CHARLES DARWIN UNIVERSITY

Family Name	
Given Names	
Student Number	
Teaching Period	Semester 1, 2017

FINAL EXAMINATION	DURATION
ENG480 – Applied Fluid Mechanics	Reading Time: **10** minutes Writing Time: **180** minutes

INSTRUCTIONS TO CANDIDATES

ALL questions must be answered in your answer booklet

The total mark for this examination is **40 marks**

EXAM CONDITIONS

<u>You may begin writing from the commencement of the examination session.</u> The reading time indicated above is provided as a guide only.

This is a CLOSED BOOK examination

Any non-programmable calculator is permitted

No handwritten notes are permitted

No dictionaries are permitted

ADDITIONAL AUTHORISED MATERIALS	EXAMINATION MATERIALS TO BE SUPPLIED
No additional printed material is permitted	1 x 16 Page Book Formula Sheet/s Graph Paper Reference Information

THIS EXAMINATION IS PRINTED DOUBLE-SIDED.

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Question 1

Standard atmospheric air (T_0 = 15 °C, p_o = 101.3 kPa) is drawn steadily through a frictionless and adiabatic converging nozzle into an adiabatic, constant cross-sectional area duct. The duct is 3 m long and has an inside diameter of 0.15 m. The average friction factor for the duct may be estimated as being equal to 0.03. What is the maximum mass flow rate in kg/s through the duct? For this maximum flowrate, determine the values of static temperature, static pressure, stagnation temperature, stagnation pressure, and velocity at the inlet [section (1)] and exit [section (2)] of the constant area duct. Sketch the temperature-entropy diagram for this flow (Assume subsonic flow).

Marks (10)
Suggested Time: 45 minutes

Question 2

A centrifugal water pump shown in Fig. 1 having an impeller diameter of 0.5 m operates at 900 rpm. The water enters the pump parallel to the pump shaft. If the exit blade angle, β_2 (see figure), is 25°, determine the shaft power required to turn the impeller when the flow through the pump is 0.16 m^3/s. The uniform blade height is 50 mm and r_2 = 0.25m.

