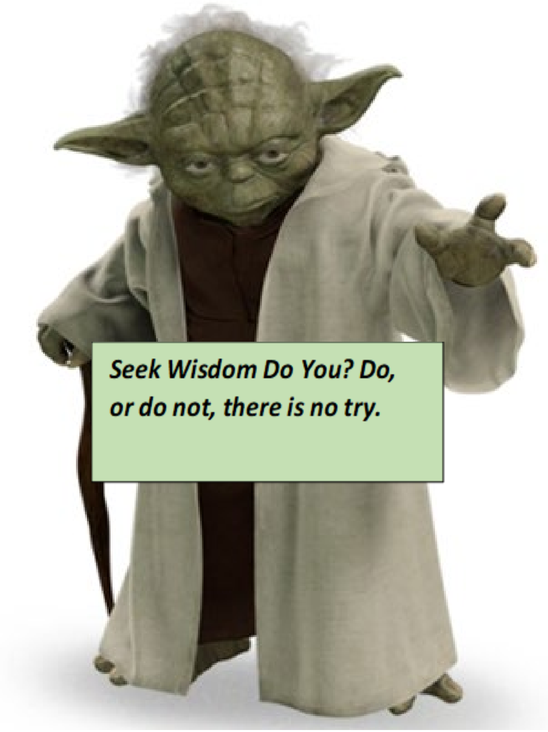
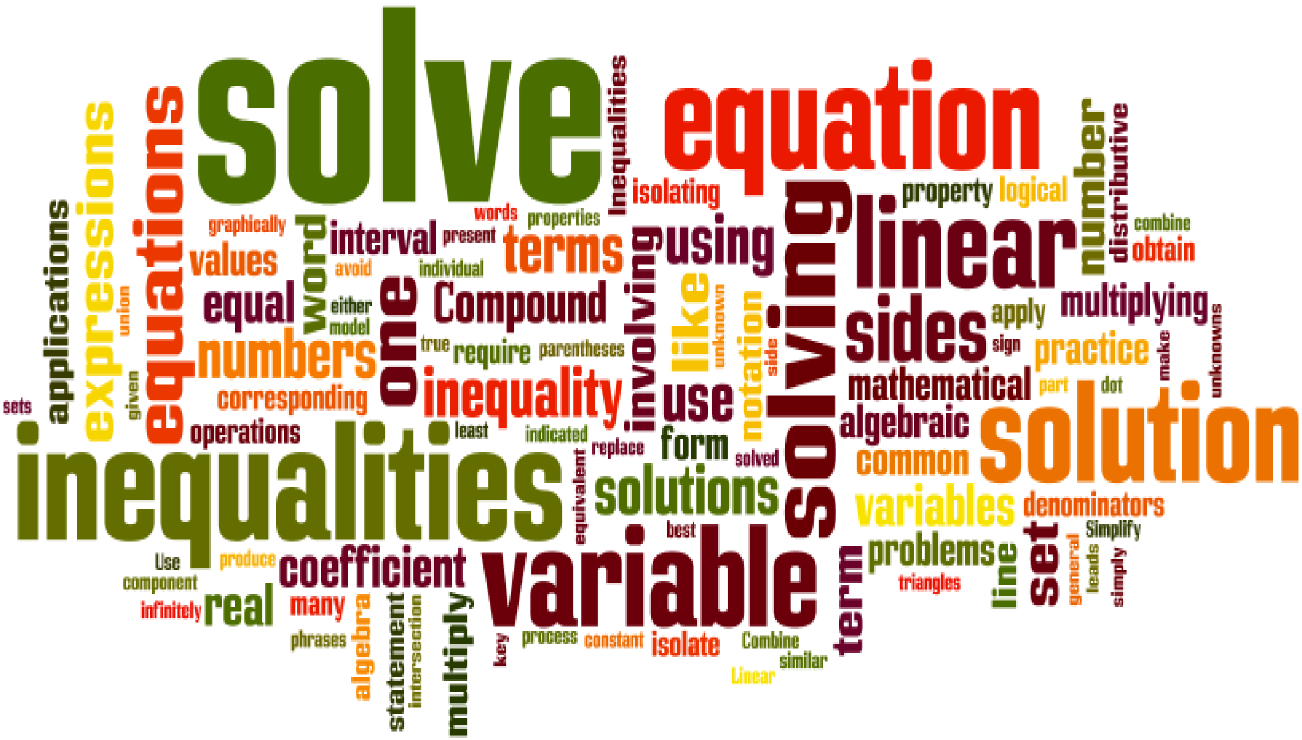
FLUID MECHANICS EQUATIONS

DISTRIBUTED FOR ALL
QUIZES/EXAMS



Seek Wisdom Do You? Do, or do not, there is no try.

$$
\begin{array}{r}
x + 2 = 3 \\
-2 = -2 \\
\hline
x = 1
\end{array}
$$



UNITS

UNIT CONVERSIONS

	SI	BKS	Conversion
Force	N	lbf	1N = 0.224809 lbf
Mass	kg	slug	1kg = 0.0685 slug $\left(\frac{lb_f - s^2}{ft}\right)$
Length	m	ft	1m = 3.28084 ft
Volume	m3	ft3	1m3 = 35.3147 ft3
Velocity	m/s	ft/s	1m/s=3.28084 ft/s
Energy	J	BTU	1BTU = 1,055 J
Power	W (J/s)	ft-lbs/s	1W=0.74 ft-lbf/s=0.00134 hp=3.41BTU/h
Temperature	C (K)	F (R)	C=(F-32)/1.8, K=C+273, R=F+460
Time	s	s	

Engineering Analysis W/O Proper Units Receives 0 Credits

PROPERTIES

FLUID PROPERTIES			
Pressure	N/m2=Pa=F/A	lbf/ft2	1 Pa=0.021 psf
Dynamic Viscosity	N-s/m2=Pa-s	lbf-s/ft2	1Pa-s = 0.02089 lbf-s/ft2
Kinematic Viscosity	m2/s	ft2/s	1m2/s = 10.75381 ft2/s
Density	kg/m3	slugs/ft3	1kg/m3 = 0.00194 slug/ft3
Specific Weight	N/m3=F/V	lbf/ft3	1N/m3 = 0.00637 lbf/ft3
Shear Stress	Pa	lbf/ft2	1 Pa = 0.021 psf

MECH-322 Fluid Mechanics

EQUATIONS SHEET

$$\tau \equiv shear\ stress = \mu[\frac{N-s}{m^2};\frac{lbf-s}{ft^2}]\frac{\partial u}{\partial y} = \left[\frac{N}{m^2};\frac{lb_f}{ft^2}\right]$$

$$\gamma \equiv specific\ weight = \rho[\frac{mass}{vol}]g = \frac{F}{V} = \left[\frac{N}{m^3};\frac{lb_f}{ft^3}\right]$$

$$p = \rho RT \equiv Ideal\ Gas\ Law\,[Pa]$$

$$\mu(T) = De^{B/T} \equiv Andrade's\ Equation$$

$$\mu(T) = \frac{CT^{3/2}}{T+S} \equiv Sutherland's\ Equation$$

Pressure ,Water, and Air Conversions and Properties

$$P_{abs} = 14.7\,psia = 760mm\ hg = 29.9"hg = 101\,kPa$$

$$\gamma = \rho g = \frac{F}{V}$$

$$\gamma_{h_2 0} = 62.4\frac{lb_f}{ft^3} = 9810\frac{N}{m^3}$$

$$\rho_{h_2 0} = 1.94\frac{slugs}{ft^3} = 1000\frac{kg}{m^3},$$

$$\rho_{air} = 2.38x10^{-3}\frac{slugs}{ft^3} = 1.23\frac{kg}{m^3}$$

$$\mu_{h_2 0} = 1.12x10^{-3}\frac{N-s}{m^2} = 2.34x10^{-5}\frac{lb_f-s}{ft^2},$$

$$\mu_{air} = 1.79x10^{-5}\frac{N-s}{m^2} = 3.74x10^{-7}\frac{lb_f-s}{ft^2}$$

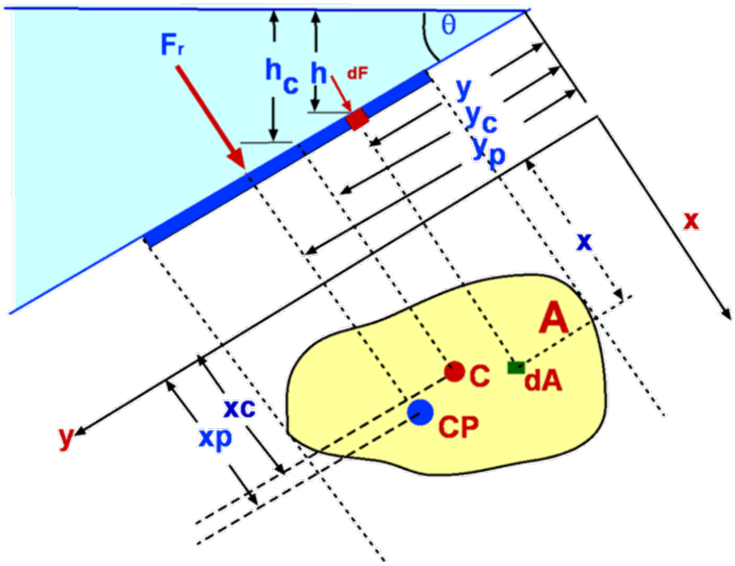
$$\nu = \frac{\mu}{\rho} \rightarrow \text{Kinematic Viscosity (m}^2\text{/s;ft}^2\text{/s)}$$

