UNIVERSITY OF JOHANNESBURG

PROGRAM : BACCALAUREUS INGENERIAE
MECHANICAL ENGINEERING SCIENCE

SUBJECT : FLUID DYNAMICS 3A

CODE : STR3A

DATE : SUPPLEMENTARY EXAM (JULY 2019)

DURATION : 3 HOURS

WEIGHT : 50 : 50

TOTAL MARKS : 100

EXAMINER : Dr. S Kruger

MODERATOR : Dr. CR Bester

NUMBER OF PAGES : 5 PAGES AND 5 ANNEXURES

INSTRUCTIONS TO CANDIDATES:

PLEASE ANSWER ALL THE QUESTIONS.
DON'T WRITE IN PENCIL/RED PEN

QUESTION 1 [20]

Consider two infinitely long parallel plates (Figure 1), where the top plate is moving to the right at a velocity U_1 of while the lower plate is moving at a velocity U_2 also to the right.

- Derive with the aid of the Navier-Stokes equations the velocity profile for laminar, fully developed, incompressible flow in the space between the two plates if the volume flow per unit width is Q.
- Determine an expression for the pressure loss over a length L.
- Determine the POSITION and VALUE of the maximum velocity

NOTE: Show all algebraic calculations.

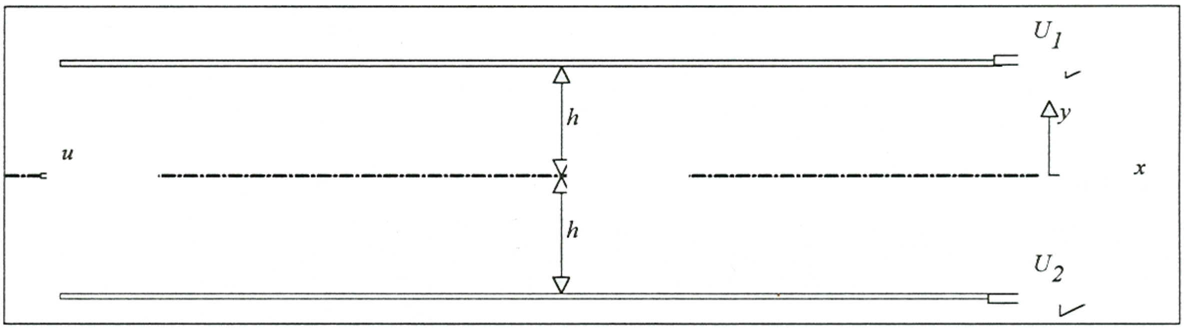

Figure 1

QUESTION 2 [12]

In a certain steady, two-dimensional flow field the fluid may be assumed to be ideal and weight of the fluid (specific weight = 7850N/m^3) is the only body force. The x-component of velocity is known to be $u = 6x$ which gives the velocity in m/s when x is measured in meters. The y component of velocity is known to be a function of y only. The y-axis is vertical, and at the origin the velocity is zero.

3.1 Determine the y-component of velocity so that the continuity equation is satisfied.

3.2 Can the difference in pressures between the points x = 0.3m, y = 0.3m and x = 0.3m and y = 1.2m be determined from the Bernoulli equation? If so, determine the value in N/m^2. If not, explain.

QUESTION 3 [19]

Find an expression for the velocity potential and stream function for a ***cylinder with circulation***

Determine expressions for the radial and transverse velocity components

Make use of Bernoulli's equation to find an expression for the boundary pressure around a cylinder with circulation. Refer to Figure 2.

Show that the lift is given by $L = \rho V_0 A$

Hint: $\sin^2\theta = \frac{1}{2}(1 - \cos(2\theta))$ and $\int \sin^3 du = \frac{1}{3}\cos^3 u - \cos u + C$

NB: Show all the steps.

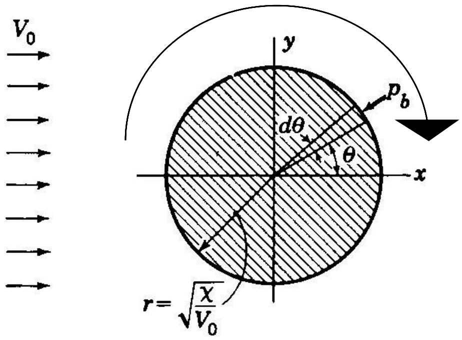

Figure 2

QUESTION 4 [17]

Air flows from a reservoir where P_{01} = 300kPa and T_{01} = 500K through a throat to section 1 as shown in Figure 3, where there is a normal shock wave.

