1-1 ~~1-5-1~~ Speed of Sound and Mach Number

sound : a pressure wave of infinitesimal strength

infinitesimal p. change ⇒ reversible
little time for heat transfer ⇒ adiabatic (and small ΔT)
} ⇒ isentropic

⇒ $a^2 = \left(\frac{\partial p}{\partial \rho}\right)_s$; a : sonic speed ; s : entropy

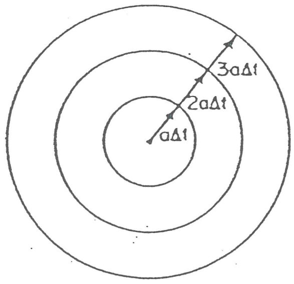
or $a = \sqrt{\frac{E_v}{\rho}}$ or $a = \sqrt{\frac{K}{\rho}}$; in terms of bulk modulus, $E_v \,(\text{or } K) = \frac{dp}{d\rho/\rho} = \rho \frac{dp}{d\rho}$

For an ideal gas :

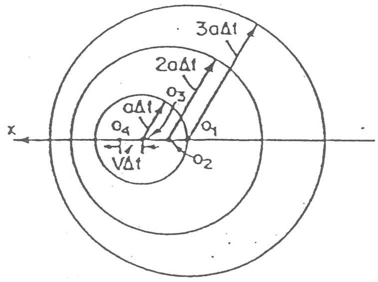
⇒ $a = \sqrt{\frac{\gamma p}{\rho}} = \sqrt{\gamma R T}$; $\gamma \equiv \frac{c_p}{c_v}$ = specific heat ratio

Define Mach Number, $M \equiv \frac{V}{a}$

⇒

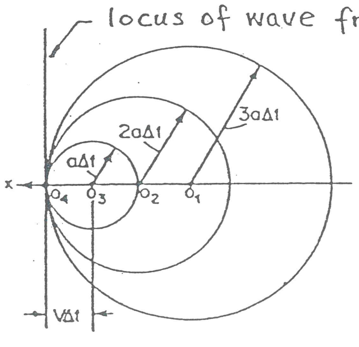


(a) V=0 : stationary source



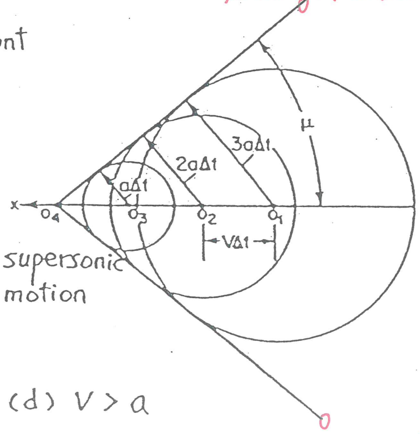
(b) V<a : Doppler Effect

Doppler Effect : A stationary observer would hear more peaks per unit time as the source approaches than after it passes.



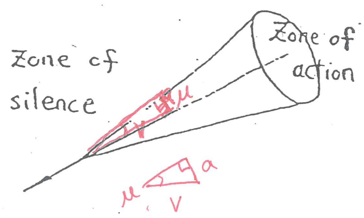
(c) V=a

like 漸近線



(d) V>a

Mach Cone :



V > a

$\sin \mu = \frac{a}{V} = \frac{1}{M}$

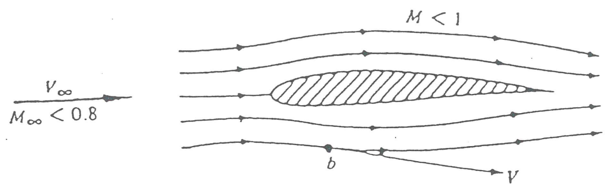
Mach angle $\mu = \sin^{-1}\left(\frac{1}{M}\right)$

Sonic wave 被限於 Zone of action

Navier-Stoke 從橢圓 → hyperbolic 双曲線

1-2
~~1-5-2~~ Classification of Compressible Flows

The compressible flows can be classified based on Mach number, M.



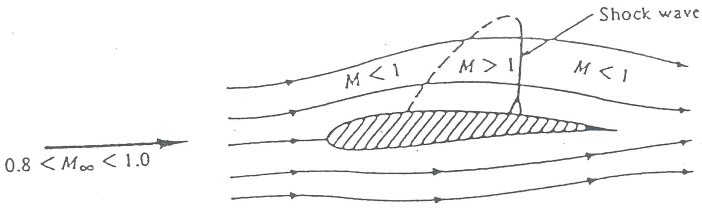
(1) Subsonic Flow

(a) M < 1 at every point

(b) Smooth streamlines and continuously varying properties.