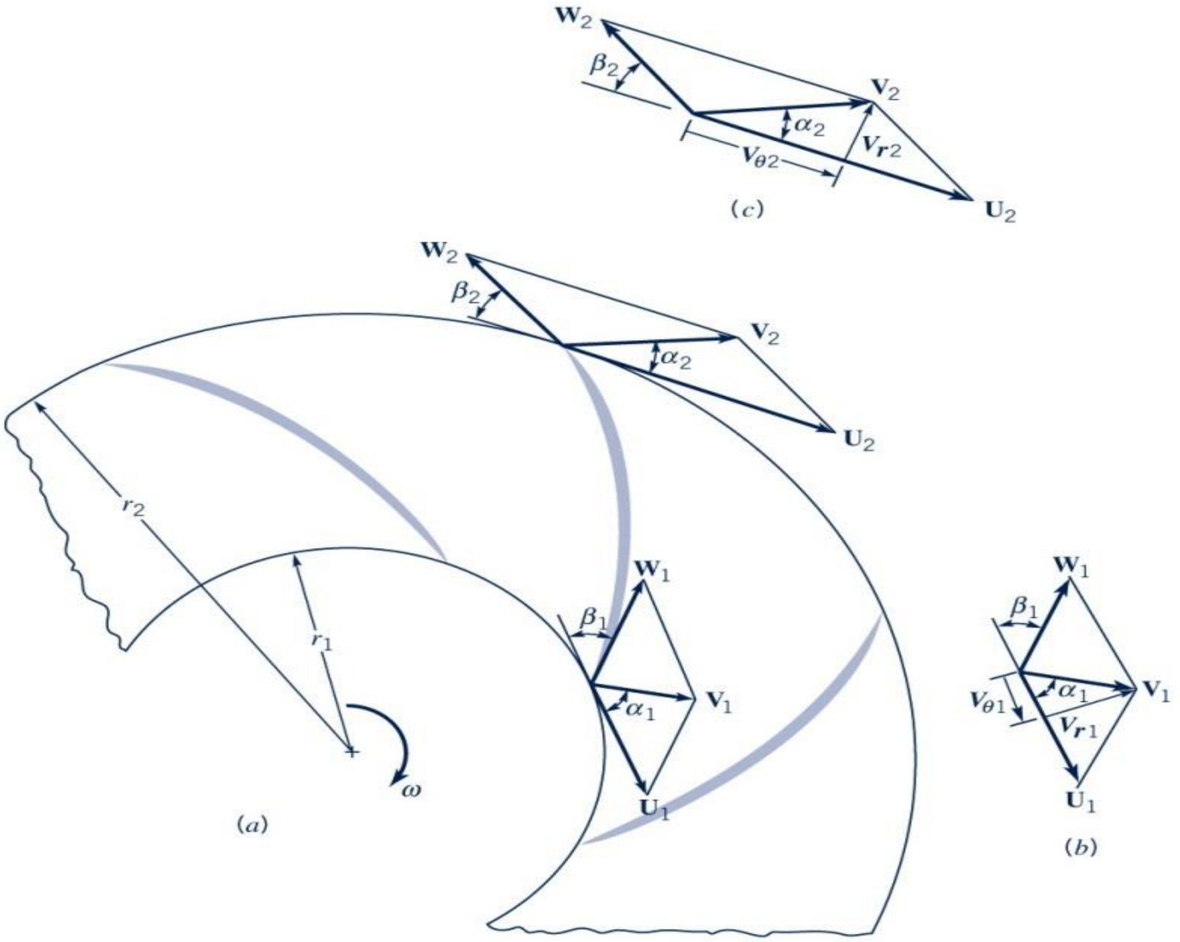


Fig. 1: Centrifugal water pump

Marks (10)
Suggested Time: 45 minutes

Question 3

a. At a given instant, two pressure waves, each moving at the speed of sound, emitted by a point sources moving with constant velocity in a fluid at rest is shown in Fig. 2. Determine the Mach number involved, and indicate with a sketch the instantaneous location of the point source.

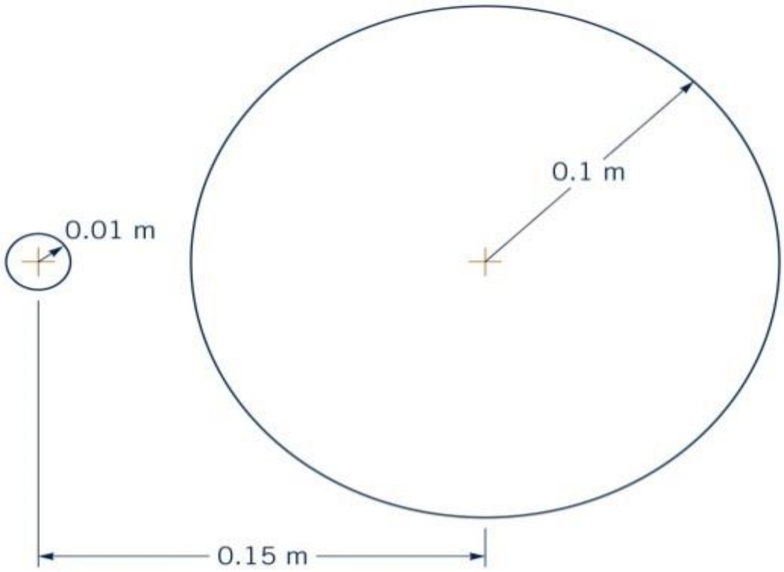


Fig. 2: Two pressure waves

Marks (5)

b. At seashore, you observe a high-speed aircraft moving overhead at an elevation of 3048 m. you hear the plane 8 s after it passes directly overhead. Using a nominal air temperature of 4.4 °C, estimate the Mach number and speed of the aircraft.

Marks (5)

Suggested Time: 45 minutes

Question 4

Air enters a square duct through a 0.3 m opening as shown in Fig. 3. Because the boundary layer displacement thickness increases in the direction of flow, it is necessary to increase the cross-sectional size of the duct if a constant U = 0.6 m/s velocity is to be maintained outside the boundary layer. Plot a graph of the duct size, d, as a function of x for $0 \leq x \leq 3$ m if U is to be remained constant. Assume laminar flow.