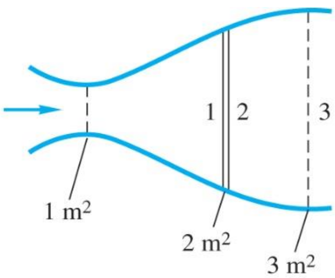

Figure 3

Calculate the following:

a) The static pressure before the shock
b) The static pressure after the shock
c) The new stagnation pressure after the shock
d) The new critical area
e) The stagnation pressure at point 3
f) A^*_3
g) P_3
h) T_{03}

QUESTION 5 [10]

Air is heated as it flows subsonically through a 10cm x 10cm square duct. The properties of air at the inlet are maintained at Ma_1=0.4, P_1 = 400kPa, and T_1=360K at all times. Disregarding frictional losses, determine the highest rate of heat transfer to the air in the duct without affecting the inlet conditions**.**

Use R = 0.287 kJ/kg.K, and k = 1.4

QUESTION 6 [13]

In the autogyro (Figure 4), the lift is developed by freely rotating vanes. The rotation is caused by the aerodynamic forces on the vanes themselves. Using flat-plate theory, what is the aerodynamic torque needed to overcome skin friction for an angular speed of the vanes of 50 rev/min?

Take each vane to be a flat plate of dimension 4.5m by 0.3m. The air is at a temperature of 10°C. Transition takes place at $\mathrm{Re}_{cr} = 3.2\times10^{5}$. Consider as an approximation, the equation for smooth plates, low Reynolds number turbulent flow to be valid for the turbulent boundary layer. Take $\upsilon = 1.55\times10^{-5}$ m^2/s and P =101.404 kPa.

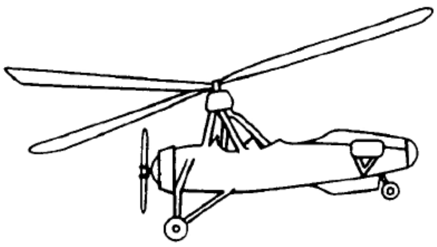

Figure 4

QUESTION 7 [9]

Ocean liners have in the past been equipped with retractable hydrofoils for purposes of maintaining stability in heavy water.

If the ship is moving at 40 knots, what is the skin friction drag on the hydrofoil if each is 2m long and 2m wide? Transition takes place at $Re_{cr} = 10^6$. *1 knot = 0.5144* m/s. Compute the skin friction drag of the hydrofoils taking the turbulent boundary layer over the entire length. Then calculate skin drag, taking into account the laminar portion of the boundary layer.

For seawater take $\mu = 1.395 \times 10^{-3}$ N.s/m^2*, and* $\rho = 1026$ *kg/m*^{3}.

ANNEXURE

FORMULA SHEET

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial p}{\partial x}+\rho g_x+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)$$

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=-\frac{\partial p}{\partial y}+\rho g_y+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)$$

$$\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=-\frac{\partial p}{\partial z}+\rho g_z+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)$$

$$\overline{\omega}=\omega_x\hat{i}+\omega_y\hat{j}+\omega_z\hat{k}=\frac{1}{2}\left(\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}\right)+\frac{1}{2}\left(\frac{\partial w}{\partial y}-\frac{\partial v}{\partial z}\right)+\frac{1}{2}\left(\frac{\partial u}{\partial z}-\frac{\partial w}{\partial x}\right)$$

$$\frac{\partial \phi}{\partial r}=\frac{1}{r}\frac{\partial \psi}{\partial \theta} \qquad \frac{1}{r}\frac{\partial \phi}{\partial \theta}=-\frac{\partial \psi}{\partial r} \qquad \oiint_{CS}\overline{T}dA+\iiint_{CV}\overline{B}\rho dv=\oiint_{CS}\overline{V}\left(\rho\overline{V}dA\right)+\frac{\partial}{\partial t}\iiint_{CV}\overline{V}\rho dv$$

$$\frac{\partial V_x}{\partial x}+\frac{\partial V_y}{\partial y}+\frac{\partial V_z}{\partial z}=0 \qquad \frac{p}{\gamma}+z+\frac{V^2}{2g}=const \qquad \gamma=\rho g \qquad \Gamma=\oint_c \overline{V}.ds$$

$$V_x=\frac{\partial \psi}{\partial y} \qquad V_y=-\frac{\partial \psi}{\partial x} \qquad V_x=\frac{\partial \phi}{\partial x} \qquad V_y=\frac{\partial \phi}{\partial y} \qquad V_r=\frac{1}{r}\frac{\partial \psi}{\partial \theta} \qquad \boxed{\mathrm{Re}=\frac{\rho VD}{\mu}=\frac{VD}{\upsilon}}$$