Unit Conversions

$$1BTU = 778.2\,ft - lb_f$$

$$1HP = 550\,ft - lb_f\ /\ \sec = 760W$$

Forces on Submerged Surfaces:



$F_r = \mathit{Force}$ Magnitude of Pressure Distribution

$= \gamma_f h_c A;$ *where*

$\gamma_f =$ specific weight of fluid

$h_c =$ veritical distance from surface to geoemtric area centroid

$A =$ planar area

Location of Pressure Force

$y_p =$ location of resulting force measured along axis of plate from surface

$=$ Center of Pressure

$$= \mathrm{y}_c + \frac{I_{xc}}{y_c A}$$

$y_c =$ distance from surface to CENTROID measured along axis of plate

$\mathrm{I}_{\mathrm{xc}} =$ momement of intertia about X axis through centroid

$x_p =$ xc for areas symmetric about Y axis

Hydrostatics

$$\frac{dP}{dz} = +\gamma \quad g \downarrow z \downarrow$$

Manometer

$$\Delta P = \gamma \Delta z$$

$$P_1 + \Delta P_{1-2} = P_2$$

Bernoulli Equation and Mass Conservation

Material or TOTAL Derivative (or TIME RATE OF CHANGE)

$$\frac{D()}{Dt} = \frac{\partial()}{\partial t} + u\frac{\partial()}{\partial x} + v\frac{\partial()}{\partial y} + w\frac{\partial()}{\partial z}$$

$$a_x = \frac{D(u)}{Dt} = \frac{\partial(u)}{\partial t} + u\frac{\partial(u)}{\partial x} + v\frac{\partial(u)}{\partial y} + w\frac{\partial(u)}{\partial z}$$

$$a_y = \frac{D(v)}{Dt} = \frac{\partial(v)}{\partial t} + u\frac{\partial(v)}{\partial x} + v\frac{\partial(v)}{\partial y} + w\frac{\partial(v)}{\partial z}$$

$$a_z = \frac{D(w)}{Dt} = \frac{\partial(w)}{\partial t} + u\frac{\partial(w)}{\partial x} + v\frac{\partial(w)}{\partial y} + w\frac{\partial(w)}{\partial z}$$

IN GENERAL, where "Ψ" is any scalar function

Time rate of change of Ψ

$$\frac{D(\Psi)}{Dt} = \frac{\partial(\Psi)}{\partial t} + u\frac{\partial(\Psi)}{\partial x} + v\frac{\partial(\Psi)}{\partial y} + w\frac{\partial(\Psi)}{\partial z}$$

$$\|\vec{a}\| = \sqrt{a_x{}^2 + a_y{}^2 + a_z{}^2}$$

$$a(x,y,z) = \|\vec{a}\|(\cos\theta_x\hat{i} + \cos\theta_y\hat{j} + \cos\theta_z\hat{k})$$

$$\cos\theta_0 = \frac{a_0}{\|\vec{a}\|}$$

Conservation of Mass

$$\frac{dM_{sys}}{dt} = \frac{d}{dt}\int_{\forall} \rho d\forall + \int_{cs} \rho \vec{V} \bullet \hat{n}\, dA = 0$$

$$= \frac{d}{dt}\int_{\forall} \rho d\forall + \sum\nolimits_{out} \dot{m} - \sum\nolimits_{in} \dot{m} = 0 \text{ ; (constant properties)}$$

STEADY STATE

$$\sum\nolimits_{out} \dot{m} - \sum\nolimits_{in} \dot{m} = 0 \rightarrow \text{ NO STORAGE OF MASS IN CV}$$

$$\dot{\mathrm{m}} = \rho \mathrm{A} \overline{\mathrm{V}}$$

Conservation of Momentum

$$\sum F_x = \frac{d}{dt}\int_{CV} \rho u d\forall + \int_{CS} \rho u \left(\vec{V} \cdot d\vec{A}\right)$$

$$\sum F_y = \frac{d}{dt}\int_{CV} \rho v d\forall + \int_{CS} \rho v \left(\vec{V} \cdot d\vec{A}\right)$$

$$\sum F_z = \frac{d}{dt}\int_{CV} \rho w d\forall + \int_{CS} \rho w \left(\vec{V} \cdot d\vec{A}\right)$$

Steady Flow Assumptions and Constant Properties

$$\sum F_x = \sum_{out} \dot{m}(\pm u) - \sum_{in} \dot{m}(\pm u)$$

$$\sum F_y = \sum_{out} \dot{m}(\pm v) - \sum_{in} \dot{m}(\pm v)$$

$$\sum F_z = \sum_{out} \dot{m}(\pm w) - \sum_{in} \dot{m}(\pm w)$$

Conservation of Energy

GENERAL ENERGY EQUATION: EVERY TERM: WATTS or BTU/s

$$\dot{Q}_{in/out} - \dot{W}_{shaft} = \sum_{out} \dot{m}(\mathrm{u}_2 + \frac{V_2^2}{2} + gz_2 + \frac{p_2}{\rho}) - \sum_{in} \dot{m}(\mathrm{u}_1 + \frac{V_1^2}{2} + gz_1 + \frac{p_1}{\rho}) + H_{major} + H_{\mathrm{minor}}$$

SINGLE INLET/SINGLE EXIT: EVERY TERM: m or ft($\div$mg)

$$\frac{H_{\mathrm{major/minor}}}{(\dot{m}g)} = h_{\mathrm{major/minor}}$$

$$-\frac{\dot{W}_{shaft}}{\dot{m}g} = h_{loss} + h_{major} + h_{\mathrm{minor}} + \frac{p_2 - p_1}{\gamma} + \frac{V_2^2 - V_1^2}{2g} + z_2 - z_1; h_{loss} = \frac{\mathrm{u}_2 - \mathrm{u}_1}{g} - \frac{\dot{Q}_s}{\dot{m}g}$$

$$-w_s = h_{loss} + h_{major} + h_{\mathrm{minor}} + \frac{p_2 - p_1}{\gamma} + \frac{V_2^2 - V_1^2}{2g} + z_2 - z_1; h_{loss} = \frac{\mathrm{u}_2 - \mathrm{u}_1}{g} - q_s$$

$$q_s = \frac{\dot{Q}_s}{\dot{m}g}; w_s = \frac{\dot{W}_{shaft}}{\dot{m}g} = \frac{\dot{W}_{Turbine} - \dot{W}_{Pump}}{\dot{m}g} (\text{ft or m})$$

FOR IDEAL GAS ONLY

$$\dot{Q}_s - \dot{W}_{shaft} = \dot{m}\left[c_p T_2 + \frac{1}{2}V_2^2 - c_p T_1 - \frac{1}{2}V_1^2 + g(z_2 - z_1)\right] + H_{major} + H_{\mathrm{minor}}$$

$\dot{Q}_s(heat\ IN)$ is positive; $\dot{W}_{shaft}(shaft\ work\ OUT\ is\ POSITIVE)$

Major Frictional and Minor Flow Lossess

$$h_{major} = \sum \frac{fL}{D}\frac{V^2}{2g}$$

$$h_{\mathrm{minor}} = \sum K_L \frac{V^2}{2g}$$

GENERAL ENERGY EQUATION--MULTIPLE I/O STREAMS

$$\dot{Q}_{cs} - \dot{W}_{s_{IDEAL}} + \sum_{in}\left(\dot{m}g\left(\frac{p_1}{\gamma}+\frac{u_1}{g}+\frac{V_1^2}{2g}+z_1\right)\right) = \sum_{out}\left(\dot{m}g\left(\frac{p_2}{\gamma}+\frac{u_2}{g}+\frac{V_2^2}{2g}+z_2\right)\right) + \sum H_L; W \text{ or } ft-lbf/s;$$

$LET \rightarrow$

UNITS: WATTS or FT-LBF/s

$$\dot{W}_{s_{IDEAL}} = \dot{W}_{Turbine_{IDEAL}} - \dot{W}_{Pump_{IDEAL}};$$

$H_L[Watts] = \dot{m}_B(kg/s)(g)h_{L_{A-B}}(m) = \dot{m}_B g\left(h_q + h_{\text{minor}} + h_{\text{major}}\right) \rightarrow$ Total SYSTEM Losses; → OR

$$H_{L_{A-B}}[ft-lbf/\sec] = \dot{m}_B(slugs/s)gh_{A-B}(ft)$$

(one INLET/one EXIT) →

Energy Equation → "m;ft" → $(\div \dot{m}g)$

$$\frac{\dot{Q}_{cs}}{\dot{m}g} + \frac{\dot{W}_{Pump_{IDEAL}}}{\dot{m}g} + \frac{p_1}{\gamma} + \frac{u_1}{g} + \frac{V_1^2}{2g} + z_1 = \frac{\dot{W}_{Turbine_{IDEAL}}}{\dot{m}g} + \frac{p_2}{\gamma} + \frac{u_2}{g} + \frac{V_2^2}{2g} + z_2 + h_q(m); units = m, \text{or}, \text{ft}$$

$$h_p + h_1 = h_T + h_2 + h_q$$

UNITS: m or ft

$h_{\text{minor}}(m) = \sum_i K_i \frac{V_i^2}{2g}; \rightarrow$ Component Losses