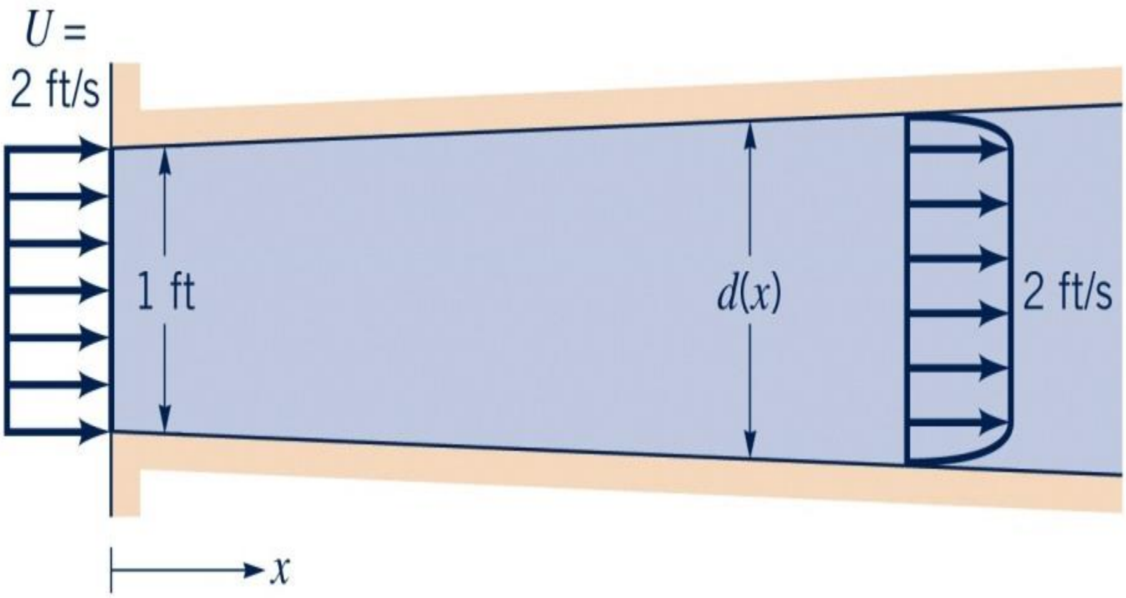


Fig. 3: Square duct

Marks (10)
Suggested Time: 45 minutes

Data sheets, Conversion table and Formulae:

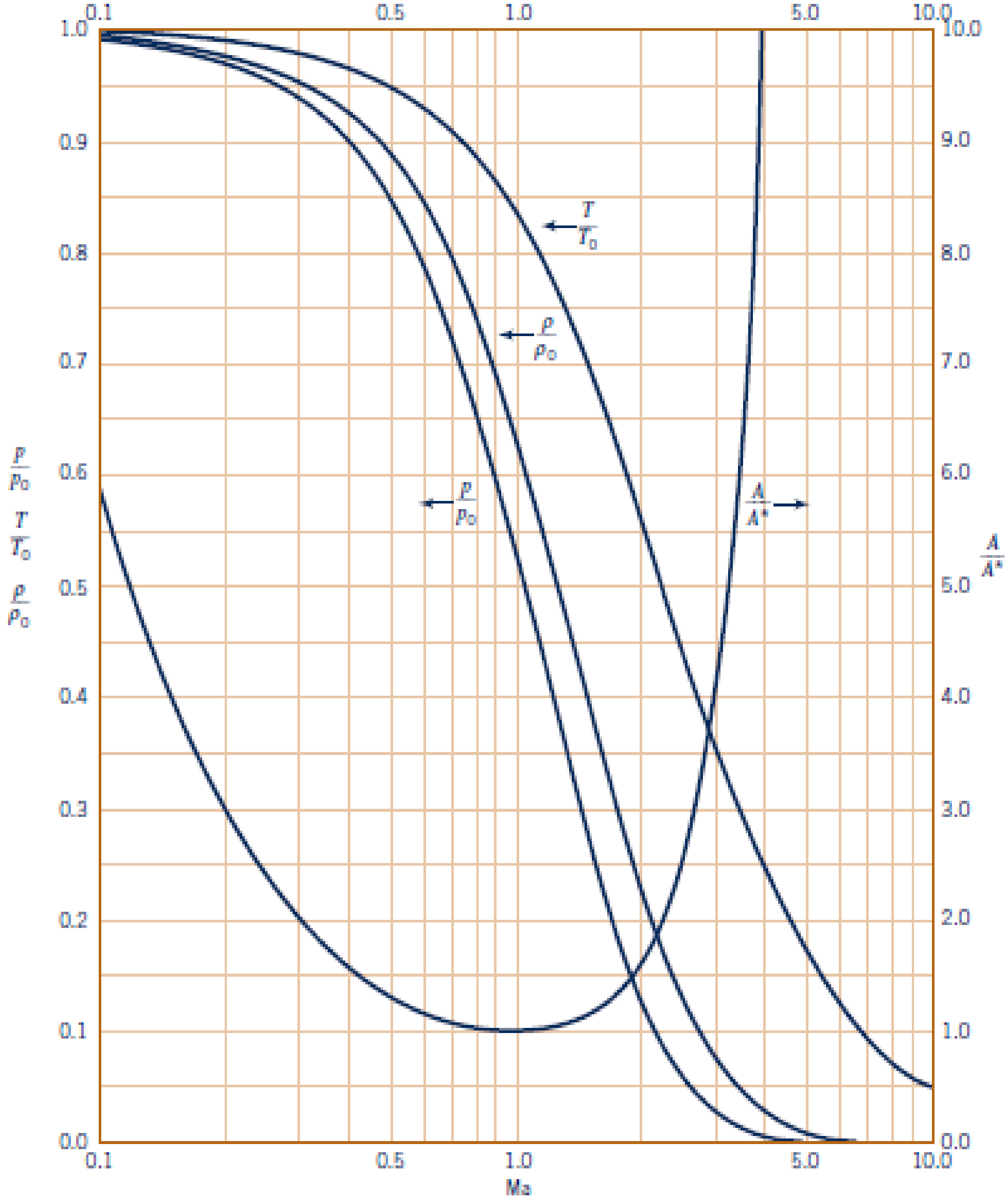
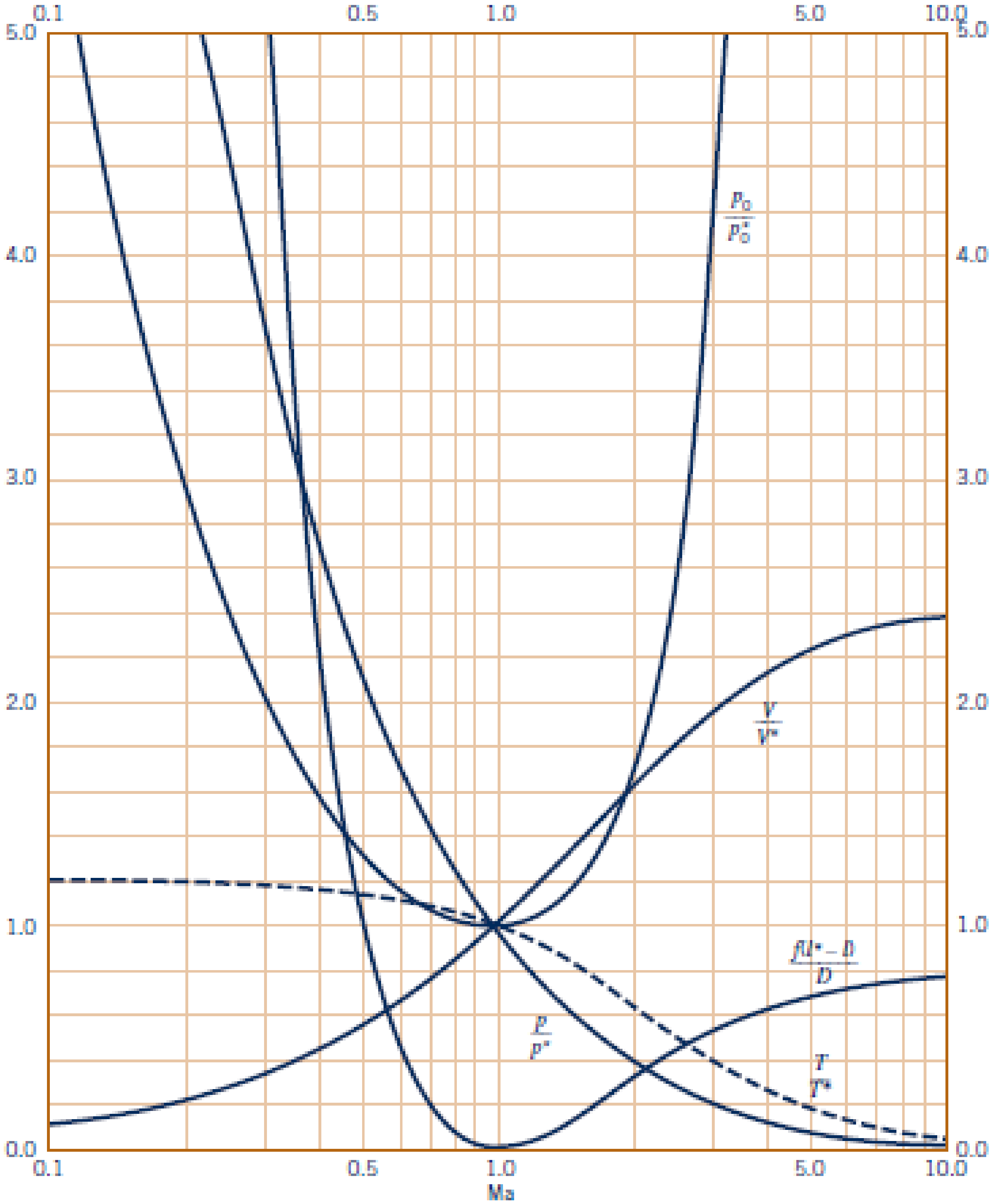


Figure D.1 Isentropic flow of an ideal gas with $k = 1.4$. (Graph provided by Dr. Bruce A. Reichert.)



