APPENDIX A

UNITS OF MEASURE, PHYSICAL CONSTANTS, AND MATERIAL PROPERTIES

A-1 UNITS OF MEASURE

LENGTH

1 micron (μ) = 10^{-3} millimeter (mm) = 10^{4} angstroms (Å)
1 Å = 10^{-7} mm
1 mm = 10^{-1} centimeter (cm) = 10^{-3} meter (m)
1 foot (ft) = 12 inches (in.) = 304.8 mm
1 fathom = 6 ft
1 statute mile (stat. mile or mile) = 5,280 ft
1 U.S. nautical mile (naut. mile) = 6,080.21 ft = length of 1 minute of longitude of the earth at the Equator at sea level
1 kilometer (km) = 3,281 ft = 1,000 m = 0.6214 mile

AREA

1 square inch (in.^{2}) = 6.452 square centimeters (cm^2)
1 square foot (ft^2) = 929.0 cm^2
1 acre = 43,560 ft^2
1 square statute mile (mile^2) = 640 acres = 27.88×10^6 ft^2 = 2.59 square kilometers (km^2)

VOLUME

1 cubic centimeter (cc or cm^3) = 3.531×10^{-5} cubic feet (ft^3)
1 liter = 10^3 cm^3
1 cubic foot (ft^3) = 1.728 in.^{3} = 7.48 U.S. gallons (gal)
1 U.S. gal = 231 in.^{3} = 0.134 ft^3
1 Imp. gal = 277.42 in.^{3}
1 million U.S. gal (mg) = 134,000 ft^3
1 square mile inch (mile^2-in.) = 2.315×10^6 ft^3 = 53.3 acre-ft
1 day second foot (dsf) $\equiv$ 1 cfs for 1 day = 86,400 ft^3 = 1.98 acre-ft
1 mile^2-in. = 26.89 dsf

1 acre-inch = 3,630 ft^3
1 cubic mile = 147×10^9 ft^3

TIME

1 minute (min) = 60 seconds (sec)
1 hour (hr) = 60 min
1 day = 24 hr = 86,400 sec
1 month = 2.63×10^6 sec
1 year = 8,760 hr = 31.5×10^6 sec

VELOCITY

1 centimeter per second (cm sec^{-1}) = 3.281×10^{-2} foot per second (fps)
1 kilometer per hour (km hr^{-1}) = 27.78 cm sec^{-1} = 54.68 feet per minute (fpm)
1 statute mile per hour (mph) = 44.7 cm sec^{-1} = 88 fpm = 1.467 fps = 1.609 km hr^{-1}
1 nautical mile per hour (knot) = 51.48 cm sec^{-1} = 101.3 fpm = 1.689 fps = 1.853 km hr^{-1} = 1.152 mph

FORCE

1 dyne = 2.248×10^{-6} pound (lb)
[A force of 1 dyne will impart an acceleration of 1 cm sec^{-2} to a mass of 1 gram (g).]

MASS

1 slug $\equiv$ 1 lb-sec^2 ft^{-1} = 14.6×10^3 g = 32.17 lb mass (lbm)
1 g = 10^{-3} kilogram (kg)

ENERGY

1 erg = 1 dyne-centimeter (dyne-cm) = 9.480×10^{-11} British thermal unit (Btu) = 7.367×10^{-8} foot-pound (ft-lb)
1 Btu = 778.26 ft-lb
1 joule = 10^7 ergs
1 calorie (cal) $\equiv$ 1 gram-calorie (g-cal) = 3.969×10^{-3} Btu

ENERGY FLUX OR POWER

1 erg per second = 5.689×10^{-9} Btu min^{-1} = 4.426×10^{-6} ft-lb min^{-1} = 1.433×10^{-6} cal min^{-1}

ENERGY DENSITY

1 langley (ly) = 1 calorie per square centimeter (cal cm^{-2}) = 3.69 Btu ft^{-2}

DYNAMIC VISCOSITY

1 poise = 1 dyne-sec cm^{-2} = 2.09×10^{-3} lb-sec ft^{-2}
1 centipoise (cp) = 10^{-2} poise

TEMPERATURE (T)

