×10^{-7}
1 horsepower-hour per pound (mass)=	1.414×10^3	5.920×10^{10}	5.920×10^6	2.545	1.980×10^6	1

NOTE FOR TABLES M & N: The engineering units enclosed within the heavy lines have been properly related to the pound mass rather than the pound force because these specific thermal quantities depend on unit mass and have nothing to do with weight. However, in engineering practice it is customary to relate energy and energy per degree to weight. Thus we speak of Btu/lb, ft-lb/lb and hp-hr/lb of weight. The conversion factors given in Tables M & N are equally valid for this purpose if the local acceleration of gravity if the earth standard value of $g = 32.174$ ft/sec^2 = 9.80665 meter/sec^2. This is true because the pound-force and the pound-mass are numerically equal at standard gravity. It should be realized that relating specific quantities to weight, rather than mass, involves a change of concept because weight and mass are not dimensional equivalents. The relation between units of mass and weight is not a relation between the concepts of mass and weight. The units are related by

$$lb_f = 32.174\ lb_m\ ft/sec^2$$

	Btu/hr	Btu/sec	ft - lb/min	ft - lb/sec	hp	cal/sec	kw	**WATT**
1 British thermal unit per hour =	1	2.778 × 10^{-4}	12.97	0.2161	3.929 × 10^{-4}	7.000 × 10^{-2}	2.930 × 10^{-4}	0.2930
1 British thermal unit per second =	3600	1	4.669 × 10^{4}	777.9	1.414	252.0	1.055	1.055 × 10^{3}
1 foot-pound per minute =	7.713 × 10^{-2}	2.142 × 10^{-5}	1	1.667 × 10^{-2}	3.030 × 10^{-5}	5.399 × 10^{-3}	2.260 × 10^{-5}	2.260 × 10^{-2}
1 foot-pound per second =	4.628	1.286 × 10^{-3}	60	1	1.818 × 10^{-3}	0.3239	1.356 × 10^{-3}	1.356
1 horsepower =	2545	0.7069	3.3 × 10^{4}	550	1	178.2	0.7457	745.7
1 calorie per second =	14.29	0.3950	1.852 × 10^{2}	3.087	5.613 × 10^{-3}	1	4.186 × 10^{-3}	4.186
1 kilowatt =	3413	0.9481	4.425 × 10^{4}	737.6	1.341	238.9	1	1000
1 **WATT** =	3.413	9.481 × 10^{-4}	44.25	0.7376	1.341 × 10^{-3}	0.2389	0.001	1

Q. HEAT TRANSFER COEFFICIENT, h

	cal / (sec–cm^2 °C)	WATT / (M^2 °K)	watt / (in^2 °C)	Btu / (hr - ft^2 °F)	Btu / (sec - in^2 °F)	hp / (ft^2 °F)
1 calorie per sec per centimeter^2 - °C =	1	4.185 × 10^{4}	27.00	7.372 × 10^{3}	1.422 × 10^{-2}	2.895
1 **WATT** per **METER**^{2} per **DEG KELVIN** =	2.390 × 10^{-5}	1	6.452 × 10^{-4}	0.1762	3.398 × 10^{-7}	6.922 × 10^{-5}
1 watt per inch^2 per deg Centigrade =	3.704 × 10^{-2}	1550	1	273.1	5.267 × 10^{-4}	0.1073
1 Btu per hour per per foot^2 - °F =	1.356 × 10^{-4}	5.675	3.663 × 10^{-3}	1	1.929 × 10^{-6}	3.928 × 10^{-4}
1 Btu per sec per inch^2 - °F =	70.31	2.943 × 10^{6}	1.899 × 10^{3}	5.184 × 10^{5}	1	203.6
1 horsepower per foot^2 - °F =	0.3452	1.445 × 10^{4}	9.322	2.546 × 10^{3}	4.911 × 10^{-3}	1

R. R. THERMAL CONDUCTIVITY, k

	$\frac{\text{cal}}{\text{sec–cm °C}}$	$\frac{\text{WATTS}}{\text{METER °K}}$	$\frac{\text{watts}}{\text{in °C}}$	$\frac{\text{Btu}}{\text{hr - ft °F}}$	$\frac{\text{Btu}}{\text{sec - in °F}}$	$\frac{\text{hp}}{\text{ft °F}}$
1 calorie per sec per centimeter-deg C =	1	418.5	10.63	241.9	5.600×10^{-3}	9.503×10^{-2}
1 **WATT** per **METER** per **DEG KELVIN** =	2.390×10^{-3}	1	2.540×10^{-2}	0.5781	1.338×10^{-5}	2.271×10^{-4}
1 watt per inch per deg Centigrade =	9.407×10^{-2}	39.37	1	22.76	5.269×10^{-4}	8.939×10^{-3}
1 Btu per hour per foot-deg F =	4.134×10^{-3}	1.730	4.394×10^{-2}	1	2.315×10^{-3}	3.929×10^{-4}
1 Btu per sec per inch-deg F =	1.786×10^{2}	7.474×10^{4}	1.898×10^{3}	4.320×10^{4}	1	16.97
1 horsepower per foot-deg F =	10.52	4403	111.8	2546	5.894×10^{-2}	1