(c) Streamlines deflect far upstream of the body.

(d) $M_\infty \lesssim 0.8$ for airplane aerodynamics.

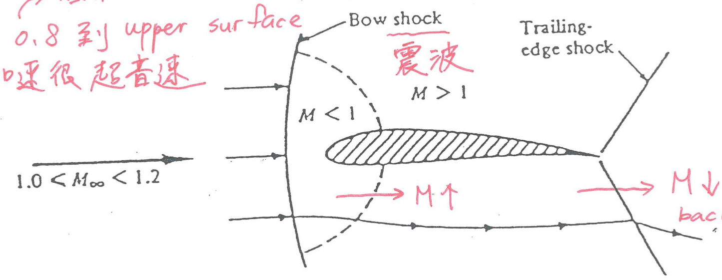


(2) Transonic Flow

(a) subsonic + supersonic.

(b) $0.8 < M_\infty < 1.2$.

(c) Subsonic region exists after bow shock.

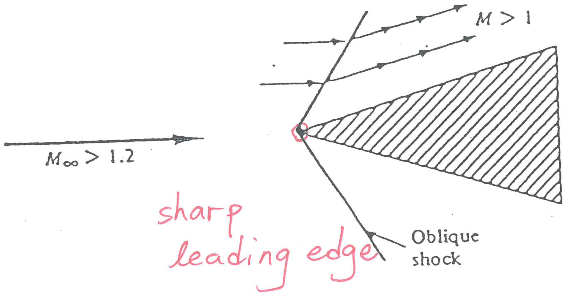


(3) Supersonic Flow

(a) M > 1 (everywhere).

(b) A straight, oblique shock wave is attached to the sharp nose of the wedge.

(c) Free stream is unaware of the presence of the body.



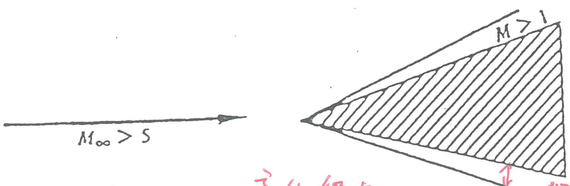
(4) Hypersonic Flow

(a) $M_\infty > 5$.

(b) Thin shock layer.

(c) High-temperature shock layer.

(d) Entropy layer.