Degrees Fahrenheit (°F) = $\frac{9}{5}$ (T in degrees Celsius) + 32
Degrees Celsius (°C) = $\frac{5}{9}$ (T in degrees Fahrenheit − 32)
Degrees Kelvin (°K) = T in °C + 273.16
Degrees Rankine (°R) = T in °F + 459.69

PRESSURE INTENSITY

1 millibar (mb) = 1,000 dynes cm^{-2} = 1.45×10^{-2} pounds per square inch (psi) = 100 $kg\ s^{-2}\ m^{-1}$ N/m^2
1 millimeter of mercury (mm Hg) = 1.33 mb
1 inch of mercury = 33.9 mb = 0.492 psi
1 standard atmosphere (atm) = 1,013.25 mb = 760 mm Hg = 14.7 psi

A-2 PHYSICAL CONSTANTS

Gas constant: R_0 (dry gas) = 8.315×10^7 ergs $°K^{-1}$ $mole^{-1}$
= 1.9857 cal $°K^{-1}$ $mole^{-1}$
= 1,545.4 ft-lb $°R^{-1}$ lb mass-$mole^{-1}$
R (dry air) = 2.876×10^6 dyne-cm g^{-1} $°K^{-1}$
= 2.876×10^6 cm^2 sec^{-2} $°K^{-1}$
= 1.715×10^3 ft^2 $°R^{-1}$ sec^{-2}

1 mole of dry air = 28.967 g
Specific heat of dry air: c_p = 0.240 cal g^{-1} $°K^{-1}$
c_v = 0.171 cal g^{-1} $°K^{-1}$
Solar constant: W_{B0} = 2.00 cal cm^{-2} min^{-1}
Stefan's constant: σ = 0.826×10^{-10} cal cm^{-2} min^{-1} $°K^{-4}$
= 0.1713×10^{-8} Btu ft^{-2} hr^{-1} $°R^{-4}$
Planck's constant: h = 6.624×10^{-27} erg-sec
Boltzmann's constant: k = 1.380×10^{-16} erg $°K^{-1}$
Speed of light: c = 2.998×10^{10} cm sec^{-1}
Gravitational constant: g_0 = 32.17 ft sec^{-2} = 980.7 cm sec^{-2}
Volume per mole or gram molecular weight of ideal gas (1 atm, 0°C) = 22.412 liters

Bowen constant: $C_B = 6.1 \times 10^{-4}\ ^\circ C^{-1}$
Mean radius of earth = 3,956 miles
Mean earth-sun distance = 93.1×10^6 miles

WATER

Latent heat of fusion = 79.7 cal g^{-1} (at 0°C)
Latent heat of vaporization = 597.3 cal g^{-1} (at 0°C)
Latent heat of sublimation = 677.0 cal g^{-1} (at 0°C)
Specific heat: c_p = 1.000 cal $g^{-1}\ ^\circ C^{-1}$ (at 14.5 °C)

$10^{-3}\ g\ cm^3$
$= 10^{-6}\ kg/cm^3$
$= 1\ kg/m^3$

A-3 MATERIAL PROPERTIES

Dry air at 1 atm pressure, cm-g-sec system of units

T °C	*Viscosity* *poise*	c_p *cal* $g^{-1}\ ^\circ K^{-1}$	$k = c_p/c_v$	ρ *g* cm^{-3}
0	1.718×10^{-4}	0.2397	1.403	0.00140
10	1.768×10^{-4}	0.2398		
20	1.818×10^{-4}	0.2399	.....	0.00119
30	1.866×10^{-4}	0.2400		
40	1.914×10^{-4}	0.2401	.....	0.00112
50	1.951×10^{-4}	0.2403		
60	1.997×10^{-4}	0.2404	.....	0.00105
70	2.043×10^{-4}			
80	2.088×10^{-4}	.....	.....	0.00099
90	2.132×10^{-4}			
100	2.175×10^{-4}	.....	1.401	0.00094