$$V_r=\frac{\partial \phi}{\partial r} \qquad V_\theta=\frac{\partial \phi}{r\partial \theta} \qquad \frac{\partial \phi}{\partial r}=\frac{1}{r}\frac{\partial \psi}{\partial \theta} \qquad \frac{1}{r}\frac{\partial \phi}{\partial \theta}=-\frac{\partial \psi}{\partial r} \qquad V_\theta=-\frac{\partial \psi}{\partial r} \qquad C_f=\frac{D}{\frac{1}{2}\rho U^2 A}$$

$$\frac{\partial \psi}{\partial y}=\frac{\partial \phi}{\partial x}$$

$$c=\sqrt{kRT} \qquad \tau_w=\left(\frac{du}{dy}\right)_w \qquad \boxed{c_f=\frac{\tau_w}{\frac{1}{2}\rho U^2}}$$

$$\frac{\partial \psi}{\partial x}=-\frac{\partial \phi}{\partial y}$$

$$C_f=\frac{0.455}{\left(\log \mathrm{Re}\right)^{2.58}}-\frac{A}{\mathrm{Re}} \qquad D=\int_A \tau_w dA \qquad \boxed{C_f=\frac{0.074}{\mathrm{Re}_L^{\frac{1}{5}}}-\frac{A}{\mathrm{Re}_L}}$$

$$C_f=\frac{1.328}{\sqrt{\mathrm{Re}_L}} \qquad C_f=\frac{D}{\frac{1}{2}\rho U^2 A}$$

Re_{cr}	300 000	500 000	10^6	3×10^6
A	1050	1700	3300	8700

$T_0 = T + \frac{V^2}{2C_p}$ $\qquad$ $\frac{dQ}{dm} = c_p(T_0)_2 - c_p(T_0)_1 = c_p(T_{02} - T_{01})$

One-dimensional isentropic relations†

M	A/A^*	p/p_0	ρ/ρ_0	T/T_0	M	A/A^*	p/p_0	ρ/ρ_0	T/T_0
0.00	...	1.000	1.000	1.000	0.86	1.02	0.617	0.708	0.871
0.01	57.87	0.9999	0.9999	0.9999	0.88	1.01	0.604	0.698	0.865
0.02	28.94	0.9997	0.9999	0.9999	0.90	1.01	0.591	0.687	0.860
0.04	14.48	0.999	0.999	0.9996	0.92	1.01	0.578	0.676	0.855
0.06	9.67	0.997	0.998	0.999	0.94	1.00	0.566	0.666	0.850
0.08	7.26	0.996	0.997	0.999	0.96	1.00	0.553	0.655	0.844
0.10	5.82	0.993	0.995	0.998	0.98	1.00	0.541	0.645	0.839
0.12	4.86	0.990	0.993	0.997	1.00	1.00	0.528	0.632	0.833
0.14	4.18	0.986	0.990	0.996	1.02	1.00	0.516	0.623	0.828
0.16	3.67	0.982	0.987	0.995	1.04	1.00	0.504	0.613	0.822
0.18	3.28	0.978	0.984	0.994	1.06	1.00	0.492	0.602	0.817
0.20	2.96	0.973	0.980	0.992	1.08	1.01	0.480	0.592	0.810
0.22	2.71	0.967	0.976	0.990	1.10	1.01	0.468	0.582	0.805
0.24	2.50	0.961	0.972	0.989	1.12	1.01	0.457	0.571	0.799
0.26	2.32	0.954	0.967	0.987	1.14	1.02	0.445	0.561	0.794
0.28	2.17	0.947	0.962	0.985	1.16	1.02	0.434	0.551	0.788
0.30	2.04	0.939	0.956	0.982	1.18	1.02	0.423	0.541	0.782
0.32	1.92	0.932	0.951	0.980	1.20	1.03	0.412	0.531	0.776
0.34	1.82	0.923	0.944	0.977	1.22	1.04	0.402	0.521	0.771
0.36	1.74	0.914	0.938	0.975	1.24	1.04	0.391	0.512	0.765
0.38	1.66	0.905	0.931	0.972	1.26	1.05	0.381	0.502	0.759
0.40	1.59	0.896	0.924	0.969	1.28	1.06	0.371	0.492	0.753
0.42	1.53	0.886	0.917	0.966	1.30	1.07	0.361	0.483	0.747
0.44	1.47	0.876	0.909	0.963	1.32	1.08	0.351	0.474	0.742
0.46	1.42	0.865	0.902	0.959	1.34	1.08	0.342	0.464	0.736
0.48	1.38	0.854	0.893	0.956	1.36	1.09	0.332	0.455	0.730
0.50	1.34	0.843	0.885	0.952	1.38	1.10	0.323	0.446	0.724
0.52	1.30	0.832	0.877	0.949	1.40	1.11	0.314	0.437	0.718
0.54	1.27	0.820	0.868	0.945	1.42	1.13	0.305	0.429	0.713
0.56	1.24	0.808	0.859	0.941	1.44	1.14	0.297	0.420	0.707
0.58	1.21	0.796	0.850	0.937	1.46	1.15	0.289	0.412	0.701
0.60	1.19	0.784	0.840	0.933	1.48	1.16	0.280	0.403	0.695
0.62	1.17	0.772	0.831	0.929	1.50	1.18	0.272	0.395	0.690
0.64	1.16	0.759	0.821	0.924	1.52	1.19	0.265	0.387	0.684
0.66	1.13	0.747	0.812	0.920	1.54	1.20	0.257	0.379	0.678
0.68	1.12	0.734	0.802	0.915	1.56	1.22	0.250	0.371	0.672
0.70	1.09	0.721	0.792	0.911	1.58	1.23	0.242	0.363	0.667
0.72	1.08	0.708	0.781	0.906	1.60	1.25	0.235	0.356	0.661
0.74	1.07	0.695	0.771	0.901	1.62	1.27	0.228	0.348	0.656
0.76	1.06	0.682	0.761	0.896	1.64	1.28	0.222	0.341	0.650
0.78	1.05	0.669	0.750	0.891	1.66	1.30	0.215	0.334	0.645
0.80	1.04	0.656	0.740	0.886	1.68	1.32	0.209	0.327	0.639
0.82	1.03	0.643	0.729	0.881	1.70	1.34	0.203	0.320	0.634
0.84	1.02	0.630	0.719	0.876	1.72	1.36	0.197	0.313	0.628