■ Figure D.2 Fanno flow of an ideal gas with $k = 1.4$. (Graph provided by Dr. Bruce A. Reichert.)

■ TABLE 1.6

Approximate Physical Properties of Some Common Liquids (SI Units)

Liquid	Temperature (°C)	Density, ρ (kg/m³)	Specific Weight, γ (kN/m³)	Dynamic Viscosity, μ (N · s/m²)	Kinematic Viscosity, ν (m²/s)	Surface Tension,[a] σ (N/m)	Vapor Pressure, p_v [N/m² (abs)]	Bulk Modulus,[b] E_v (N/m²)
Carbon tetrachloride	20	1,590	15.6	9.58 E − 4	6.03 E − 7	2.69 E − 2	1.3 E + 4	1.31 E + 9
Ethyl alcohol	20	789	7.74	1.19 E − 3	1.51 E − 6	2.28 E − 2	5.9 E + 3	1.06 E + 9
Gasoline[c]	15.6	680	6.67	3.1 E − 4	4.6 E − 7	2.2 E − 2	5.5 E + 4	1.3 E + 9
Glycerin	20	1,260	12.4	1.50 E + 0	1.19 E − 3	6.33 E − 2	1.4 E − 2	4.52 E + 9
Mercury	20	13,600	133	1.57 E − 3	1.15 E − 7	4.66 E − 1	1.6 E − 1	2.85 E + 10
SAE 30 oil[c]	15.6	912	8.95	3.8 E − 1	4.2 E − 4	3.6 E − 2	—	1.5 E + 9
Seawater	15.6	1,030	10.1	1.20 E − 3	1.17 E − 6	7.34 E − 2	1.77 E + 3	2.34 E + 9
Water	15.6	999	9.80	1.12 E − 3	1.12 E − 6	7.34 E − 2	1.77 E + 3	2.15 E + 9

[a] In contact with air.
[b] Isentropic bulk modulus calculated from speed of sound.
[c] Typical values. Properties of petroleum products vary.

■ TABLE 1.8

Approximate Physical Properties of Some Common Gases at Standard Atmospheric Pressure (SI Units)

Gas	Temperature (°C)	Density, ρ (kg/m³)	Specific Weight, γ (N/m³)	Dynamic Viscosity, μ (N · s/m²)	Kinematic Viscosity, ν (m²/s)	Gas Constant,[a] R (J/kg · K)	Specific Heat Ratio,[b] k
Air (standard)	15	1.23 E + 0	1.20 E + 1	1.79 E − 5	1.46 E − 5	2.869 E + 2	1.40
Carbon dioxide	20	1.83 E + 0	1.80 E + 1	1.47 E − 5	8.03 E − 6	1.889 E + 2	1.30
Helium	20	1.66 E − 1	1.63 E + 0	1.94 E − 5	1.15 E − 4	2.077 E + 3	1.66
Hydrogen	20	8.38 E − 2	8.22 E − 1	8.84 E − 6	1.05 E − 4	4.124 E + 3	1.41
Methane (natural gas)	20	6.67 E − 1	6.54 E + 0	1.10 E − 5	1.65 E − 5	5.183 E + 2	1.31
Nitrogen	20	1.16 E + 0	1.14 E + 1	1.76 E − 5	1.52 E − 5	2.968 E + 2	1.40
Oxygen	20	1.33 E + 0	1.30 E + 1	2.04 E − 5	1.53 E − 5	2.598 E + 2	1.40

[a] Values of the gas constant are independent of temperature.
[b] Values of the specific heat ratio depend only slightly on temperature.