$h_{\text{major}}(m) = \sum_i f_i \frac{L_i}{D_i}\frac{V_i^2}{2g}; \rightarrow$ Straight Pipe Section Losses

$h_q(m) = \frac{u_2}{g} - \frac{u_1}{g} - \frac{\dot{Q}_{cs}}{\dot{m}g} + h_{L_{A-B}}; \rightarrow$ Thermal Losses

Pump and Turbine Power & Efficiency

$$W_{P_{ACTUAL}} = \frac{\gamma Q h_{P_{IDEAL}}}{\eta_p} = \frac{Q\Delta P}{\eta_p} \rightarrow PUMP$$

$$W_{T_{ACTUAL}} = \gamma Q h_{T_{IDEAL}} \eta_t \rightarrow TURBINE$$

$$\eta_p \equiv \text{pump efficiency} = \frac{W_{ideal}}{W_{actual}} = \frac{W_{actual} - Loss}{W_{actual}}$$

$$\eta_t \equiv \text{turbine efficiency} = \frac{W_{actual}}{W_{ideal}} = \frac{W_{actual}}{W_{actual} + Loss}$$

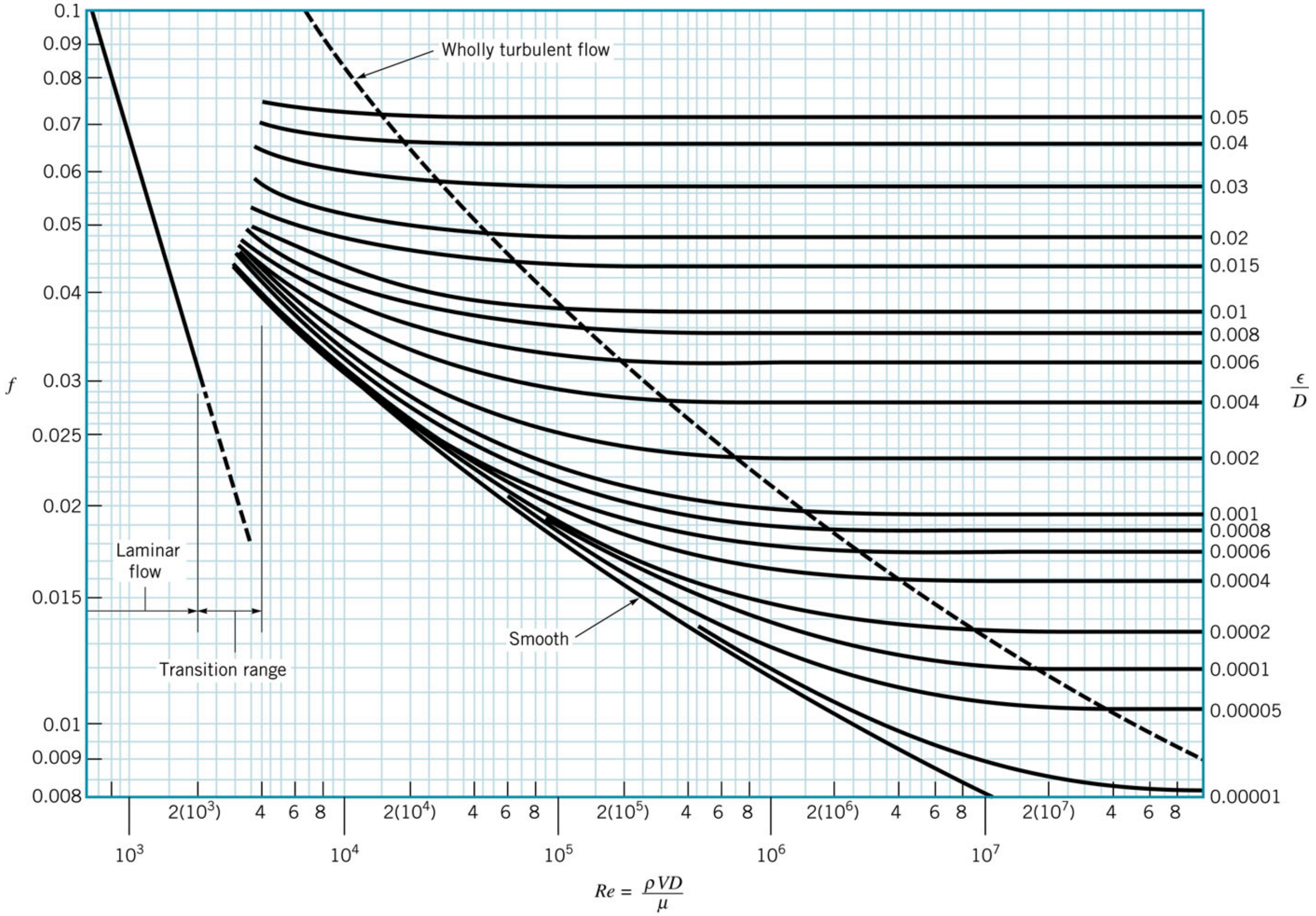
Class 16: Moody diagram

Haaland EQN. formula for turbulent flow

$$f = \frac{64}{\mathrm{Re}_D}; \text{Laminar Flow}$$

Wall roughness & friction factor

$$\frac{1}{\sqrt{f}} = -1.8\log_{10}\left(\left(\frac{\varepsilon / D}{3.7}\right)^{1.11} + \frac{6.9}{\mathrm{Re}}\right)$$



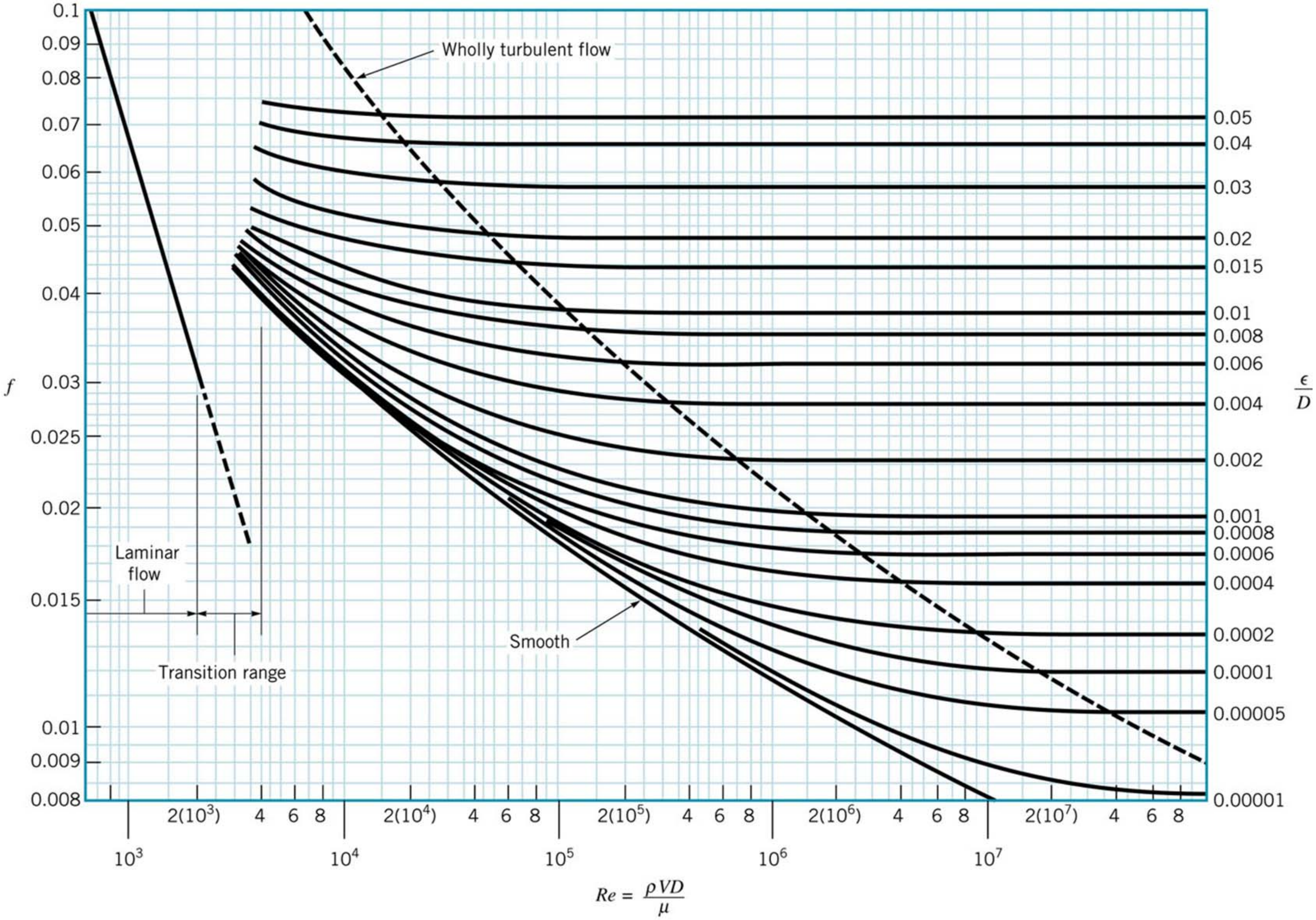
Class 16: Moody diagram

$f = \frac{64}{Re_D}$; Laminar Flow

Wall roughness & friction factor

Colebrook formula for turbulent flow

$$\frac{1}{\sqrt{f}} = -2.0\log\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{\mathrm{Re}\sqrt{f}}\right)$$