TABLE B5 *Continued*

M	A/A^*	p/p_0	ρ/ρ_0	T/T_0	M	A/A^*	p/p_0	ρ/ρ_0	T/T_0
1.74	1.38	0.191	0.306	0.623	2.50	2.64	0.059	0.132	0.444
1.76	1.40	0.185	0.300	0.617	2.52	2.69	0.057	0.129	0.441
1.78	1.42	0.179	0.293	0.612	2.54	2.74	0.055	0.126	0.437
1.80	1.44	0.174	0.287	0.607	2.56	2.79	0.053	0.123	0.433
1.82	1.46	0.169	0.281	0.602	2.58	2.84	0.052	0.121	0.429
1.84	1.48	0.164	0.275	0.596	2.60	2.90	0.050	0.118	0.425
1.86	1.51	0.159	0.269	0.591	2.62	2.95	0.049	0.115	0.421
1.88	1.53	0.154	0.263	0.586	2.64	3.01	0.047	0.113	0.418
1.90	1.56	0.149	0.257	0.581	2.66	3.06	0.046	0.110	0.414
1.92	1.58	0.145	0.251	0.576	2.68	3.12	0.044	0.108	0.410
1.94	1.61	0.140	0.246	0.571	2.70	3.18	0.043	0.106	0.407
1.96	1.63	0.136	0.240	0.566	2.72	3.24	0.042	0.103	0.403
1.98	1.66	0.132	0.235	0.561	2.74	3.31	0.040	0.101	0.400
2.00	1.69	0.128	0.230	0.556	2.76	3.37	0.039	0.099	0.396
2.02	1.72	0.124	0.225	0.551	2.78	3.43	0.038	0.097	0.393
2.04	1.75	0.120	0.220	0.546	2.80	3.50	0.037	0.095	0.389
2.06	1.78	0.116	0.215	0.541	2.82	3.57	0.036	0.093	0.386
2.08	1.81	0.113	0.210	0.536	2.84	3.64	0.035	0.091	0.383
2.10	1.84	0.109	0.206	0.531	2.86	3.71	0.034	0.089	0.379
2.12	1.87	0.106	0.201	0.526	2.88	3.78	0.033	0.087	0.376
2.14	1.90	0.103	0.197	0.522	2.90	3.85	0.032	0.085	0.373
2.16	1.94	0.100	0.192	0.517	2.92	3.92	0.031	0.083	0.370
2.18	1.97	0.097	0.188	0.513	2.94	4.00	0.030	0.081	0.366
2.20	2.01	0.094	0.184	0.508	2.96	4.08	0.029	0.080	0.363
2.22	2.04	0.091	0.180	0.504	2.98	4.15	0.028	0.078	0.360
2.24	2.08	0.088	0.176	0.499	3.00	4.23	0.027	0.076	0.357
2.26	2.12	0.085	0.172	0.495	3.10	4.66	0.023	0.0685	0.342
2.28	2.15	0.083	0.168	0.490	3.20	5.12	0.020	0.062	0.328
2.30	2.19	0.080	0.165	0.486	3.3	5.63	0.0175	0.0555	0.315
2.32	2.23	0.078	0.161	0.482	3.4	6.18	0.015	0.050	0.302
2.34	2.27	0.075	0.157	0.477	3.5	6.79	0.013	0.045	0.290
2.36	2.32	0.073	0.154	0.473	3.6	7.45	0.0114	0.041	0.278
2.38	2.36	0.071	0.150	0.469	3.7	8.17	0.0099	0.037	0.2675
2.40	2.40	0.068	0.147	0.465	3.8	8.95	0.0086	0.0335	0.257
2.42	2.45	0.066	0.144	0.461	3.9	9.80	0.0075	0.030	0.247
2.44	2.49	0.064	0.141	0.456	4.0	10.72	0.0066	0.028	0.238
2.46	2.54	0.062	0.138	0.452					
2.48	2.59	0.060	0.135	0.448					