Table E.1

Listing by Physical Quantity

To convert from	to	Multiply by
Acceleration		
foot/second^2	meter/second^2	3.048 E − 1*
free fall, standard	meter/second^2	9.806 65 E + 0*
gal (galileo)	meter/second^2	1.00 E − 2*
inch/second^2	meter/second^2	2.54 E − 2*
Area		
acre	meter^2	4.046 856 422 4 E + 3*
are	meter^2	1.00 E + 2*
barn	meter^2	1.00 E − 28*
foot^2	meter^2	9.290 304 E − 2*
hectare	meter^2	1.00 E + 4*
inch^2	meter^2	6.4516 E − 4*
mile^2 (U.S. statute)	meter2	2.589 988 110 336 E + 6*
section	meter^2	2.589 988 110 336 E + 6*
township	meter2	9.323 957 2 E + 7
yard^2	meter^2	8.361 273 6 E − 1*
Density		
gram/centimeter^3	kilogram/meter^3	1.00 E + 3*
lbm/inch^3	kilogram/meter^3	2.767 990 5 E + 4
lbm/foot^3	kilogram/meter^3	1.601 846 3 E + 1
slug/foot^3	kilogram/meter^3	5.153 79 E + 2

Table E.1 (continued)

To convert from	to	Multiply by
Energy		
British thermal unit: (IST after 1956)	joule	1.055 056 E + 3
British thermal unit (thermochemical)	joule	1.054 350 E + 3
calorie (International Steam Table)	joule	4.1868 E + 0
calorie (thermochemical)	joule	4.184 E + 0*
calorie (kilogram, International Steam Table)	joule	4.1868 E + 3
calorie (kilogram, thermochemical)	joule	4.184 E + 3*
electron volt	joule	1.602 191 7 E − 19
erg	joule	1.00 E − 7*
foot lbf	joule	1.355 817 9 E + 0
foot poundal	joule	4.214 011 0 E − 2
joule (international of 1948)	joule	1.000 165 E + 0
kilocalorie (Internation Steam Table)	joule	4.1868 E + 3
kilocalorie (thermochemical)	joule	4.184 E + 3*
kilowatt hour	joule	3.60 E + 6*
watt hour	joule	3.60 E + 3*
Force		
dyne	newton	1.00 E − 5*
kilogram force (kgf)	newton	9.806 65 E + 0*
kilopound force	newton	9.806 65 E + 0*
kip	newton	4.448 221 615 260 5 E + 3*
lbf (pound force, avoirdupois)	newton	4.448 221 615 260 5 E + 0*
ounce force (avoirdupois)	newton	2.780 138 5 E − 1
pound force, lbf (avoirdupois)	newton	4.448 221 615 260 5 E + 0*
poundal	newton	1.382 549 543 76 E − 1*
Length		
angstrom	meter	1.00 E − 10*
astronomical unit (IAU)	meter	1.496 00 E + 11
cubit	meter	4.572 E − 1*
fathom	meter	1.8288 E + 0*
foot	meter	3.048 E − 1*
furlong	meter	2.011 68 E + 2*
hand	meter	1.016 E − 1*
inch	meter	2.54 E − 2*
league (international nautical)	meter	5.556 E + 3*
light year	meter	9.460 55 E + 15
meter	wavelengths Kr 86	1.650 763 73 E + 6*
micron	meter	1.00 E − 6*
mil	meter	2.54 E − 5*
mile (U.S. statute)	meter	1.609 344 E + 3*
nautical mile (U.S.)	meter	1.852 E + 3*
rod	meter	5.0292 E + 0*
yard	meter	9.144 E − 1*

Table E.1 (continued)