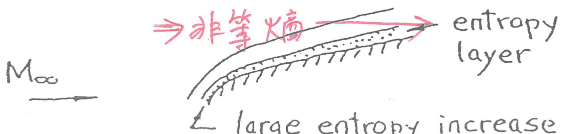


TABLE B.2. ISENTROPIC FLOW (*Concluded*)
Perfect Gas, $k = 1.4$

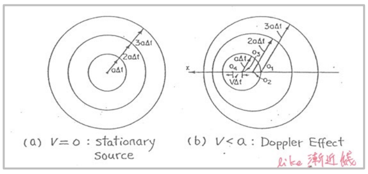
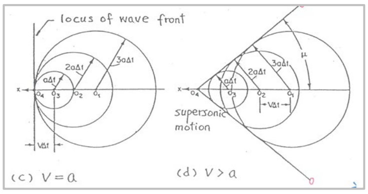
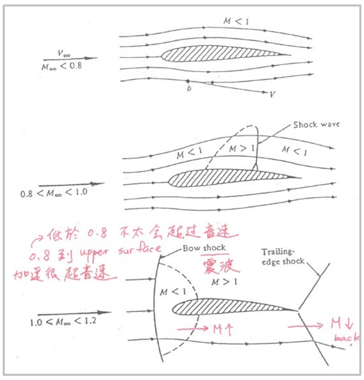
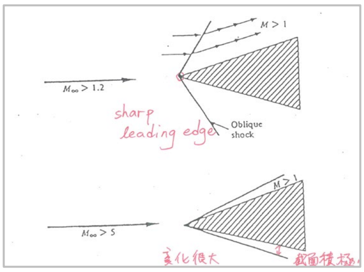
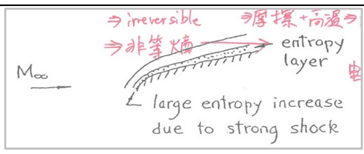
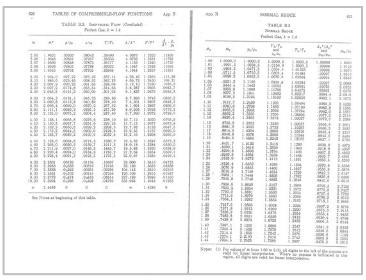
M	M*	p/p_0	ρ/ρ_0	T/T_0	A/A^*	F/F^*	$\frac{A}{A^*} \cdot \frac{p}{p_0}$
2.95	1.9521	.02935	.08043	.36490	4.0376	1.2322	.11850
2.96	1.9545	.02891	.07957	.36333	4.0763	1.2331	.11785
2.97	1.9569	.02848	.07872	.36177	4.1153	1.2340	.11720
2.98	1.9593	.02805	.07788	.36022	4.1547	1.2348	.11656
2.99	1.9616	.02764	.07705	.35868	4.1944	1.2357	.11591
3.00	1.964,0	.027,22	.076,23	.357,14	4.23,46	1.2366	.115,28
3.10	1.986,6	.023,45	.068,52	.342,23	4.65,73	1.2450	.109,21
3.20	2.007,9	.020,23	.061,65	.328,08	5.12,10	1.2530	.1035,9
3.30	2.027,9	.0174,8	.055,54	.314,66	5.6,287	1.2605	.0983,7
3.40	2.046,6	.0151,2	.050,09	.301,93	6.1,837	1.2676	.0935,3
3.50	2.064,2	.0131,1	.045,23	.289,86	6.7,896	1.2743	.0890,2
3.60	2.080,8	.0113,8	.040,89	.278,40	7.4,501	1.2807	.0848,2
3.70	2.096,4	.0099,0	.0370,2	.267,52	8.1,691	1.2867	.0809,0
3.80	2.111,1	.0086,3	.0335,5	.257,20	8.9,506	1.2924	.0772,3
3.90	2.125,0	.0075,3	.0304,4	.247,40	9.7,990	1.2978	.0738,0
4.00	2.138,1	.0065,8	.0276,6	.238,10	10.7,19	1.3029	.0705,9
4.10	2.150,5	.0057,7	.0251,6	.229,25	11.7,15	1.3077	.0675,8
4.20	2.162,2	.0050,6	.0229,2	.2208,5	12.7,92	1.3123	.0647,5
4.30	2.173,2	.0044,5	.0209,0	.2128,6	13.9,55	1.3167	.0620,9
4.40	2.183,7	.0039,2	.0190,9	.2052,5	15.2,10	1.3208	.0595,9
4.50	2.193,6	.0034,6	.0174,5	.1980,2	16.5,62	1.3247	.0572,3
4.60	2.203,0	.0030,5	.0159,7	.1911,3	18.0,18	1.3284	.0550,0
4.70	2.211,9	.0027,0	.0146,3	.1845,7	19.5,83	1.3320	.0528,9
4.80	2.220,4	.0024,0	.0134,3	.1783,2	21.2,64	1.3354	.0509,1
4.90	2.228,4	.0021,3	.0123,3	.1723,5	23.0,67	1.3386	.0490,4
5.00	2.2361	.00189	.01134	.16667	25.000	1.3416	.04725
6.00	2.2953	$.0_3633$	.00519	.12195	53.180	1.3655	.03368
7.00	2.3333	$.0_3242$	.00261	.09259	104.143	1.3810	.02516
8.00	2.3591	$.0_3102$	.00141	.07246	190.109	1.3915	.01947
9.00	2.3772	$.0_4474$	$.0_3815$	.05814	327.189	1.3989	.01550
10.00	2.3904	$.0_4236$	$.0_3495$	.04762	535.938	1.4044	.01263
∞	2.4495	0	0	0	∞	1.4289	0

See Notes at beginning of this table.