Dry air at 1 atm pressure, ft-lb-sec system of units

T °F	*Viscosity* *lb-sec* ft^{-2}	c_p *Btu* $slug^{-1}\ ^\circ R^{-1}$	$k = c_p/c_v$	ρ *slugs* ft^{-3}
0	3.38×10^{-7}	.....	.....	0.00268
20	3.50×10^{-7}	.....	.....	0.00257
40	3.62×10^{-7}	.....	.....	0.00247
60	3.74×10^{-7}	7.624	1.403	0.00237
80	3.85×10^{-7}	.....	.....	0.00228
100	3.96×10^{-7}	.....	.....	0.00220
120	4.07×10^{-7}	.....	.....	0.00215
150	4.23×10^{-7}	.....	.....	0.00204
200	4.49×10^{-7}	.....	.....	0.00187

Properties of the standard atmosphere

z ft	T $°F$	p $lb\ ft^{-2}$	ρ $slugs\ ft^{-3}$	$\mu \times 10^7$ $slugs\ ft^{-1}\ sec^{-1}$	$\nu \times 10^4$ $ft^2\ sec^{-1}$
0	59.00	2,116.2	0.002378	3.719	1.564
1,000	57.44	2,040.9	0.002310	3.699	1.602
2,000	51.87	1,967.7	0.002242	3.679	1.641
3,000	48.31	1,896.7	0.002177	3.659	1.681
4,000	44.74	1,827.7	0.002112	3.639	1.723
5,000	41.18	1,760.8	0.002049	3.618	1.766
6,000	37.62	1,696.0	0.001988	3.598	1.810
7,000	34.05	1,633.0	0.001928	3.577	1.855
8,000	30.49	1,571.9	0.001869	3.557	1.903
9,000	26.92	1,512.8	0.001812	3.536	1.951
10,000	23.36	1,455.4	0.001756	3.515	2.002
11,000	19.80	1,399.8	0.001702	3.495	2.054
12,000	16.23	1,345.9	0.001649	3.474	2.107
13,000	12.67	1,293.7	0.001597	3.453	2.163
14,000	9.10	1,243.2	0.001546	3.432	2.220
15,000	5.54	1,194.3	0.001497	3.411	2.280
16,000	1.98	1,147.0	0.001448	3.390	2.341
17,000	−1.59	1,101.1	0.001401	3.369	2.404
18,000	−5.15	1,056.9	0.001355	3.347	2.470
19,000	−8.72	1,014.0	0.001311	3.326	2.538
20,000	−12.28	972.6	0.001267	3.305	2.608
21,000	−15.84	932.5	0.001225	3.283	2.681
22,000	−19.41	893.8	0.001183	3.262	2.757
23,000	−22.97	856.4	0.001143	3.240	2.834
24,000	−26.54	820.3	0.001104	3.218	2.915
25,000	−30.10	785.3	0.001066	3.196	2.999
26,000	−33.66	751.7	0.001029	3.174	3.087
27,000	−37.23	719.2	0.000993	3.153	3.177
28,000	−40.79	687.9	0.000957	3.130	3.270
29,000	−44.36	657.6	0.000923	3.108	3.367
30,000	−47.92	628.5	0.000890	3.086	3.469
31,000	−51.48	600.4	0.000858	3.064	3.573
32,000	−55.05	573.3	0.000826	3.041	3.682
33,000	−58.61	547.3	0.000796	3.019	3.795
34,000	−62.18	522.2	0.000766	2.997	3.913
35,000	−65.74	498.0	0.000737	2.974	4.036
35,332	−67.6	489.8	0.000727	2.961	4.073
36,000	−67.6	474.8	0.000709	2.961	4.176

Properties of the standard atmosphere (*Continued*)

z *ft*	T °F	p *lb ft*$^{-2}$	ρ *slugs ft*$^{-3}$	$\mu \times 10^7$ *slugs ft*$^{-1}$ *sec*$^{-1}$	$\nu \times 10^4$ *ft*^{2} *sec*$^{-1}$
37,000	−67.6	452.5	0.0006766	2.961	4.376
38,000	−67.6	431.2	0.0006448	2.961	4.592
39,000	−67.6	411.0	0.0006145	2.961	4.819
40,000	−67.6	391.8	0.0005857	2.961	5.055
41,000	−67.6	373.4	0.0005582	2.961	5.305
42,000	−67.6	355.8	0.0005320	2.961	5.566
43,000	−67.6	339.1	0.0005071	2.961	5.839
44,000	−67.6	323.2	0.0004833	2.961	6.127
45,000	−67.6	308.0	0.0004605	2.961	6.430

SOURCE: Notes and Tables for Use in the Analysis of Supersonic Flow, *NACA Tech. Note* 1428, 1947.