S. ABSOLUTE OR DYNAMIC VISCOSITY, μ

	centipoise	poise	$\frac{kgm_f\text{-sec}}{meter^2}$	$\frac{lb-sec}{ft^2}$	**KGM/M–SEC**	$\frac{lb_m}{ft-sec}$
1 centipoise =	1	10^{-2}	1.020×10^{-4}	2.089×10^{-5}	10^{-3}	6.720×10^{-4}
1 poise =	100	1	1.020×10^{-2}	2.089×10^{-3}	0.100	6.720×10^{-2}
1 kg (force) – sec per meter^2 =	9.807×10^3	98.07	1	0.2048	9.807	6.590
1 lb (force) – sec per foot^2 =	4.788×10^4	4.788×10^2	4.882	1	47.88	32.174
1 **KILOGRAM** per **METER-SEC** =	10^3	10	0.1020	2.089×10^{-2}	1	0.6720
1 lb (mass) per foot – sec =	1.488×10^3	14.88	0.1518	3.108×10^{-2}	1.488	1

NOTE FOR TABLE S: The absolute viscosity μ is properly expressed in force units according to its definition. In heat transfer and fluid mechanics it is usually expressed in mass-equivalent units to avoid the use of a conversion factor in Reynolds Number. Mass units have been used in the portion of the table enclosed in heavy lines. The proper force units for μ in the mksq system are **NEWTON-SEC** per **METER**^{2}; they are seldom used. The poise is the cgs force unit and is defined by

$$1 \text{ poise} = 1 \ \frac{\text{dyne - second}}{\text{centimeter}^2}$$

T. KINEMATIC VISCOSITY, ν = μ/ρ

	centistoke	stoke	**METER**^{2}/**SEC**	ft^2/sec
1 centistoke =	1	10^{-2}	10^{-6}	1.076×10^{-5}
1 stoke =	100	1	10^{-4}	1.076×10^{-3}
1 **METER**^{2}/**SEC** =	10^6	10^4	1	10.76
1 ft^2/sec =	9.290×10^4	929.0	9.290×10^{-2}	1

1 stoke = 1 centimeter^2/sec

Units	R_0
ft-lb/lb-mole R°	1544
ft-lb/lb-mole K°	2779
ft-lb/lb-mole R°	3.407
Btu/lb-mole R°	1.987
ft^3 atm/lb-mole R°	0.729
ft^3 atm/lb-mole K°	1.315

DENSITY			
Material	(lb/ft^3)	Material	(lb/ft^3)
Aluminum	172	Mercury	847
Brass	540	SAE 20 Motor Oil	57
Carbon tetrachloride	99.4	Seawater	63.9
Copper	570	Stainless Steel	499 - 512
Ethyl Alcohol	49.3	Water	62.4
Gasoline	42.5	Wrought Iron	474 - 499
Glycerin	78.6	Air @ 32 °F and 1 atmosphere	0.0805
Kerosene	50	Air @ 70 °F and 1 atmosphere	0.0749

Gauge pressure	Density of air [lb/ft^3] at different temperatures [°F]											
[psi]	30	40	50	60	70	80	90	100	120	140	150	200
0	0.081	0.08	0.078	0.076	0.075	0.074	0.072	0.071	0.069	0.066	0.065	0.06
5	0.109	0.107	0.105	0.102	0.101	0.099	0.097	0.095	0.092	0.089	0.087	0.081
10	0.136	0.134	0.131	0.128	0.126	0.124	0.121	0.119	0.115	0.111	0.109	0.101
20	0.192	0.188	0.185	0.18	0.177	0.174	0.171	0.168	0.162	0.156	0.154	0.142
30	0.247	0.242	0.238	0.232	0.228	0.224	0.22	0.216	0.208	0.201	0.198	0.183
40	0.302	0.295	0.291	0.284	0.279	0.274	0.269	0.264	0.255	0.246	0.242	0.225
50	0.357	0.35	0.344	0.336	0.33	0.324	0.318	0.312	0.302	0.291	0.287	0.265
60	0.412	0.404	0.397	0.388	0.381	0.374	0.367	0.361	0.348	0.337	0.331	0.306
70	0.467	0.458	0.451	0.44	0.432	0.424	0.416	0.409	0.395	0.382	0.375	0.347
80	0.522	0.512	0.504	0.492	0.483	0.474	0.465	0.457	0.441	0.427	0.42	0.388
90	0.578	0.566	0.557	0.544	0.534	0.524	0.515	0.505	0.488	0.472	0.464	0.429
100	0.633	0.62	0.61	0.596	0.585	0.574	0.564	0.554	0.535	0.517	0.508	0.47
120	0.743	0.728	0.717	0.7	0.687	0.674	0.662	0.65	0.628	0.607	0.597	0.552
140	0.853	0.836	0.823	0.804	0.789	0.774	0.76	0.747	0.721	0.697	0.686	0.634
150	0.909	0.89	0.876	0.856	0.84	0.824	0.809	0.795	0.768	0.742	0.73	0.675
200	1.185	1.161	1.142	1.116	1.095	1.075	1.055	1.036	1.001	0.967	0.951	0.879
250	1.46	1.431	1.408	1.376	1.35	1.325	1.301	1.278	1.234	1.193	1.173	1.084
300	1.736	1.702	1.674	1.636	1.605	1.575	1.547	1.519	1.467	1.418	1.395	1.289
400	2.29	2.24	2.21	2.16	2.12	2.08	2.04	2	1.933	1.868	1.838	1.698
500	2.84	2.78	2.74	2.68	2.63	2.58	2.53	2.48	2.4	2.32	2.28	2.11
700	3.94	3.86	3.8	3.72	3.65	3.58	3.51	3.45	3.33	3.22	3.17	2.93
800	4.49	4.4	4.33	4.24	4.16	4.08	4	3.93	3.8	3.67	3.61	3.34
900	5.05	4.95	4.87	4.76	4.67	4.58	4.5	4.42	4.26	4.12	4.05	3.75
1000	5.6	5.49	5.4	5.28	5.18	5.08	4.99	4.9	4.73	4.57	4.5	4.16