To convert from	to	Multiply by
Mass		
carat (metric)	kilogram	2.00 E − 4*
grain	kilogram	6.479 891 E − 5*
gram	kilogram	1.00 E − 3*
ounce mass (avoirdupois)	kilogram	2.834 952 312 5 E − 2*
pound mass, lbm (avoirdupois)	kilogram	4.535 923 7 E − 1*
slug	kilogram	1.459 390 29 E + 1
ton (long)	kilogram	1.016 046 908 8 E + 3*
ton (metric)	kilogram	1.00 E + 3*
ton (short, 2000 pound)	kilogram	9.071 847 4 E + 2*
tonne	kilogram	1.00 E + 3*
Power		
Btu (thermochemical)/second	watt	1.054 350 264 488 E + 3
calorie (thermochemical)/second	watt	4.184 E + 0*
foot lbf/second	watt	1.355 817 9 E + 0
horsepower (550 foot lbf/second)	watt	7.456 998 7 E + 2
kilocalorie (thermochemical)/second	watt	4.184 E + 3*
watt (international of 1948)	watt	1.000 165 E + 0
Pressure		
atmosphere	newton/meter^2	1.013 25 E + 5*
bar	newton/meter^2	1.00 E + 5*
barye	newton/meter^2	1.00 E − 1*
centimeter of mercury (0 °C)	newton/meter^2	1.333 22 E + 3
centimeter of water (4 °C)	newton/meter^2	9.806 38 E + 1
dyne/centimeter^2	newton/meter^2	1.00 E − 1*
foot of water (39.2 °F)	newton/meter^2	2.988 98 E + 3
inch of mercury (32 °F)	newton/meter^2	3.386 389 E + 3
inch of mercury (60 °F)	newton/meter^2	3.376 85 E + 3
inch of water (39.2 °F)	newton/meter^2	2.490 82 E + 2
inch of water (60 °F)	newton/meter^2	2.4884 E + 2
kgf/centimeter^2	newton/meter^2	9.806 65 E + 4*
kgf/meter^2	newton/meter^2	9.806 65 E + 0*
lbf/foot^2	newton/meter^2	4.788 025 8 E + 1
lbf/inch^2 (psi)	newton/meter^2	6.894 757 2 E + 3
millibar	newton/meter^2	1.00 E + 2*
millimeter of mercury (0 °C)	newton/meter^2	1.333 224 E + 2
pascal	newton/meter^2	1.00 E + 0*
psi (lbf/inch^2)	newton/meter^2	6.894 757 2 E + 3
torr (0 °C)	newton/meter^2	1.333 22 E + 2
Speed		
foot/second	meter/second	3.048 E − 1*
inch/second	meter/second	2.54 E − 2*
kilometer/hour	meter/second	2.777 777 8 E − 1
knot (international)	meter/second	5.144 444 444 E − 1
mile/hour (U.S. statute)	meter/second	4.4704 E − 1*

Table E.1 (continued)

To convert from	to	Multiply by
Temperature		
Celsius	kelvin	$t_K = t_C + 273.15$
Fahrenheit	kelvin	$t_K = (5/9)(t_F + 459.67)$
Fahrenheit	Celsius	$t_C = (5/9)(t_F - 32)$
Rankine	kelvin	$t_K = (5/9)t_R$
Time		
day (mean solar)	second (mean solar)	8.64 E + 4*
hour (mean solar)	second (mean solar)	3.60 E + 3*
minute (mean solar)	second (mean solar)	6.00 E + 1*
year (calendar)	second (mean solar)	3.1536 E + 7*
Viscosity		
centistoke	meter^2/second	1.00 E − 6*
stoke	meter^2/second	1.00 E − 4*
foot^2/second	meter^2/second	9.290 304 E − 2*
centipoise	newton second/meter^2	1.00 E − 3*
lbm/foot second	newton second/meter^2	1.488 163 9 E + 0
lbf second/foot^2	newton second/meter^2	4.788 025 8 E + 1
poise	newton second/meter^2	1.00 E − 1*
poundal second/foot^2	newton second/meter^2	1.488 163 9 E + 0
slug/foot second	newton second/meter^2	4.788 025 8 E + 1
rhe	meter^2/newton second	1.00 E + 1*
Volume		
acre foot	meter^3	1.233 481 837 547 52 E + 3*
barrel (petroleum, 42 gallons)	meter^3	1.589 873 E − 1
board foot	meter^3	2.359 737 216 E − 3*
bushel (U.S.)	meter^3	3.523 907 016 688 E − 2*
cord	meter^3	3.624 556 3 E + 0
cup	meter^3	2.365 882 365 E − 4*
dram (U.S. fluid)	meter^3	3.696 691 195 312 5 E − 6*
fluid ounce (U.S.)	meter^3	2.957 352 956 25 E − 5*
foot^3	meter^3	2.831 684 659 2 E − 2*
gallon (U.K. liquid)	meter^3	4.546 087 E − 3
gallon (U.S. liquid)	meter^3	3.785 411 784 E − 3*
inch^3	meter^3	1.638 706 4 E − 5*
liter	meter^3	1.00 E − 3*
ounce (U.S. fluid)	meter^3	2.957 352 956 25 E − 5*
peck (U.S.)	meter^3	8.809 767 541 72 E − 3*
pint (U.S. liquid)	meter^3	4.731 764 73 E − 4*
quart (U.S. liquid)	meter^3	9.463 529 5 E − 4
stere	meter^3	1.00 E + 0*
tablespoon	meter^3	1.478 676 478 125 E − 5*
teaspoon	meter^3	4.928 921 593 75 E − 6*
yard^3	meter^3	7.645 548 579 84 E − 1*