†For a perfect gas with constant specific heat, $k = 1.4$

Table B.6 One-dimensional normal-shock relations†

M_1	M_2	$\frac{p_2}{p_1}$	$\frac{T_2}{T_1}$	$\frac{(p_0)_2}{(p_0)_1}$	$\frac{(A^*)_2}{(A^*)_1}$	M_1	M_2	$\frac{p_2}{p_1}$	$\frac{T_2}{T_1}$	$\frac{(p_0)_2}{(p_0)_1}$	$\frac{(A^*)_2}{(A^*)_1}$
1.00	1.000	1.000	1.000	1.000	1.000	1.80	0.617	3.613	1.532	0.813	1.228
1.02	0.980	1.047	1.013	1.000	1.000	1.82	0.612	3.698	1.547	0.804	1.239
1.04	0.962	1.095	1.026	1.000	1.000	1.84	0.608	3.783	1.562	0.795	1.252
1.06	0.944	1.144	1.039	1.000	1.000	1.86	0.604	3.869	1.577	0.786	1.273
1.08	0.928	1.194	1.052	0.999	1.000	1.88	0.600	3.957	1.592	0.777	1.286
1.10	0.912	1.245	1.065	0.999	1.000	1.90	0.596	4.045	1.608	0.767	1.307
1.12	0.896	1.297	1.078	0.998	1.000	1.92	0.592	4.134	1.624	0.758	1.319
1.14	0.882	1.350	1.090	0.997	1.010	1.94	0.588	4.224	1.639	0.749	1.339
1.16	0.868	1.403	1.103	0.996	1.000	1.96	0.584	4.315	1.655	0.740	1.352
1.18	0.855	1.458	1.115	0.995	1.000	1.98	0.581	4.407	1.671	0.730	1.373
1.20	0.842	1.513	1.128	0.993	1.010	2.00	0.577	4.500	1.688	0.721	1.391
1.22	0.830	1.570	1.140	0.991	1.015	2.02	0.574	4.594	1.704	0.711	1.411
1.24	0.818	1.627	1.153	0.988	1.010	2.04	0.571	4.689	1.720	0.702	1.430
1.26	0.807	1.686	1.166	0.986	1.013	2.06	0.567	4.784	1.737	0.693	1.447
1.28	0.796	1.745	1.178	0.983	1.017	2.08	0.564	4.881	1.754	0.683	1.467
1.30	0.786	1.805	1.191	0.979	1.022	2.10	0.561	4.978	1.770	0.674	1.485
1.32	0.776	1.866	1.204	0.976	1.027	2.12	0.558	5.077	1.787	0.665	1.504
1.34	0.766	1.928	1.216	0.972	1.022	2.14	0.555	5.176	1.805	0.656	1.522
1.36	0.757	1.991	1.229	0.968	1.026	2.16	0.553	5.277	1.822	0.646	1.551
1.38	0.748	2.055	1.242	0.963	1.032	2.18	0.550	5.378	1.839	0.637	1.570
1.40	0.740	2.120	1.255	0.958	1.037	2.20	0.547	5.480	1.857	0.628	1.667
1.42	0.731	2.186	1.268	0.953	1.051	2.22	0.544	5.583	1.875	0.619	1.614
1.44	0.723	2.253	1.281	0.948	1.057	2.24	0.542	5.687	1.892	0.610	1.642
1.46	0.716	2.320	1.294	0.942	1.063	2.26	0.539	5.792	1.910	0.601	1.667
1.48	0.708	2.389	1.307	0.936	1.068	2.28	0.537	5.898	1.929	0.592	1.686
1.50	0.701	2.458	1.320	0.930	1.083	2.30	0.534	6.005	1.947	0.583	1.712
1.52	0.694	2.529	1.334	0.923	1.077	2.32	0.532	6.113	1.965	0.575	1.739
1.54	0.687	2.600	1.347	0.917	1.081	2.34	0.530	6.222	1.984	0.566	1.767
1.56	0.681	2.673	1.361	0.910	1.090	2.36	0.527	6.331	2.003	0.557	1.798
1.58	0.675	2.746	1.374	0.903	1.095	2.38	0.525	6.442	2.021	0.549	1.825
1.60	0.668	2.820	1.388	0.895	1.110	2.40	0.523	6.553	2.040	0.540	1.852
1.62	0.663	2.895	1.402	0.888	1.125	2.42	0.521	6.666	2.060	0.532	1.886
1.64	0.657	2.971	1.416	0.880	1.128	2.44	0.519	6.779	2.079	0.523	1.912
1.66	0.651	3.048	1.430	0.872	1.136	2.46	0.517	6.894	2.098	0.515	1.945
1.68	0.646	3.126	1.444	0.864	1.147	2.48	0.515	7.009	2.118	0.507	1.977
1.70	0.641	3.205	1.458	0.856	1.156	2.50	0.513	7.125	2.138	0.499	2.009
1.72	0.635	3.285	1.473	0.847	1.169	2.52	0.511	7.242	2.157	0.491	2.041
1.74	0.631	3.366	1.487	0.839	1.185	2.54	0.509	7.360	2.177	0.483	2.073
1.76	0.626	3.447	1.502	0.830	1.20	2.56	0.507	7.479	2.198	0.475	2.104
1.78	0.621	3.530	1.517	0.821	1.214	2.58	0.506	7.599	2.218	0.468	2.139