Class 16: Loss coefficient for piping components

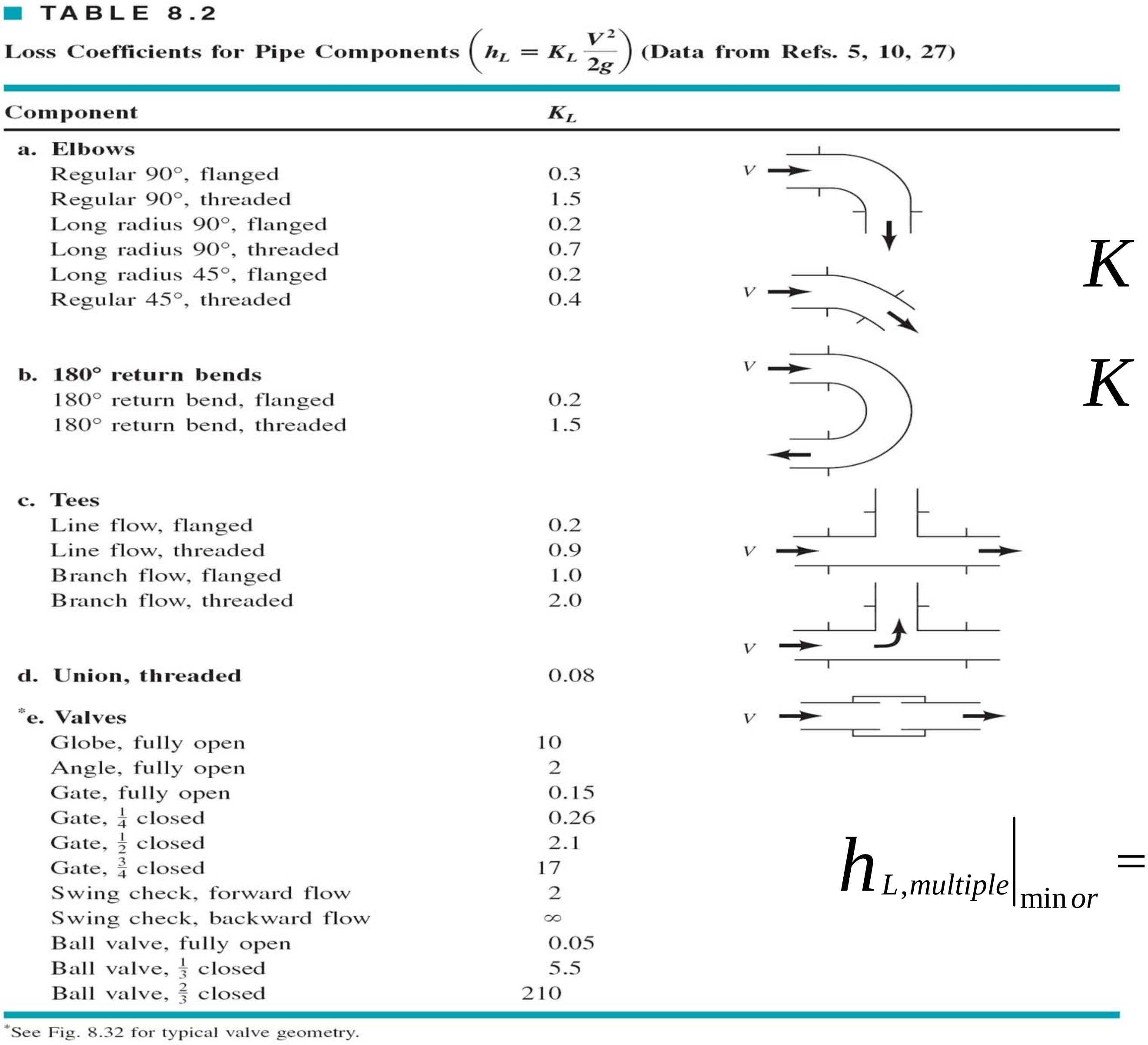


TABLE 8.2

Loss Coefficients for Pipe Components $\left(h_L = K_L \dfrac{V^2}{2g}\right)$ (Data from Refs. 5, 10, 27)

Component	K_L
a. Elbows	
Regular 90°, flanged	0.3
Regular 90°, threaded	1.5
Long radius 90°, flanged	0.2
Long radius 90°, threaded	0.7
Long radius 45°, flanged	0.2
Regular 45°, threaded	0.4
b. 180° return bends	
180° return bend, flanged	0.2
180° return bend, threaded	1.5
c. Tees	
Line flow, flanged	0.2
Line flow, threaded	0.9
Branch flow, flanged	1.0
Branch flow, threaded	2.0
d. Union, threaded	0.08
***e. Valves**	
Globe, fully open	10
Angle, fully open	2
Gate, fully open	0.15
Gate, $\frac{1}{4}$ closed	0.26
Gate, $\frac{1}{2}$ closed	2.1
Gate, $\frac{3}{4}$ closed	17
Swing check, forward flow	2
Swing check, backward flow	∞
Ball valve, fully open	0.05
Ball valve, $\frac{1}{3}$ closed	5.5
Ball valve, $\frac{2}{3}$ closed	210

*See Fig. 8.32 for typical valve geometry.

$$K_{L_{inlet}} = 0.5$$

$$K_{L_{exit}} = 1.0$$

For multi-component systems

$$h_{L,multiple}\Big|_{minor} = h_{L1} + h_{L2} + h_{L3} + \ldots..$$

TABLE 8.1

Equivalent Roughness for New Pipes [From Moody (Ref. 7) and Colebrook (Ref. 8)]

	Equivalent Roughness, ε	
Pipe	**Feet**	**Millimeters**
Riveted steel	0.003–0.03	0.9–9.0
Concrete	0.001–0.01	0.3–3.0
Wood stave	0.0006–0.003	0.18–0.9
Cast iron	0.00085	0.26
Galvanized iron	0.0005	0.15
Commercial steel or wrought iron	0.00015	0.045
Drawn tubing	0.000005	0.0015
Plastic, glass	0.0 (smooth)	0.0 (smooth)

Coefficient of Drag and Lift

$$C_D = \frac{F_D}{1/2\rho V^2 A}$$

$$C_L = \frac{F_L}{1/2\rho V^2 A}$$

Compressible Flow

$$k_{air} = 1.4; R_{air} = 287 N - m / kg - K$$

$$M = \frac{V}{c}; c = \sqrt{kR_{gas}T_{abs}}$$

$$\dot{m} = P_{press} \bullet A_{area} \bullet M \bullet \sqrt{\frac{k}{R_{gas}T_{abs}}} \rightarrow (\frac{kg}{s})$$