SPECIFIC GRAVITY					
Material	(SG)	Carbon dioxide	0.00198	Oxygen	0.00143
Acetylene	0.0017	Carbon monoxide	0.00126	Petrol	0.72
Air, dry	0.0013	Cast iron	7.20	PVC	1.36
Alcohol	0.82	Hydrogen	0.00009	Rubber	0.96
Aluminum	2.72	Lead	11.35	Steel	7.82
Brass	8.48	Mercury	13.59	Tin	7.28

Cadmium	8.57	Nickel	8.73	Zinc	7.12
Chromium	7.03	Nitrogen	0.00125	Water (4^{o}C)	1.00
Copper	8.79	Nylon	1.12	Water, sea	1.027

Gas or Vapor	Formula	c_p $(Btu/(lb_m{}^oF))$	c_v $(Btu/(lb_m{}^oF))$	$\kappa = c_p / c_v$	$c_p - c_v$ $(ft\ lb_f/(lb_m{}^oR))$
Acetone		0.35	0.32	1.11	
Acetylene	C2H2	0.35	0.27	1.232	59.34
Air		0.24	0.17	1.40	53.34
Alcohol	C2H5OH	0.45	0.4	1.13	
Alcohol	CH3OH	0.46	0.37	1.26	
Ammonia	NH3	0.52	0.4	1.31	96.5
Argon	Ar	0.12	0.07	1.667	
Benzene	C6H6	0.26	0.24	1.12	
Blast furnace gas		0.25	0.17	1.41	55.05
Bromine		0.06	0.05	1.28	
Butatiene				1.12	
Butane	C4H10	0.395	0.356	1.094	26.5
Carbon dioxide	CO2	0.21	0.16	1.289	38.86
Carbon monoxide	CO	0.24	0.17	1.40	55.14
Carbon disulphide		0.16	0.13	1.21	
Chlorine	Cl2	0.12	0.09	1.34	
Chloroform		0.15	0.13	1.15	
Coal gas					
Combustion products		0.24			
Ethane	C2H6	0.39	0.32	1.187	51.5
Ether		0.48	0.47	1.03	
Ethylene	C2H4	0.4	0.33	1.240	55.08
Monochlorodifluoromethane, R-22				1.18	
Helium	He	1.25	0.75	1.667	386.3
Hexane				1.06	
Hydrochloric acid					
Hydrogen	H2	3.42	2.43	1.405	765.9
Hydrogen Chloride	HCl	0.191	0.135	1.41	42.4
Hydrogen Sulfide	H2S	0.243	0.187	1.32	45.2
Hydroxyl	OH			1.384	
Krypton					
Methane	CH4	0.59	0.45	1.304	96.4
Methyl Chloride	CH3Cl	0.240	0.200	1.20	30.6
Natural Gas		0.56	0.44	1.27	79.1
Neon				1.667	

Gas or Vapor	Formula	c_p $(Btu/(lb_m{}^oF))$	c_v $(Btu/(lb_m{}^oF))$	$\kappa = c_p / c_v$	$c_p - c_v$ $(ft\ lb_f/(lb_m{}^oR))$
Nitric Oxide	NO	0.23	0.17	1.386	
Nitrogen	N2	0.25	0.18	1.400	54.99
Nitrogen tetroxide		1.12	1.1	1.02	
Nitrous oxide	N2O	0.21	0.17	1.27	35.1
Oxygen	O2	0.22	0.16	1.395	48.24
Pentane				1.07	
Propane	C3H8	0.39	0.34	1.13	35.0
Propene (propylene)	C3H6	0.36	0.31	1.15	36.8
Steam 1 psia. 120 – 600 oF		0.46	0.35	1.32	
Steam 14.7 psia. 220 – 600 oF		0.47	0.36	1.31	
Steam 150 psia. 360 – 600 oF		0.54	0.42	1.28	
Sulfur dioxide (Sulphur dioxide)	SO2	0.15	0.12	1.29	24.1