Table B.6 *Continued*

M_1	M_2	$\frac{p_2}{p_1}$	$\frac{T_2}{T_1}$	$\frac{(p_0)_2}{(p_0)_1}$	$\frac{(A^*)_2}{(A^*)_1}$	M_1	M_2	$\frac{p_2}{p_1}$	$\frac{T_2}{T_1}$	$\frac{(p_0)_2}{(p_0)_1}$	$\frac{(A^*)_2}{(A^*)_1}$
2.60	0.504	7.720	2.238	0.460	2.177	2.84	0.485	9.243	2.496	0.376	2.657
2.62	0.502	7.842	2.260	0.453	2.208	2.86	0.484	9.376	2.518	0.370	2.704
2.64	0.500	7.965	2.280	0.445	2.246	2.88	0.483	9.510	2.541	0.364	2.751
2.66	0.499	8.088	2.301	0.438	2.280	2.90	0.481	9.645	2.563	0.358	2.794
2.68	0.497	8.213	2.322	0.431	2.318	2.92	0.480	9.781	2.586	0.352	2.841
2.70	0.496	8.338	2.343	0.424	2.359	2.94	0.479	9.918	2.609	0.346	2.894
2.72	0.494	8.465	2.364	0.417	2.396	2.96	0.478	10.055	2.632	0.340	2.948
2.74	0.493	9.592	2.396	0.410	2.445	2.98	0.476	10.194	2.656	0.334	2.990
2.76	0.491	8.721	2.407	0.403	2.482	3.00	0.475	10.333	2.679	0.328	3.043
2.78	0.490	8.850	2.429	0.396	2.522						
2.80	0.488	8.980	2.451	0.389	2.566						
2.82	0.487	9.111	2.473	0.383	2.613						

†For a perfect gas with $k = 1.4$.