Drag Coefficients for Different Geometries

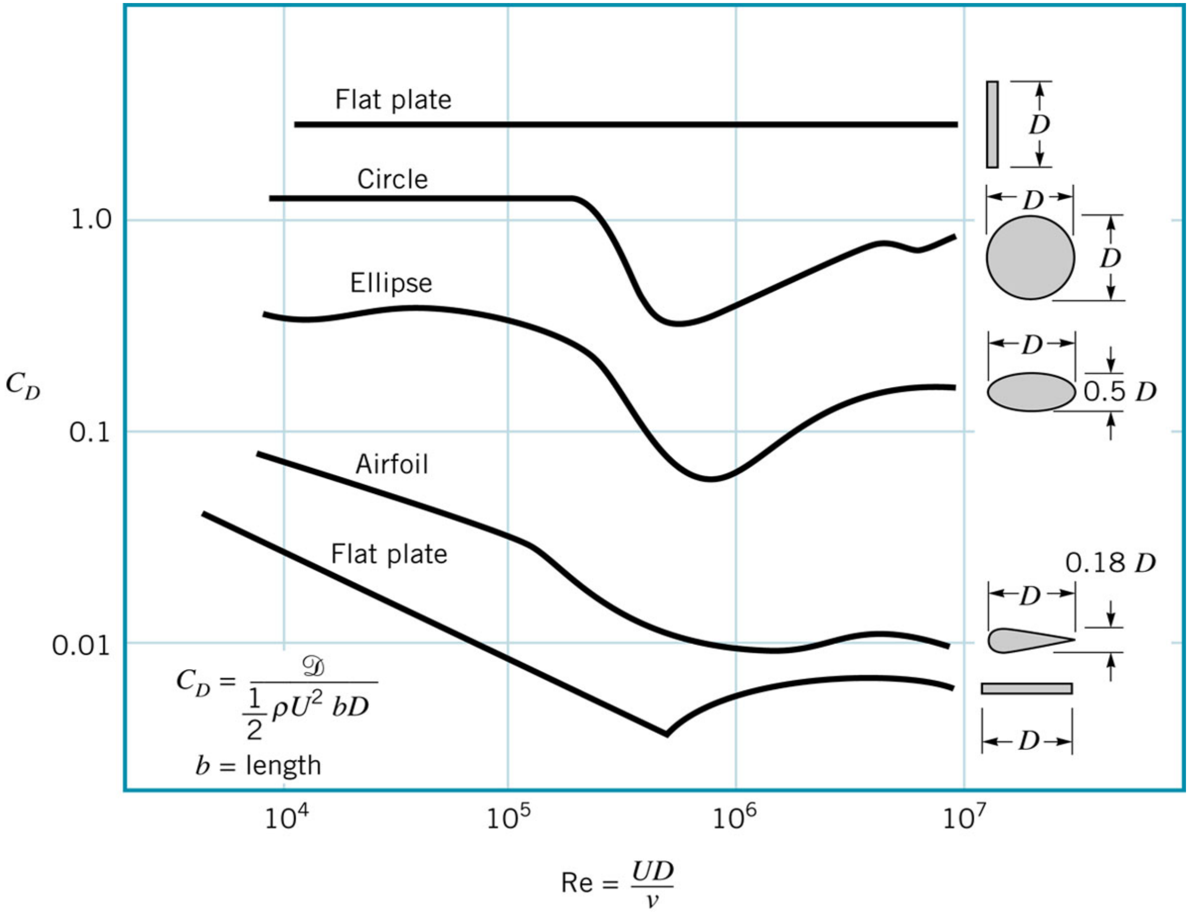


Figure: **Variation of Drag for different geometries**

$$Lift\ Coefficent,\ C_L = \frac{F_L}{1/2\rho V^2 A};$$

$$Drag\ Coefficient,\ C_D = \frac{F_D}{1/2\rho V^2 A}$$

$$Power[W] = FORCE[N] \bullet Velocity[m/s]$$

Smooth Cylinder and Sphere

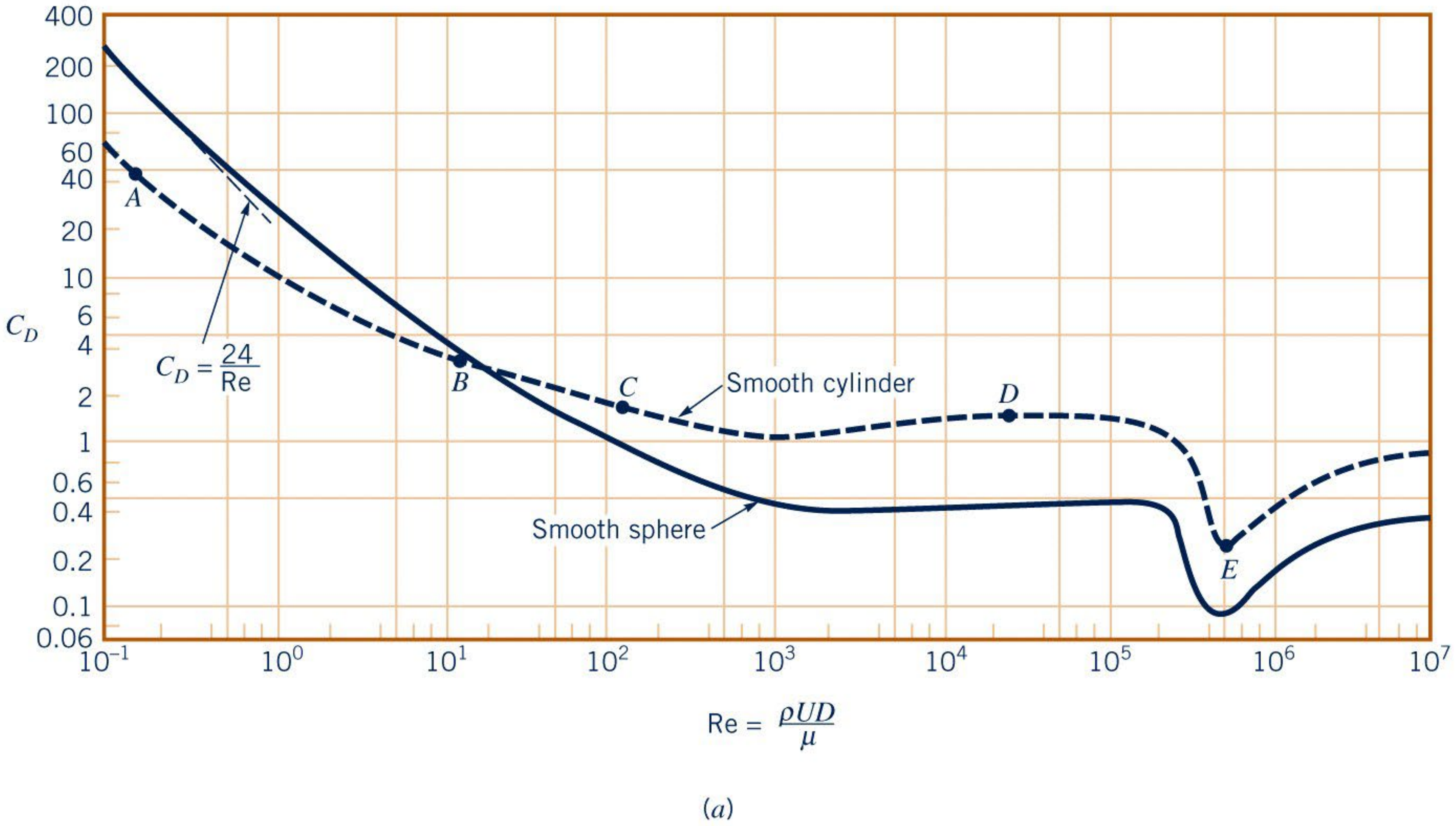


Figure 9.21a

Drag Coefficients for Different Geometries

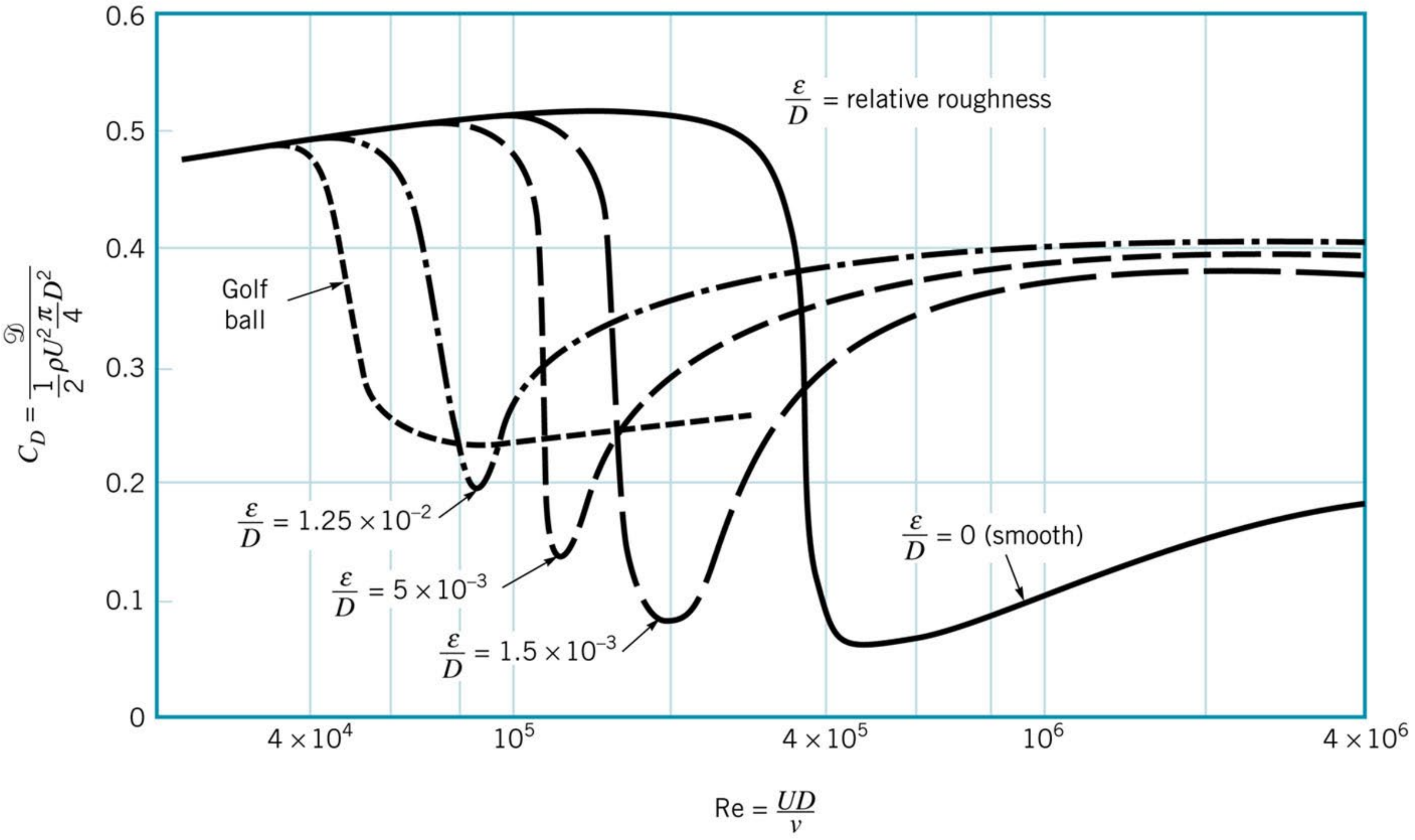
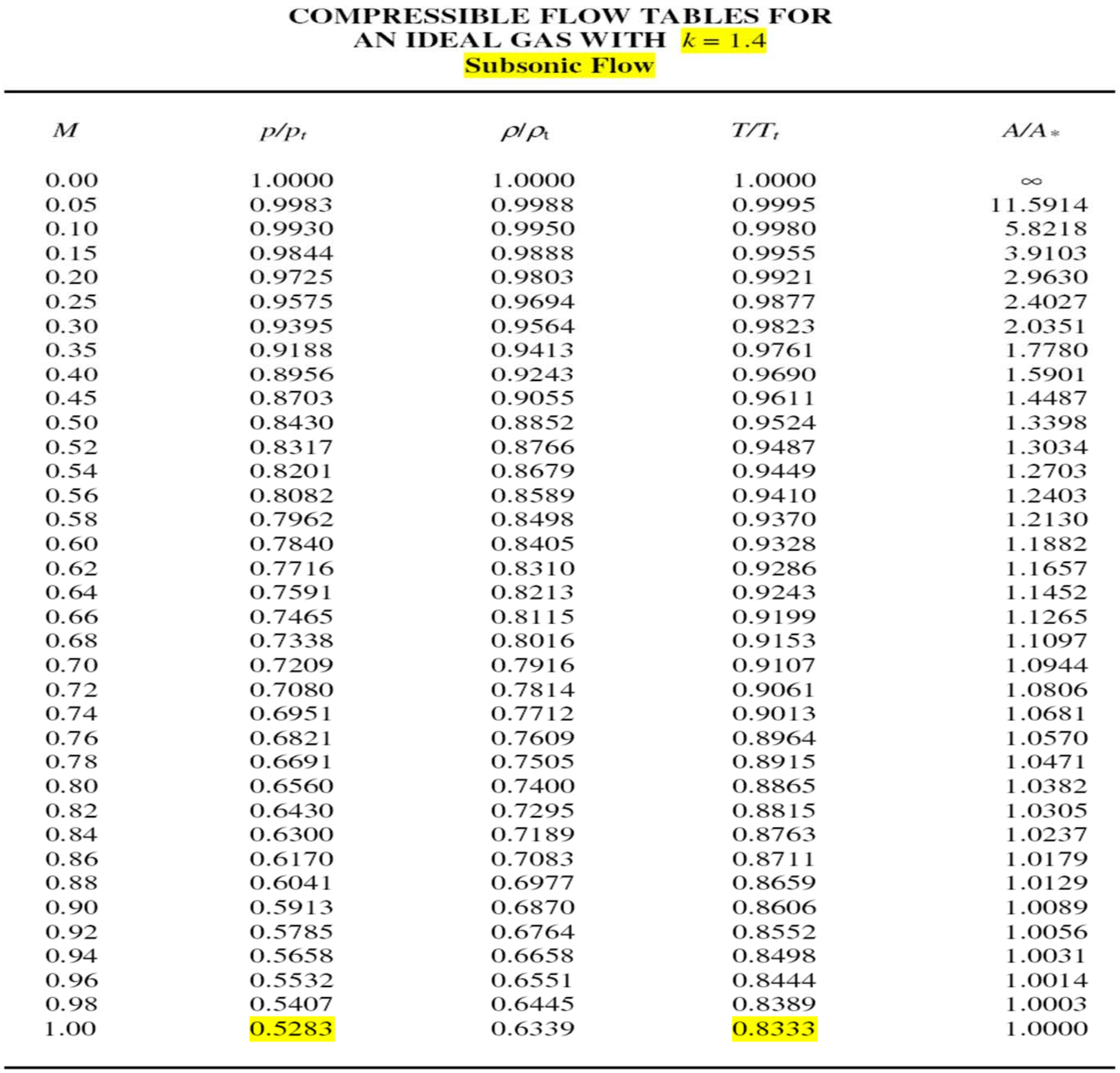


Figure: **The effect of surface roughness on the Drag coefficient.**

Compressible Flow - Table



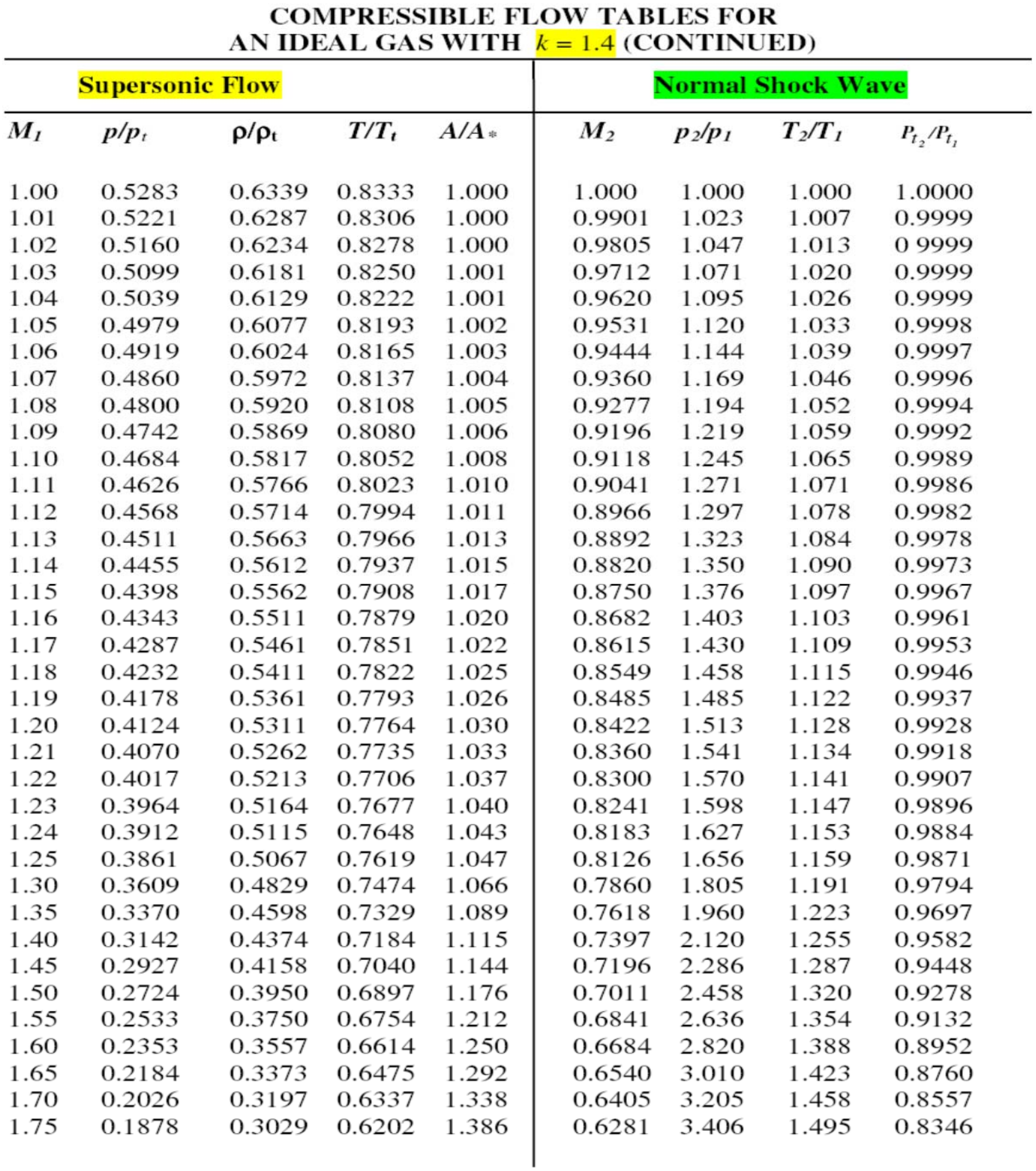
COMPRESSIBLE FLOW TABLES FOR
AN IDEAL GAS WITH $k = 1.4$
Subsonic Flow

M	p/p_t	ρ/ρ_t	T/T_t	A/A_*
0.00	1.0000	1.0000	1.0000	∞
0.05	0.9983	0.9988	0.9995	11.5914
0.10	0.9930	0.9950	0.9980	5.8218
0.15	0.9844	0.9888	0.9955	3.9103
0.20	0.9725	0.9803	0.9921	2.9630
0.25	0.9575	0.9694	0.9877	2.4027
0.30	0.9395	0.9564	0.9823	2.0351
0.35	0.9188	0.9413	0.9761	1.7780