Ideal gas equation of state	$\rho = \frac{p}{RT}$
Internal energy change	$\check{u}_2 - \check{u}_1 = c_v(T_2 - T_1)$
Enthalpy	$\check{h} = \check{u} + \frac{p}{\rho}$
Enthalpy change	$\check{h}_2 - \check{h}_1 = c_p(T_2 - T_1)$
Specific heat difference	$c_p - c_v = R$
Specific heat ratio	$k = \frac{c_p}{c_v}$
Specific heat at constant pressure	$c_p = \frac{Rk}{k-1}$
Specific heat at constant volume	$c_v = \frac{R}{k-1}$
First Tds equation	$T\,ds = d\check{u} + pd\left(\frac{1}{\rho}\right)$
Second Tds equation	$T\,ds = d\check{h} - \left(\frac{1}{\rho}\right)dp$
Entropy change	$s_2 - s_1 = c_v \ln \frac{T_2}{T_1} + R \ln \frac{\rho_1}{\rho_2}$
Entropy change	$s_2 - s_1 = c_p \ln \frac{T_2}{T_1} - R \ln \frac{p_2}{p_1}$
Isentropic flow	$\frac{p}{\rho^k} = \text{constant}$
Speed of sound	$c = \sqrt{\left(\frac{\partial p}{\partial \rho}\right)_s}$
Speed of sound in gas	$c = \sqrt{RTk}$
Speed of sound in liquid	$c = \sqrt{\frac{E_v}{\rho}}$
Mach cone angle	$\sin \alpha = \frac{c}{V} = \frac{1}{\text{Ma}}$
Mach number	$\text{Ma} = \frac{V}{c}$
Isentropic flow	$\frac{dV}{V} = -\frac{dA}{A}\frac{1}{(1 - \text{Ma}^2)}$

$$\text{Re}_x = Ux/\nu$$

Isentropic flow	$\frac{d\rho}{\rho} = \frac{dA}{A}\frac{\text{Ma}^2}{(1-\text{Ma}^2)}$
Isentropic flow	$\frac{T}{T_0} = \frac{1}{1+[(k-1)/2]\text{Ma}^2}$
Isentropic flow	$\frac{p}{p_0} = \left\{\frac{1}{1+[(k-1)/2]\text{Ma}^2}\right\}^{k/(k-1)}$
Isentropic flow	$\frac{\rho}{\rho_0} = \left\{\frac{1}{1+[(k-1)/2]\text{Ma}^2}\right\}^{1/(k-1)}$
Isentropic flow-critical pressure ratio	$\frac{p^*}{p_0} = \left(\frac{2}{k+1}\right)^{k/(k-1)}$
Isentropic flow-critical temperature ratio	$\frac{T^*}{T_0} = \frac{2}{k+1}$

Isentropic flow	$\frac{A}{A^*} = \frac{1}{\text{Ma}}\left\{\frac{1+[(k-1)/2]\text{Ma}^2}{1+[(k-1)/2]}\right\}^{(k+1)/[2(k-1)]}$
Fanno flow	$\frac{1}{k}\frac{(1-\text{Ma}^2)}{\text{Ma}^2} + \frac{k+1}{2k}\ln\left\{\frac{[(k+1)/2]\text{Ma}^2}{1+[(k-1)/2]\text{Ma}^2}\right\} = \frac{f(\ell^* - \ell)}{D}$
Fanno flow	$\frac{T}{T^*} = \frac{(k+1)/2}{1+[(k-1)/2]\text{Ma}^2}$
Fanno flow	$\frac{V}{V^*} = \left\{\frac{[(k+1)/2]\text{Ma}^2}{1+[(k-1)/2]\text{Ma}^2}\right\}^{1/2}$
Fanno flow	$\frac{p}{p^*} = \frac{1}{\text{Ma}}\left\{\frac{(k+1)/2}{1+[(k-1)/2]\text{Ma}^2}\right\}^{1/2}$
Fanno flow	$\frac{p_0}{p_0^*} = \frac{1}{\text{Ma}}\left[\left(\frac{2}{k+1}\right)\left(1+\frac{k-1}{2}\text{Ma}^2\right)\right]^{[(k+1)/2(k-1)]}$

Boundary layer displacement thickness	$\delta^* = \int_0^\infty \left(1 - \frac{u}{U}\right) dy$
Boundary layer momentum thickness	$\Theta = \int_0^\infty \frac{u}{U}\left(1 - \frac{u}{U}\right) dy$
Blasius boundary layer thickness, displacement thickness, and momentum thickness for flat plate	$\frac{\delta}{x} = \frac{5}{\sqrt{\text{Re}_x}}, \quad \frac{\delta^*}{x} = \frac{1.721}{\sqrt{\text{Re}_x}}, \quad \frac{\Theta}{x} = \frac{0.664}{\sqrt{\text{Re}_x}}$