TABLE B.8
Rayleigh line†

M	$\frac{T_0}{T_0^*}$	$\frac{T}{T^*}$	$\frac{p}{p^*}$	$\frac{p_0}{p_0^*}$	$\frac{V}{V^*}$
0	0	0	2.40	1.27	0
0.01	0.000	0.000	2.40	1.27	0.000
0.02	0.002	0.002	2.40	1.27	0.001
0.04	0.008	0.009	2.39	1.27	0.004
0.06	0.017	0.020	2.39	1.26	0.009
0.08	0.030	0.036	2.38	1.26	0.015
0.10	0.047	0.056	2.37	1.26	0.024
0.12	0.067	0.080	2.35	1.26	0.034
0.14	0.089	0.107	2.34	1.25	0.046
0.16	0.115	0.137	2.32	1.25	0.059
0.18	0.143	0.171	2.30	1.24	0.074
0.20	0.174	0.207	2.27	1.23	0.091
0.22	0.206	0.244	2.25	1.23	0.109
0.24	0.239	0.284	2.22	1.22	0.128
0.26	0.274	0.325	2.19	1.21	0.148
0.28	0.310	0.367	2.16	1.21	0.170
0.30	0.347	0.409	2.13	1.20	0.192
0.32	0.384	0.451	2.10	1.19	0.215
0.34	0.421	0.493	2.06	1.18	0.239
0.36	0.457	0.535	2.03	1.17	0.263
0.38	0.493	0.576	2.00	1.16	0.288
0.40	0.529	0.615	1.96	1.16	0.314
0.42	0.564	0.653	1.92	1.15	0.340
0.44	0.597	0.690	1.89	1.14	0.366
0.46	0.630	0.725	1.85	1.13	0.392
0.48	0.661	0.759	1.81	1.12	0.418
0.50	0.691	0.790	1.78	1.11	0.444
0.52	0.720	0.820	1.74	1.10	0.471
0.54	0.747	0.847	1.70	1.10	0.497
0.56	0.772	0.872	1.67	1.09	0.523
0.58	0.796	0.896	1.63	1.08	0.549
0.60	0.819	0.917	1.60	1.08	0.574
0.62	0.840	0.936	1.56	1.07	0.600
0.64	0.859	0.953	1.52	1.06	0.625
0.66	0.877	0.968	1.49	1.06	0.649
0.68	0.894	0.981	1.46	1.05	0.674
0.70	0.908	0.993	1.423	1.043	0.698
0.72	0.922	1.003	1.391	1.038	0.721
0.74	0.934	1.011	1.358	1.032	0.744
0.76	0.945	1.017	1.327	1.028	0.766
0.78	0.955	1.022	1.296	1.023	0.788
0.80	0.964	1.025	1.266	1.019	0.810
0.82	0.972	1.028	1.236	1.016	0.831
0.84	0.978	1.028	1.207	1.012	0.852
0.86	0.984	1.028	1.179	1.010	0.872
0.88	0.988	1.027	1.152	1.007	0.892
0.90	0.992	1.024	1.125	1.005	0.911
0.92	0.995	1.021	1.098	1.003	0.930
0.94	0.997	1.017	1.073	1.002	0.948
0.96	0.999	1.012	1.048	1.001	0.966
0.98	1.000	1.006	1.024	1.000	0.983
1.00	1.000	1.000	1.000	1.000	1.000
1.02	1.000	0.993	0.977	1.000	1.016
1.04	0.999	0.986	0.954	1.001	1.032
1.06	0.998	0.978	0.933	1.002	1.048
1.08	0.996	0.969	0.911	1.003	1.063
1.10	0.994	0.960	0.891	1.005	1.078
1.12	0.991	0.951	0.871	1.007	1.092
1.14	0.989	0.942	0.851	1.010	1.106
1.16	0.986	0.932	0.832	1.012	1.120
1.18	0.982	0.922	0.814	1.016	1.133
1.20	0.979	0.912	0.796	1.019	1.146
1.22	0.975	0.902	0.778	1.023	1.158
1.24	0.971	0.891	0.761	1.028	1.171
1.26	0.967	0.881	0.745	1.033	1.182
1.28	0.962	0.870	0.729	1.038	1.194
1.30	0.958	0.859	0.713	1.044	1.205
1.32	0.953	0.848	0.698	1.050	1.216
1.34	0.949	0.838	0.683	1.056	1.226
1.36	0.944	0.827	0.669	1.063	1.237
1.38	0.939	0.816	0.655	1.070	1.247
1.40	0.934	0.805	0.641	1.078	1.256
1.42	0.929	0.795	0.628	1.086	1.266
1.44	0.924	0.784	0.615	1.094	1.275
1.46	0.919	0.773	0.602	1.103	1.284
1.48	0.914	0.763	0.590	1.112	1.293
1.50	0.909	0.752	0.578	1.122	1.301
1.52	0.904	0.742	0.567	1.132	1.309
1.54	0.899	0.732	0.556	1.142	1.318
1.56	0.894	0.722	0.544	1.153	1.325
1.58	0.889	0.712	0.534	1.164	1.333
1.60	0.884	0.702	0.524	1.176	1.340
1.62	0.879	0.692	0.513	1.188	1.348
1.64	0.874	0.682	0.504	1.200	1.355
1.66	0.869	0.672	0.494	1.213	1.361
1.68	0.864	0.663	0.485	1.226	1.368
1.70	0.860	0.654	0.476	1.240	1.374
1.72	0.855	0.644	0.467	1.254	1.381