0.40	0.8956	0.9243	0.9690	1.5901
0.45	0.8703	0.9055	0.9611	1.4487
0.50	0.8430	0.8852	0.9524	1.3398
0.52	0.8317	0.8766	0.9487	1.3034
0.54	0.8201	0.8679	0.9449	1.2703
0.56	0.8082	0.8589	0.9410	1.2403
0.58	0.7962	0.8498	0.9370	1.2130
0.60	0.7840	0.8405	0.9328	1.1882
0.62	0.7716	0.8310	0.9286	1.1657
0.64	0.7591	0.8213	0.9243	1.1452
0.66	0.7465	0.8115	0.9199	1.1265
0.68	0.7338	0.8016	0.9153	1.1097
0.70	0.7209	0.7916	0.9107	1.0944
0.72	0.7080	0.7814	0.9061	1.0806
0.74	0.6951	0.7712	0.9013	1.0681
0.76	0.6821	0.7609	0.8964	1.0570
0.78	0.6691	0.7505	0.8915	1.0471
0.80	0.6560	0.7400	0.8865	1.0382
0.82	0.6430	0.7295	0.8815	1.0305
0.84	0.6300	0.7189	0.8763	1.0237
0.86	0.6170	0.7083	0.8711	1.0179
0.88	0.6041	0.6977	0.8659	1.0129
0.90	0.5913	0.6870	0.8606	1.0089
0.92	0.5785	0.6764	0.8552	1.0056
0.94	0.5658	0.6658	0.8498	1.0031
0.96	0.5532	0.6551	0.8444	1.0014
0.98	0.5407	0.6445	0.8389	1.0003
1.00	0.5283	0.6339	0.8333	1.0000

Source: Roberson and Crowe, Engineering Fluid Mechanics, 6th Edition, 1996, John Wiley and Sons.