Water at 1 atm pressure, cm-g-sec system of units

T °C	*Surface tension dynes cm*$^{-1}$	*Viscosity poises*	*Vapor pressure mm Hg*	ρ *g cm*$^{-3}$
0	75.6	17.93×10^{-3}	4.58	0.99987
5	74.9	15.18×10^{-3}	6.54	0.99999
10	74.2	13.09×10^{-3}	9.21	0.99973
15	73.5	11.44×10^{-3}	12.79	0.99913
20	72.8	10.08×10^{-3}	17.55	0.99823
25	72.1	8.94×10^{-3}	23.78	0.99708
30	71.4	8.00×10^{-3}	31.86	0.99568
35	70.7	7.20×10^{-3}	42.23	0.99406
40	70.0	6.53×10^{-3}	55.40	0.99225
45	69.3	5.97×10^{-3}	71.97	0.99025
50	68.6	5.49×10^{-3}	92.6	0.98807
55	67.8	5.07×10^{-3}	118.2	0.98573
60	67.1	4.69×10^{-3}	149.6	0.98324
65	66.4	4.36×10^{-3}	187.8	0.98059
70	65.7	4.07×10^{-3}	233.9	0.97781
75	65.0	3.80×10^{-3}	289.3	0.97489
80	64.3	3.57×10^{-3}	355.4	0.97183
85	63.6	3.35×10^{-3}	433.7	0.96865
90	62.9	3.16×10^{-3}	526.0	0.96534
95	62.2	2.99×10^{-3}	634.1	0.96192
100	61.5	2.83×10^{-3}	760.0	0.95838

Water at 1 atm pressure, ft-lb-sec system of units

T °F	*Surface tension* $lb\ ft^{-1}$	*Viscosity* $lb\text{-}sec\ ft^{-2}$	*Vapor pressure* *psia*	ρ $slugs\ ft^{-3}$
32	0.00518	3.75×10^{-5}	0.09	1.94
40	0.00514	3.24×10^{-5}	0.12	1.94
50	0.00508	2.74×10^{-5}	0.18	1.94
60	0.00503	2.34×10^{-5}	0.26	1.94
70	0.00497	2.04×10^{-5}	0.36	1.94
80	0.00492	1.80×10^{-5}	0.51	1.93
90	0.00486	1.59×10^{-5}	0.70	1.93
100	0.00479	1.42×10^{-5}	0.96	1.93
120	0.00466	1.17×10^{-5}	1.7	1.92
150	0.00446	0.906×10^{-5}	3.7	1.90
180	0.00426	0.726×10^{-5}	7.5	1.88
212	0.00403	0.594×10^{-5}	14.7	1.86

Specific heats of water substance

Values of c_p in cal g^{-1} $°K^{-1}$

T °C	*Pure ice*	*Sea ice* *Salinity in* 0/00			*Pure water*
		2	6	15	
−100	0.330				
−90	0.346				
−80	0.363				
−70	0.380				
−60	0.397				
−50	0.415	....	....	....	1.3
−40	0.433	....	....	....	1.14
−30	0.450	....	....	....	1.08
−20	0.468	0.52	0.57	0.68	1.04
−10	0.485	0.57	0.71	1.02	1.02
0	0.503	....	....	....	1.0074
5	.....	....	....	....	1.0037
10	.....	....	....	....	1.0013
15	.....	....	....	....	0.9998
20	.....	....	....	....	0.9988
25	.....	....	....	....	0.9983
30	.....	....	....	....	0.9980
35	.....	....	....	....	0.9979
40	.....	....	....	....	0.9980
45	.....	....	....	....	0.9982
50	.....	....	....	....	0.9985
55	.....	....	....	....	0.9989
60	.....	....	....	....	0.9994
70	.....	....	....	....	1.0001
80	.....	....	....	....	1.0014
90	.....	....	....	....	1.0028
100	.....	....	....	....	1.0043