TABLE B.8 *Continued*

M	$\frac{T_0}{T_0^*}$	$\frac{T}{T^*}$	$\frac{p}{p^*}$	$\frac{p_0}{p_0^*}$	$\frac{V}{V^*}$
1.74	0.850	0.635	0.458	1.269	1.387
1.76	0.846	0.626	0.450	1.284	1.393
1.78	0.841	0.618	0.442	1.300	1.399
1.80	0.836	0.609	0.434	1.316	1.405
1.82	0.832	0.600	0.426	1.332	1.410
1.84	0.827	0.592	0.418	1.349	1.416
1.86	1.823	0.584	0.411	1.367	1.421
1.88	0.818	0.575	0.403	1.385	1.426
1.90	0.814	0.567	0.396	1.403	1.431
1.92	0.810	0.559	0.390	1.422	1.436
1.94	0.806	0.552	0.383	1.442	1.441
1.96	0.802	0.544	0.376	1.462	1.446
1.98	0.797	0.536	0.370	1.482	1.450
2.00	0.793	0.529	0.364	1.503	1.454
2.02	0.789	0.522	0.357	1.525	1.459
2.04	0.785	0.514	0.352	1.547	1.463
2.06	0.782	0.507	0.346	1.569	1.467
2.08	0.778	0.500	0.340	1.592	1.471
2.10	0.774	0.494	0.334	1.616	1.475
2.12	0.770	0.487	0.329	1.640	1.479
2.14	0.767	0.480	0.324	1.665	1.483
2.16	0.763	0.474	0.319	1.691	1.487
2.18	0.760	0.467	0.314	1.717	1.490
2.20	0.756	0.461	0.309	1.743	1.494
2.22	0.753	0.455	0.304	1.771	1.497
2.24	0.749	0.449	0.299	1.799	1.501
2.26	0.746	0.443	0.294	1.827	1.504
2.28	0.743	0.437	0.290	1.856	1.507
2.30	0.740	0.431	0.286	1.886	1.510
2.32	0.736	0.426	0.281	1.916	1.513
2.34	0.733	0.420	0.277	1.948	1.516
2.36	0.730	0.414	0.273	1.979	1.520
2.38	0.727	0.409	0.269	2.012	1.522
2.40	0.724	0.404	0.265	2.045	1.525
2.42	0.721	0.399	0.261	2.079	1.528
2.44	0.718	0.384	0.257	2.114	1.531
2.46	0.716	0.388	0.253	2.149	1.533
2.48	0.713	0.384	0.250	2.185	1.536
2.50	0.710	0.379	0.246	2.222	1.538
2.52	0.707	0.374	0.243	2.259	1.541
2.54	0.705	0.369	0.239	2.298	1.543
2.56	0.702	0.365	0.236	2.337	1.546
2.58	0.700	0.360	0.232	2.377	1.548
2.60	0.697	0.356	0.229	2.418	1.551
2.62	0.694	0.351	0.226	2.459	1.553
2.64	0.692	0.347	0.223	2.502	1.555
2.66	0.690	0.343	0.220	2.545	1.557
2.68	0.687	0.338	0.217	2.589	1.559
2.70	0.685	0.334	0.214	2.634	1.561
2.72	0.683	0.330	0.211	2.680	1.563
2.74	0.680	0.326	0.208	2.727	1.565
2.76	0.678	0.322	0.206	2.775	1.567
2.78	0.676	0.319	0.203	2.824	1.569
2.80	0.674	0.315	0.200	2.873	1.571
2.82	0.672	0.311	0.198	2.924	1.573
2.84	0.670	0.307	0.195	2.975	1.575
2.86	0.668	0.304	0.193	3.028	1.577
2.88	0.665	0.300	0.190	3.081	1.578
2.90	0.664	0.297	0.188	3.136	1.580
2.92	0.662	0.293	0.186	3.191	1.582
2.94	0.660	0.290	0.183	3.248	1.583
2.96	0.658	0.287	0.181	3.306	1.585
2.98	0.656	0.283	0.179	3.365	1.587
3.00	0.654	0.280	0.176	3.424	1.588

†Perfect gas, $k = 1.4$.