A* is critical area for choked flow at throat.

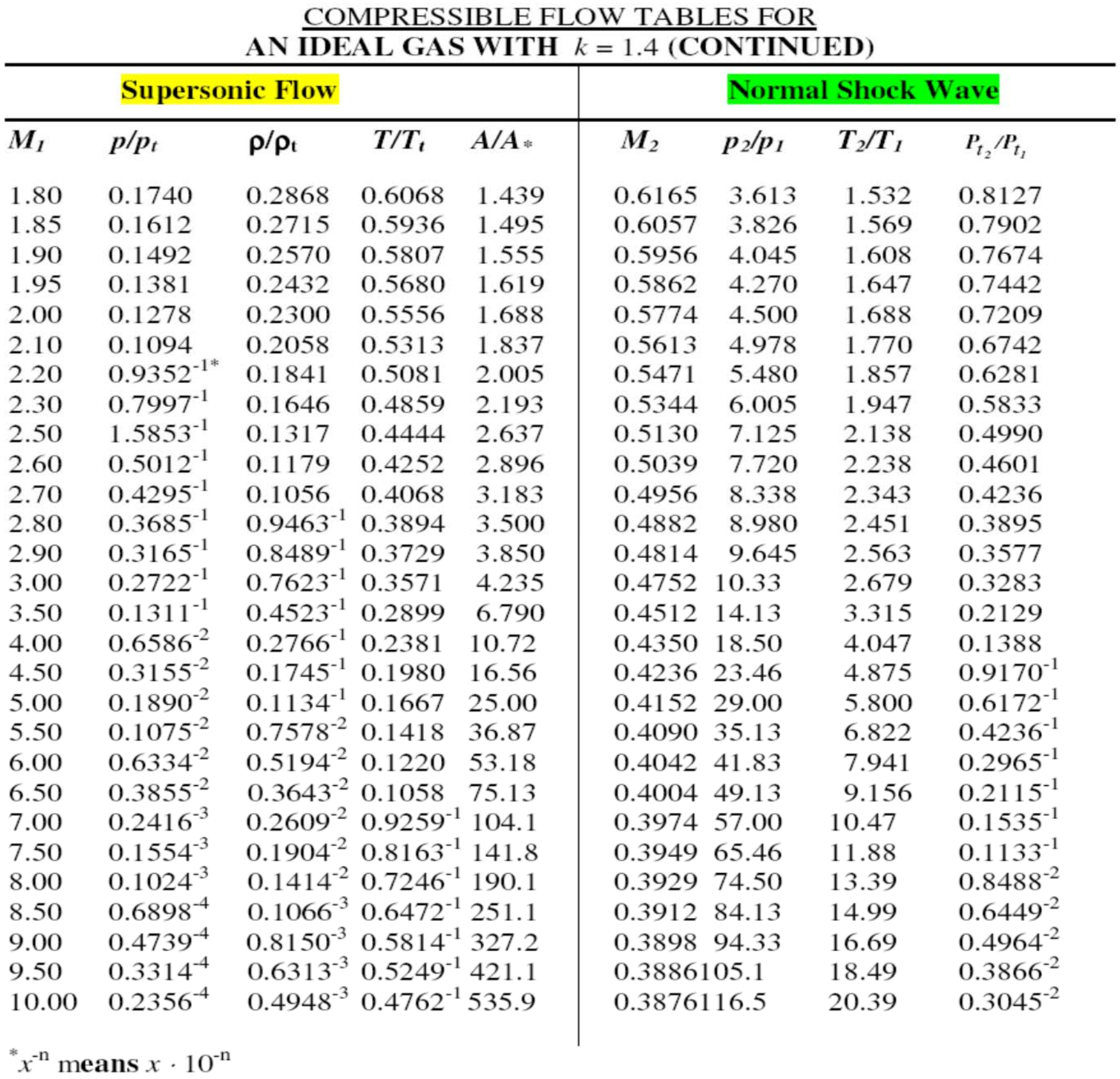
Compressible Flow - Table



COMPRESSIBLE FLOW TABLES FOR
AN IDEAL GAS WITH $k = 1.4$ (CONTINUED)

Supersonic Flow					Normal Shock Wave			
M_1	p/p_t	ρ/ρ_t	T/T_t	A/A_*	M_2	p_2/p_1	T_2/T_1	P_{t_2}/P_{t_1}
1.00	0.5283	0.6339	0.8333	1.000	1.000	1.000	1.000	1.0000
1.01	0.5221	0.6287	0.8306	1.000	0.9901	1.023	1.007	0.9999
1.02	0.5160	0.6234	0.8278	1.000	0.9805	1.047	1.013	0 9999
1.03	0.5099	0.6181	0.8250	1.001	0.9712	1.071	1.020	0.9999
1.04	0.5039	0.6129	0.8222	1.001	0.9620	1.095	1.026	0.9999
1.05	0.4979	0.6077	0.8193	1.002	0.9531	1.120	1.033	0.9998
1.06	0.4919	0.6024	0.8165	1.003	0.9444	1.144	1.039	0.9997
1.07	0.4860	0.5972	0.8137	1.004	0.9360	1.169	1.046	0.9996
1.08	0.4800	0.5920	0.8108	1.005	0.9277	1.194	1.052	0.9994
1.09	0.4742	0.5869	0.8080	1.006	0.9196	1.219	1.059	0.9992
1.10	0.4684	0.5817	0.8052	1.008	0.9118	1.245	1.065	0.9989
1.11	0.4626	0.5766	0.8023	1.010	0.9041	1.271	1.071	0.9986
1.12	0.4568	0.5714	0.7994	1.011	0.8966	1.297	1.078	0.9982
1.13	0.4511	0.5663	0.7966	1.013	0.8892	1.323	1.084	0.9978
1.14	0.4455	0.5612	0.7937	1.015	0.8820	1.350	1.090	0.9973
1.15	0.4398	0.5562	0.7908	1.017	0.8750	1.376	1.097	0.9967
1.16	0.4343	0.5511	0.7879	1.020	0.8682	1.403	1.103	0.9961
1.17	0.4287	0.5461	0.7851	1.022	0.8615	1.430	1.109	0.9953
1.18	0.4232	0.5411	0.7822	1.025	0.8549	1.458	1.115	0.9946
1.19	0.4178	0.5361	0.7793	1.026	0.8485	1.485	1.122	0.9937
1.20	0.4124	0.5311	0.7764	1.030	0.8422	1.513	1.128	0.9928
1.21	0.4070	0.5262	0.7735	1.033	0.8360	1.541	1.134	0.9918
1.22	0.4017	0.5213	0.7706	1.037	0.8300	1.570	1.141	0.9907
1.23	0.3964	0.5164	0.7677	1.040	0.8241	1.598	1.147	0.9896
1.24	0.3912	0.5115	0.7648	1.043	0.8183	1.627	1.153	0.9884
1.25	0.3861	0.5067	0.7619	1.047	0.8126	1.656	1.159	0.9871
1.30	0.3609	0.4829	0.7474	1.066	0.7860	1.805	1.191	0.9794
1.35	0.3370	0.4598	0.7329	1.089	0.7618	1.960	1.223	0.9697
1.40	0.3142	0.4374	0.7184	1.115	0.7397	2.120	1.255	0.9582
1.45	0.2927	0.4158	0.7040	1.144	0.7196	2.286	1.287	0.9448
1.50	0.2724	0.3950	0.6897	1.176	0.7011	2.458	1.320	0.9278
1.55	0.2533	0.3750	0.6754	1.212	0.6841	2.636	1.354	0.9132
1.60	0.2353	0.3557	0.6614	1.250	0.6684	2.820	1.388	0.8952
1.65	0.2184	0.3373	0.6475	1.292	0.6540	3.010	1.423	0.8760
1.70	0.2026	0.3197	0.6337	1.338	0.6405	3.205	1.458	0.8557
1.75	0.1878	0.3029	0.6202	1.386	0.6281	3.406	1.495	0.8346