SPECIFIC HEAT Cp			
	$(Btu/(lb_m\ {}^oF))$		$(Btu/(lb_m\ {}^oF))$
Aluminum	0.22	Osmium	0.031
Antimony	0.05	Palladium	0.057
Barium	0.048	Platinum	0.03
Beryllium	0.436	Plutonium	0.032
Bismuth	0.03	Potassium	0.180
Cadmium	0.055	Rhenium	0.033
Calsium	0.15	Rhodium	0.058
Carbon Steel	0.12	Rubidium	0.086
Cast Iron	0.11	Ruthenium	0.057
Cesium	0.057	Scandium	0.14
Chromium	0.11	Selenium	0.077
Cobalt	0.1	Silicon	0.17
Copper	0.09	Silver	0.057
Gallium	0.088	Sodium	0.29
Germanium	0.076	Strontium	0.072
Gold	0.03	Tantalum	0.034
Hafnium	0.033	Thallium	0.03
Indium	0.057	Thorium	0.03
Iridium	0.31	Tin	0.05
Iron	0.11	Titanium	0.13
Lanthanum	0.047	Tungsten	0.032

Lead	0.03	Uranium	0.028
Lithium	0.85	Vanadium	0.116
Lutetium	0.036	Yttrium	0.072
Magnesium	0.25	Zinc	0.09
Manganese	0.114	Zirconium	0.06
Mercury	0.03	Wrought Iron	0.12
Molybdenum	0.06	Ruthenium	0.22
Nickel	0.10		
Niobium (Columbium)	0.064		

MOLECULAR WEIGHT			
	(lb/kmole)		
Acetylene, C2H2	57.4	Isoprene	150
Air	63.9	Isopropylbenzene	265
Ammonia (R-717)	37.5	Krypton	185
Argon, Ar	88.1	Methane, CH4	35.4
Benzene	172	Methyl Alcohol	70.6
n - Butane, C4H10	128	Methyl Butane	159
1,2 - Butadiene	119	Methyl Chloride	111
1-Butene	124	Methylcyclohexane	216
cis -2-Butene	124	Methylcyclopentane	186
trans-2-Butene	124	2 - Methylhexane	221
Butylene	124	2 - Methylpentane	190
Carbon Dioxide, CO2	97	Natural Gas	41.9
Carbon Disulphide	168	Neon, Ne	44.5
Carbon Monoxide, CO	61.8	Neohexane	190
Chlorine	156	Neopentane	159
Cyclohexane	186	Nitric Oxide, NO	66.2
Cyclopentane	155	Nitrogen, N2	61.8
n – Decane	314	Nitrous Oxide, N2O	97
Deuterium	4.44	n – Nonane	283
2,3 - Dimetylbutane	190	n - Octane	252
2,2 - Dimethylpentane	221	Oxygen, O2	70.5
Diisobutyl	252	Ozone	106
Duoderane	375	n – Pentane	159
Ethane, C2H6	66.3	Pentylene	154
Ethene	61.8	Propane, C3H8	97.2
Ethyl Alcohol	102	Propene	92.8
Ethylbenzene	234	Propylene	92.8
Ethyl Chloride	142	R-11	303
3 - Ethylpentane	221	R-12	267

Ethylene, C2H4	61.8	R-22	191
Fluorine	83.8	R-114	377
Helium, He	8.82	R-123	337
n – Heptane	221	R-134a	225
n – Hexane	190	R-611	132
Hydrochloric Acid	80.4	Styrene	230
Hydrogen, H2	4.44	Sulfur	70.6
Hydrogen Chloride	80.4	Sulfur Dioxide (Sulphur Dioxide)	141
Hydrogen Sulfide	75.1	Sulfuric Oxide	106
Hydroxyl, OH	37.5	Toluene, toluol	203
Isobutane (2-Metyl propane)	128	Triptane	221
Isobutene	124	Xenon	289
Isooctane	464	o - Xylene, xylol	234
Isopentane	159	Water Vapor - Steam, H2O	39.7

Higher and Lower Heating Values for Common Fuels			
Fuel	**Formula**	**HHV/GHV [btu/lbm]**	**LHV/NCV [btu/lbm]**
Gasoline	C_8H_{18}	20500	19082
Kerosene	-	19800	18391
Diesel	$C_{10}H_{20}$ - $C_{15}H_{28}$	19650	18453
Hydrogen	H	61000	51500
LPG (propane/butane)	-	21180	19562
Natural Gas	-	23170	21003
Methane	CH_4	24000	21500
Methanol	CH_3OH	8580	7760
Bituminous	$C_{137}H_{97}O_9NS$	11630	11101
Anthracite	$C_{240}H_{90}O_4NS$	12750	12520

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THERMODYNAMICS:

Ideal Gas:

$$PV = mRT$$

$$PV = \frac{mR^*T}{MW}$$

$$R = \frac{R^*}{MW}$$

Where R* is the universal gas constant is 1545.4 (ft-lbf)/(lbmol-R)

Constant Heat Capacities:

At/near room temperatures-

$$\Delta s = C_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1}$$

$$\Delta s = C_v \ln\frac{T_2}{T_1} - R\ln\frac{V_2}{V_1}$$

$$C_p - C_v = R$$

$$\Delta h = C_p \Delta T \qquad \Delta u = C_v \Delta T$$

Isentropic Process: (ΔS=0)

$$T_a = T_b\left(\frac{P_a}{P_b}\right)^{\left(\frac{\gamma-1}{\gamma}\right)} \qquad \eta_{compressor} = \frac{T_2 - T_1}{T_{2\prime} - T_1}$$

Isentropic Relations for an Ideal Gas:

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = \left(\frac{\rho_2}{\rho_1}\right)^{\gamma-1}$$

$$\left(\frac{T_2}{T_1}\right)^{\frac{\gamma}{\gamma-1}} = \frac{p_2}{p_1} = \left(\frac{V_1}{V_2}\right)^{\gamma} = \left(\frac{\rho_2}{\rho_1}\right)^{\gamma}$$

$$\left(\frac{T_1}{T_2}\right)^{\frac{1}{\gamma-1}} = \left(\frac{p_1}{p_2}\right)^{\frac{1}{\gamma}} = \frac{V_2}{V_1} = \frac{\rho_1}{\rho_2}$$

$$\left(\frac{T_2}{T_1}\right)^{\frac{1}{\gamma-1}} = \left(\frac{p_2}{p_1}\right)^{\frac{1}{\gamma}} = \frac{V_1}{V_2} = \frac{\rho_2}{\rho_1}$$

$$where\ \gamma = \frac{C_p}{C_v}$$

Adiabatic: (Q=0)

$$W_{ideal} = m(h_1 - h_2)$$

Quality:

$$h = h_f + xh_{fg}$$

$$s = s_f + xs_{fg}$$

$$u = u_f + xu_{fg}$$

$$v = v_f + xvh_{fg}$$

$$x = \frac{m_{gas}}{m_{gas} + m_{fluid}}$$

$$h = xh_g + (1-x)h_f$$

$$s = xs_g + (1-x)s_f$$

$$u = xu_g + (1-x)u_f$$

$$v = xv_g + (1-x)v_f$$

HEAT TRANSFER:

Transient Heat Transfer (Newton's Method):

$$T_t = T_\infty + (T_o - T_\infty)e^{-rt}$$

Or

$$rt = -\ln\frac{(T_t - T_\infty)}{(T_o - T_\infty)}$$

Where r= rate constant (usually given)
t=time
T_∞=Surrounding Temp
To=Initial Temp
Tt=Temp at time t

Lumped Parameter Method:

If Bi<0.1:

$$T_t = T_\infty + (T_o - T_\infty)e^{-Bi(F_o)}$$

Where Fo=Fourier number (usually given)
t=time
T_∞=Surrounding Temp
To=Initial Temp
Tt=Temp at time t
Bi=Biot number

Lumped parameter-Electrical Analogy

$$T_t = T_\infty + (T_o - T_\infty)e^{t/ReCe}$$

Where t=time
T_∞=Surrounding Temp
To=Initial Temp
Tt=Temp at time t
Bi=Biot number

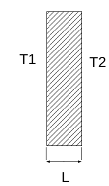
And $R_e = \frac{1}{hA_s}$
$C_e = C_p\rho V$

NOTE: ReCe is also known as the time constant (τ)

Thermal Resistance:

$$R_{th} = \frac{T_1 - T_2}{Q}\left[\frac{F \cdot hr}{Btu}\right]$$

For a plate :

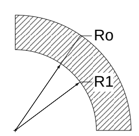


$$R_{th} = \frac{L}{kA}$$

For a film:

$$R_{th} = \frac{1}{hA}$$ Where h is the film coefficient

For a curved layer:



$$R_{th} = \frac{\ln\frac{r_o}{r_i}}{2\pi kL}$$

L=length of curved layer (into the page)

NOTE: Thermal resistance doesn't equal R value!

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FLUID MECHANICS:

Bernoullis equation:

$$\frac{P_1 g_1}{\rho_1 g_c} + \frac{V_1^2}{2g_c} + \frac{z g_1}{g_c} + E_A = \frac{P_2}{\rho_2} + \frac{V_2^2}{2g_c} + \frac{z g_2}{g_c} + E_E + E_f + E_m$$

Where: P=pressure [lbm/ft^2]
ρ=density [lbm/ft^3]
V=velocity [ft/s] or [ft/m]
g_c=gravitational constant 32.2 [lbm-ft/lbf-s^2]
g=gravitational constant at point of interest [ft]
E_a=Energy added to the system (pump or compressor) [ft]
E_E=Energy extracted from the system (turbine) [ft]
E_f=Energy lost due to friction [ft]
E_m=Energy lost due to major pipe losses (bends, fittings, valves, etc.) [ft]

Energy Added: $E_A = \frac{550\left[\frac{ft-lbs}{s-hp}\right]P_{Hp}\eta}{\dot{m}\left[\frac{lbsm}{s}\right]} = \frac{1000\left[\frac{W}{kW}\right]P_{kW}\eta}{\dot{m}}$

Where: $P_{hp} = \frac{h[ft]Q[gpm]SG}{3956} = \frac{\Delta P[psi]Q\left[ft^3/_s\right]}{550}$

Energy Extracted (turbine): $E_E = \frac{P[\frac{ft-lb}{s}]}{\dot{m}[\frac{lb}{s}]}$