Compressible Flow - Table

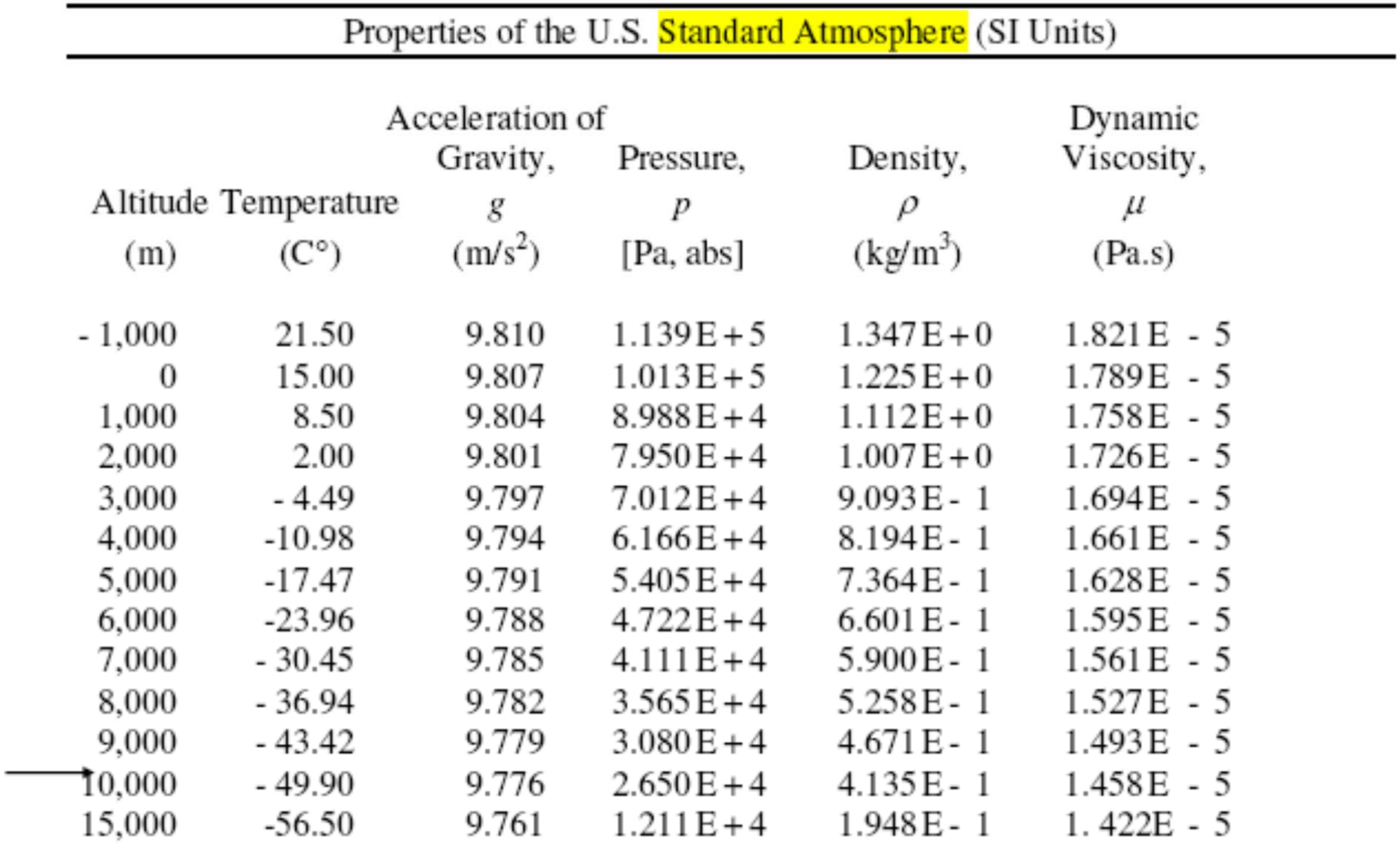


COMPRESSIBLE FLOW TABLES FOR
AN IDEAL GAS WITH $k = 1.4$ (CONTINUED)

Supersonic Flow					**Normal Shock Wave**			
M_1	p/p_t	ρ/ρ_t	T/T_t	A/A_*	M_2	p_2/p_1	T_2/T_1	p_{t_2}/p_{t_1}
1.80	0.1740	0.2868	0.6068	1.439	0.6165	3.613	1.532	0.8127
1.85	0.1612	0.2715	0.5936	1.495	0.6057	3.826	1.569	0.7902
1.90	0.1492	0.2570	0.5807	1.555	0.5956	4.045	1.608	0.7674
1.95	0.1381	0.2432	0.5680	1.619	0.5862	4.270	1.647	0.7442
2.00	0.1278	0.2300	0.5556	1.688	0.5774	4.500	1.688	0.7209
2.10	0.1094	0.2058	0.5313	1.837	0.5613	4.978	1.770	0.6742
2.20	0.9352^{-1*}	0.1841	0.5081	2.005	0.5471	5.480	1.857	0.6281
2.30	0.7997^{-1}	0.1646	0.4859	2.193	0.5344	6.005	1.947	0.5833
2.50	1.5853^{-1}	0.1317	0.4444	2.637	0.5130	7.125	2.138	0.4990
2.60	0.5012^{-1}	0.1179	0.4252	2.896	0.5039	7.720	2.238	0.4601
2.70	0.4295^{-1}	0.1056	0.4068	3.183	0.4956	8.338	2.343	0.4236
2.80	0.3685^{-1}	0.9463^{-1}	0.3894	3.500	0.4882	8.980	2.451	0.3895
2.90	0.3165^{-1}	0.8489^{-1}	0.3729	3.850	0.4814	9.645	2.563	0.3577
3.00	0.2722^{-1}	0.7623^{-1}	0.3571	4.235	0.4752	10.33	2.679	0.3283
3.50	0.1311^{-1}	0.4523^{-1}	0.2899	6.790	0.4512	14.13	3.315	0.2129
4.00	0.6586^{-2}	0.2766^{-1}	0.2381	10.72	0.4350	18.50	4.047	0.1388
4.50	0.3155^{-2}	0.1745^{-1}	0.1980	16.56	0.4236	23.46	4.875	0.9170^{-1}
5.00	0.1890^{-2}	0.1134^{-1}	0.1667	25.00	0.4152	29.00	5.800	0.6172^{-1}
5.50	0.1075^{-2}	0.7578^{-2}	0.1418	36.87	0.4090	35.13	6.822	0.4236^{-1}
6.00	0.6334^{-2}	0.5194^{-2}	0.1220	53.18	0.4042	41.83	7.941	0.2965^{-1}
6.50	0.3855^{-2}	0.3643^{-2}	0.1058	75.13	0.4004	49.13	9.156	0.2115^{-1}
7.00	0.2416^{-3}	0.2609^{-2}	0.9259^{-1}	104.1	0.3974	57.00	10.47	0.1535^{-1}
7.50	0.1554^{-3}	0.1904^{-2}	0.8163^{-1}	141.8	0.3949	65.46	11.88	0.1133^{-1}
8.00	0.1024^{-3}	0.1414^{-2}	0.7246^{-1}	190.1	0.3929	74.50	13.39	0.8488^{-2}
8.50	0.6898^{-4}	0.1066^{-3}	0.6472^{-1}	251.1	0.3912	84.13	14.99	0.6449^{-2}
9.00	0.4739^{-4}	0.8150^{-3}	0.5814^{-1}	327.2	0.3898	94.33	16.69	0.4964^{-2}
9.50	0.3314^{-4}	0.6313^{-3}	0.5249^{-1}	421.1	0.3886	105.1	18.49	0.3866^{-2}
10.00	0.2356^{-4}	0.4948^{-3}	0.4762^{-1}	535.9	0.3876	116.5	20.39	0.3045^{-2}

$^{*}x^{-n}$ means $x \cdot 10^{-n}$

Compressible Flow - Table



Properties of the U.S. Standard Atmosphere (SI Units)

Altitude (m)	Temperature (C°)	Acceleration of Gravity, g (m/s^2)	Pressure, p [Pa, abs]	Density, ρ (kg/m^3)	Dynamic Viscosity, μ (Pa.s)
- 1,000	21.50	9.810	1.139E+5	1.347E+0	1.821E - 5
0	15.00	9.807	1.013E+5	1.225E+0	1.789E - 5
1,000	8.50	9.804	8.988E+4	1.112E+0	1.758E - 5
2,000	2.00	9.801	7.950E+4	1.007E+0	1.726E - 5
3,000	- 4.49	9.797	7.012E+4	9.093E - 1	1.694E - 5
4,000	-10.98	9.794	6.166E+4	8.194E - 1	1.661E - 5
5,000	-17.47	9.791	5.405E+4	7.364E - 1	1.628E - 5
6,000	-23.96	9.788	4.722E+4	6.601E - 1	1.595E - 5
7,000	- 30.45	9.785	4.111E+4	5.900E - 1	1.561E - 5
8,000	- 36.94	9.782	3.565E+4	5.258E - 1	1.527E - 5
9,000	- 43.42	9.779	3.080E+4	4.671E - 1	1.493E - 5
→ 10,000	- 49.90	9.776	2.650E+4	4.135E - 1	1.458E - 5
15,000	-56.50	9.761	1.211E+4	1.948E - 1	1. 422E - 5