Friction Energy: $E_f = h_f \times \frac{g}{g_c} = \frac{f \times L[ft]V^2[\frac{ft}{s}]^2}{2D[ft]g_c[\frac{lbm-ft}{lbf-s^2}]}$

Where: $f = friction\ factor$ taken from Moody chart

Pipe/fitting loss energy: $E_m = h_m \times \frac{g}{g_c} = Kh_v = \frac{f \times L_e[ft]}{D[ft]} \times \frac{V^2[\frac{ft}{s}]^2}{2g_c[\frac{lbm-ft}{lbf-s^2}]}$

Reynolds Number:

$$Re = \frac{\rho V D_h}{g_c \mu}$$

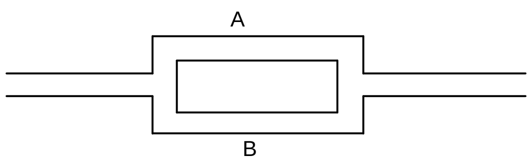
Where: ρ=density [lbm/ft^3]
V= Velocity [ft/s]
Dh=Hydraulic diameter [ft]
g_c=gravitational constant 32.2 [lbm-ft/lbf-s^2]
μ=Viscosity [lbf-s/ft^2]

Laminar Flow: Re< 2100 and $V_{average}$=1/2(V_{max})

Turbulent Flow: Re > 4000 and $V_{average}$=Q /A

Where: Q=volumetric flow [ft^3/s]
A=Area [ft^2]

Pipe Systems:



$V_A + V_B = V_t$

Where: V_A = flow through pipe A
V_B = flow through pipe B
V_t = total flow in or out of system

$$V_B = \sqrt{\left(\frac{f_A}{f_B}\right)\left(\frac{L_A}{L_B}\right)\left(\frac{D_B}{D}\right)} \times V_a$$

Where: f_A = friction factor through pipe A (unitless)
f_B = friction factor through pipe B
L_A = length of pipe A [ft]
L_B = length of pipe B
D_A = diameter of pipe A [ft]
D_B = diameter of pipe B
V_A = flow rate through pipe A [ft^3/sec]
V_B = flow rate through pipe B

$$h_A = h_B$$

Where: h_A = head loss across pipe A
h_B = head loss across pipe B

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MECHANICS OF MATERIALS:

AXIAL ELONGATION IN A BEAM:

$$\delta = \frac{L_o \sigma}{E} = \frac{L_o F}{EA}$$

Where: δ = axial deformation [ft]
Lo= original length [ft]
σ = axial stress [lb/ft^2]
E = modulus of elasticity [lbf/ft^2]

CIRCULAR SHAFT TORSION:

$$\phi = \frac{TL}{GJ}$$

And

$$\tau_{SHEAR} = \frac{Tr}{J}$$

Where: ϕ = angle of twist [rad]
T = torque [lbf-ft]
L = length [ft]
G = modulus of rigidity (or shear modulus) [lbf/ft^2]
J = Polar moment of inertia [ft^4]
r = radius of shaft [ft]

POLAR MOMENT OF SOLID SHAFT:

$$J = \frac{\pi r^4}{2}$$

POLAR MOMENT OF HOLLOW SHAFT:

$$J = \frac{\pi\left(r_{outside}^4 - r_{inside}^4\right)}{2}$$

HOOKES LAW:

$$\sigma = E\varepsilon$$

Where: σ = stress [lb/ft^2]
E = modulus of elasticity [lbf/ft^2]
ε = strain [dimensionless]

$$\tau = G\phi$$

Where: τ = shear stress [lb/ft^2]
G = modulus of rigidity (or shear modulus) [lbf/ft^2]
ϕ = shear strain [dimensionless]

BENDING STRESS IN A BEAM:

$$\sigma = \frac{Mc}{I}$$

Where: M = Moment at point of stress [lb/ft^2]
C = distance from neutral axis [ft]
I = centroidal moment of inertia [ft^4]

FAILURE THEORIES:

FOR BRITTLE MATERIALS:

Static Loading:

Max Normal Stress Theory,

Failure Criteria: $\sigma > S_u$

And $FS = \frac{S_u}{\sigma}$

$S_a = \frac{S_u}{FS}$

Where Su = ultimate strength (psi) of the material
FS=Factor of Safety
Sa = Allowable Stress

Coulomb-Mohr,

$$\frac{\sigma_1}{S_{ut}} + \frac{\sigma_2}{S_{uc}} > 1$$

Where Sut = ultimate strength (psi) of the material in tension
Sut = ultimate strength (psi) of the material in compression
$\sigma_{1,2}$ = Principal stresses (psi)

Modified Mohr,

When $\sigma_1 \geq 0$, $\sigma_1 \geq -\sigma_2$

$$FS = \frac{S_{ut}}{\sigma_1}$$

When $\sigma_1 \geq 0$, $\sigma_1 \leq -\sigma_2$

$$\frac{1}{FS} = \sigma_1\left(\frac{1}{S_{ut}} + \frac{1}{S_{uc}}\right) + \frac{\sigma_2}{S_{uc}}$$

FOR DUCTILE MATERIALS:

Static, uniaxial Loading:

Failure Criteria: $\sigma > S_y$

Max strain theory:

$$\epsilon = \frac{S_y}{E}$$

Max shear stress theory:

$S_{ys} = \frac{S_{yt}}{2}$

(yield strength in shear is half the tensile yield strength)

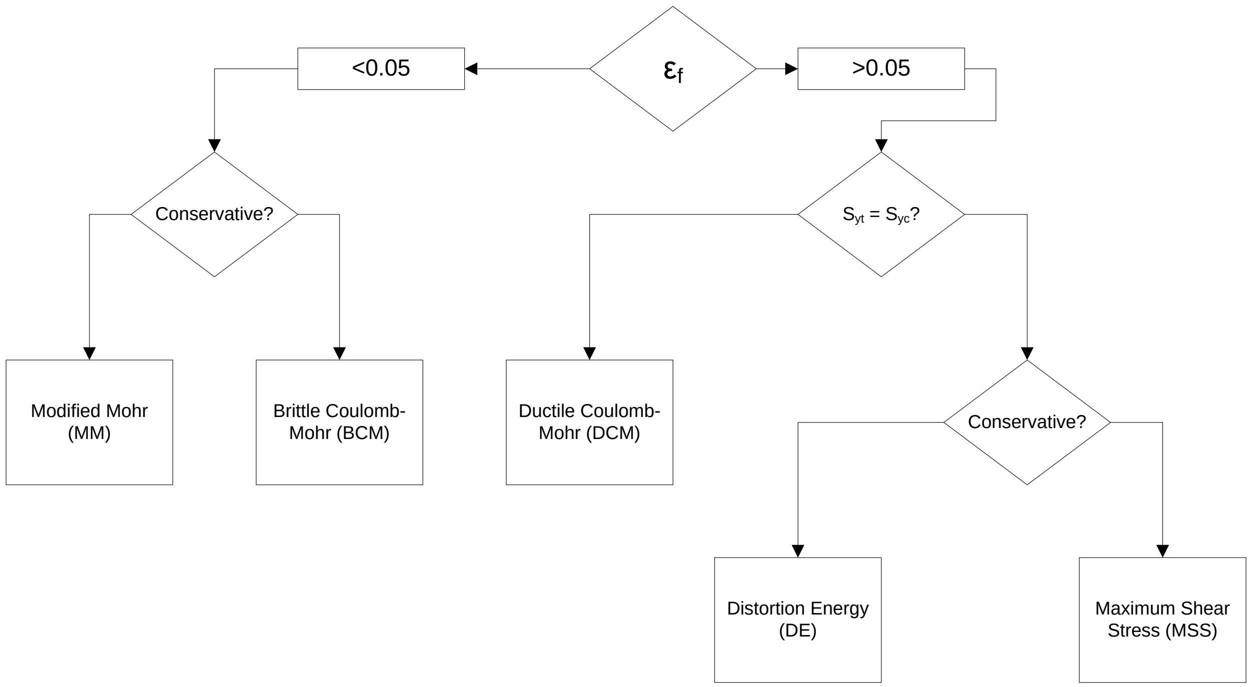
Where SY = yield strength (psi) of the material
ε=strain
E = Modulus of elasticity

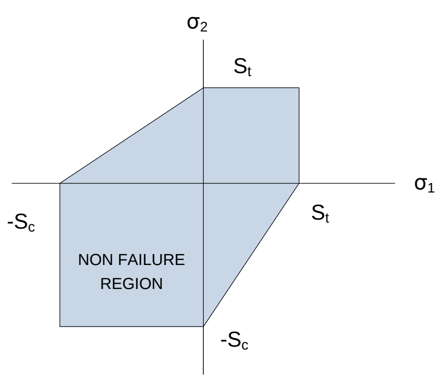
PRINCIPAL STRESS:

$$\sigma_1, \sigma_2 = \frac{1}{2}(\sigma_X + \sigma_Y) \pm \frac{1}{2}\sqrt{(\sigma_X - \sigma_Y)^2 + (2\tau)^2}$$

PRINCIPAL MAX SHEAR:

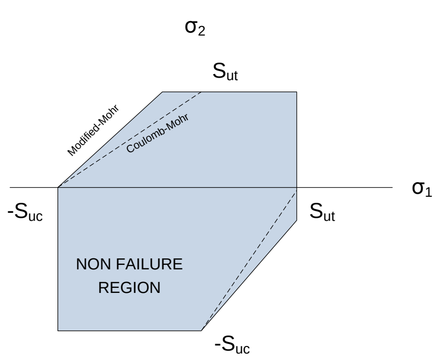
$$\tau_1, \tau_2 = \pm\frac{\sqrt{(\sigma_X - \sigma_Y)^2 + (2\tau)^2}}{2}$$





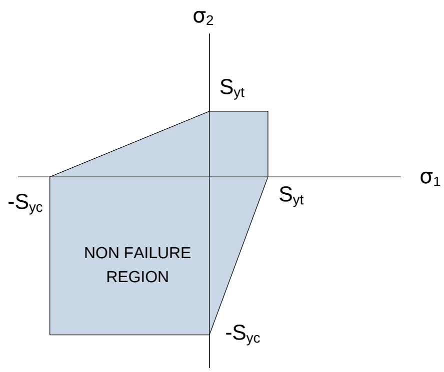
Brittle Coulomb-Mohr:

Quadrant	Failure Criteria
$\sigma_1 \geq \sigma_2 \geq 0$	$\sigma_1 = \frac{S_{ut}}{FS}$
$\sigma_1 \geq 0 \geq \sigma_2$	$\frac{\sigma_1}{S_{ut}} - \frac{\sigma_2}{S_{uc}} = \frac{1}{FS}$
$0 \geq \sigma_1 \geq \sigma_2$	$\sigma_2 = -\frac{S_{uc}}{FS}$



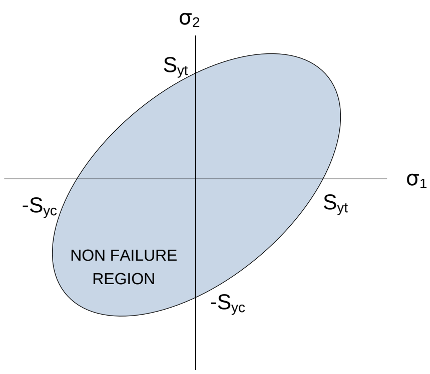
Brittle Modified-Mohr:

Quadrant	Failure Criteria
$\sigma_1 \geq \sigma_2 \geq 0$	$\sigma_1 = \frac{S_{ut}}{FS}$
$\sigma_1 \geq 0 \geq \sigma_2$ and $\left\lvert\frac{\sigma_2}{\sigma_1}\right\rvert \leq 1$	$\sigma_1 = \frac{S_{ut}}{FS}$
$\sigma_1 \geq 0 \geq \sigma_2$ and $\left\lvert\frac{\sigma_2}{\sigma_1}\right\rvert > 1$	$\frac{(S_{uc} - S_{ut})\sigma_1}{S_{uc}S_{ut}} - \frac{\sigma_2}{S_{uc}} = \frac{1}{FS}$
$0 \geq \sigma_1 \geq \sigma_2$	$\sigma_2 = -\frac{S_{uc}}{FS}$



Ductile Coulomb-Mohr:

Quadrant	Failure Criteria
$\sigma_1 \geq \sigma_2 \geq 0$	$\sigma_1 = \frac{S_{ut}}{FS}$
$\sigma_1 \geq 0 \geq \sigma_2$	$\frac{\sigma_1}{S_{ut}} - \frac{\sigma_2}{S_{uc}} = \frac{1}{FS}$
$0 \geq \sigma_1 \geq \sigma_2$	$\sigma_2 = -\frac{S_{uc}}{FS}$



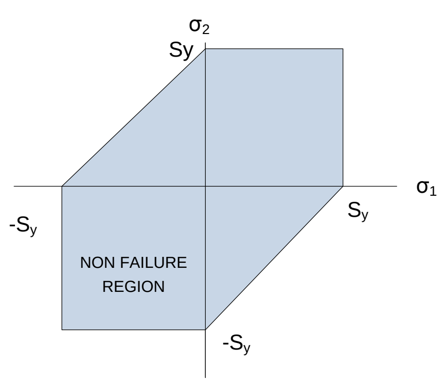
Ductile Loading: Distortion Energy Theory

Effective Stress (Von Mises Stress):

$$\sigma' = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1\sigma_2}$$

Factor of Safety:

$$FS = \frac{S_{yt}}{\sigma'}$$



Maximum Shear Stress Theory:

See MERM for equations 52.8-52.14

$S_{ys} = \frac{S_{yt}}{2}$, I.e. Yield strength in shear is half of tensile yield strength.

$\tau_{12} = \frac{\sigma_1 - \sigma_2}{2}$, $\tau_{23} = \frac{\sigma_2 - \sigma_3}{2}$, $\tau_{13} = \frac{\sigma_1 - \sigma_3}{2}$,

$\tau_{max} = \max(\tau_{12}, \tau_{23}, \tau_{13})$

Factor of Safety:

$$FS = \frac{S_{ys}}{\tau_{max}} = \frac{S_{yt}}{2\tau_{max}}$$

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Motor Equations/Electrical

BHP from Amps and Volts:

$$BHP = nameplate\ HP \times \frac{Volts_{measured} \times Amps_{measured}}{Volts_{nameplate} \times Amps_{nameplate}}$$

$$Estimated\ BHP = HP_{nameplate} \times \frac{Amps_{measured} \times Volts_{measured}}{745.7}$$

$$BHP_{single\ phase} = \frac{Amps_{measured} \times Volts_{measured} \times Efficiency \times power\ factor}{745.7}$$

$$BHP_{three\ phase} = \frac{1.732 \times Amps_{measured} \times Volts_{measured} \times Efficiency \times power\ factor \times \%of\ load}{745.7}$$

$$BHP = \frac{\tau(ft - lbs) \times 2\pi(\frac{rad}{rev}) \times \omega(rpm)}{33000}$$

Ohms law:

$$V = A \times R$$

Torque and Power:

$$T_{in-lb} = \frac{Hp \times 63025}{n}$$

Where n=rpm

$$T_{ft-lb} = \frac{Hp \times 5252}{n}$$