TABLE B.3
NORMAL SHOCK
Perfect Gas, $k = 1.4$

M_x	M_y	p_y/p_x	V_x/V_y and ρ_y/ρ_x	T_y/T_x	A_x^*/A_y^* and p_{0y}/p_{0x}	p_{0y}/p_x
1.00	1.0000,0	1.0000,0	1.0000,0	1.0000,0	1.00000	1.8929
1.01	.9901,3	1.0234,5	1.0166,9	1.0066,5	.99999	1.9152
1.02	.9805,2	1.0471,3	1.0334,4	1.01325	.99998	1.9379
1.03	.9711,5	1.0710,5	1.0502,4	1.01981	.99997	1.9610
1.04	.9620,2	1.0952,0	1.0670,9	1.02634	.99994	1.9845
1.05	.9531,2	1.1196	1.0839,8	1.03284	.99987	2.0083
1.06	.9444,4	1.1442	1.10092	1.03931	.99976	2.0325
1.07	.9359,8	1.1690	1.11790	1.04575	.99962	2.0570
1.08	.9277,2	1.1941	1.13492	1.05217	.9994,4	2.0819
1.09	.9196,5	1.2194	1.15199	1.05856	.9992,1	2.1072
1.10	.9117,7	1.2450	1.1691	1.06494	.9989,2	2.1328
1.11	.9040,8	1.2708	1.1862	1.07130	.9985,8	2.1588
1.12	.8965,6	1.2968	1.2034	1.07764	.9982,0	2.1851
1.13	.8892,2	1.3230	1.2206	1.08396	.9977,6	2.2118
1.14	.8820,4	1.3495	1.2378	1.09027	.9972,6	2.2388
1.15	.8750,2	1.3762	1.2550	1.09657	.9966,9	2.2661
1.16	.8681,6	1.4032	1.2723	1.10287	.9960,5	2.2937
1.17	.8614,5	1.4304	1.2896	1.10916	.9953,4	2.3217
1.18	.8548,8	1.4578	1.3069	1.11544	.9945,5	2.3499
1.19	.8484,6	1.4854	1.3243	1.12172	.9937,1	2.3786
1.20	.8421,7	1.5133	1.3416	1.1280	.9928,0	2.4075
1.21	.8360,1	1.5414	1.3590	1.1343	.9918,0	2.4367
1.22	.8299,8	1.5698	1.3764	1.1405	.9907,3	2.4662
1.23	.8240,8	1.5984	1.3938	1.1468	.9895,7	2.4961
1.24	.8183,0	1.6272	1.4112	1.1531	.9883,5	2.5263
1.25	.8126,4	1.6562	1.4286	1.1594	.9870,6	2.5568
1.26	.8070,9	1.6855	1.4460	1.1657	.9856,8	2.5876
1.27	.8016,5	1.7150	1.4634	1.1720	.9842,2	2.6187
1.28	.7963,1	1.7448	1.4808	1.1782	.9826,8	2.6500
1.29	.7910,8	1.7748	1.4983	1.1846	.9810,6	2.6816
1.30	.7859,6	1.8050	1.5157	1.1909	.9793,5	2.7135
1.31	.7809,3	1.8354	1.5331	1.1972	.9775,8	2.7457
1.32	.7760,0	1.8661	1.5505	1.2035	.9757,4	2.7783
1.33	.7711,6	1.8970	1.5680	1.2099	.9738,2	2.8112
1.34	.7664,1	1.9282	1.5854	1.2162	.9718,1	2.8444
1.35	.7617,5	1.9596	1.6028	1.2226	.9697,2	2.8778
1.36	.7571,8	1.9912	1.6202	1.2290	.9675,6	2.9115
1.37	.7526,9	2.0230	1.6376	1.2354	.9653,4	2.9455
1.38	.7482,8	2.0551	1.6550	1.2418	.9630,4	2.9798
1.39	.7439,6	2.0874	1.6723	1.2482	.9606,5	3.0144
1.40	.7397,1	2.1200	1.6896	1.2547	.9581,9	3.0493
1.41	.7355,4	2.1528	1.7070	1.2612	.9556,6	3.0844
1.42	.7314,4	2.1858	1.7243	1.2676	.9530,6	3.1198
1.43	.7274,1	2.2190	1.7416	1.2742	.9503,9	3.1555
1.44	.7234,5	2.2525	1.7589	1.2807	.9476,5	3.1915

Notes: (1) For values of M from 1.00 to 3.00, all digits to the left of the comma are valid for linear interpolation. Where no comma is indicated in this region, all digits are valid for linear interpolation.

NO.	圖片	來源
1		John D. Anderson Jr., Modern Compressible Flow, Tata McGrawhill India Pvt Ltd; 3rd edition (January 1, 2012), p. 132. This work is used subject to the fair use doctrine of Article 52, 65 Taiwan Copyright Act.
2		John D. Anderson Jr., Modern Compressible Flow, Tata McGrawhill India Pvt Ltd; 3rd edition (January 1, 2012), p. 132. This work is used subject to the fair use doctrine of Article 52, 65 Taiwan Copyright Act.
3		John D. Anderson Jr., Modern Compressible Flow, Tata McGrawhill India Pvt Ltd; 3rd edition (January 1, 2012), p. 16. This work is used subject to the fair use doctrine of Article 52, 65 Taiwan Copyright Act.
4		John D. Anderson Jr., Modern Compressible Flow, Tata McGrawhill India Pvt Ltd; 3rd edition (January 1, 2012), p. 16. This work is used subject to the fair use doctrine of Article 52, 65 Taiwan Copyright Act.
5		John D. Anderson Jr., Introduction to Flight, McGraw Hill; 8th edition (February 19, 2015), p. 821. This work is used subject to the fair use doctrine of Article 52, 65 Taiwan Copyright Act.
6		Ascher H. Shapiro, The Dynamics and Thermodynamics of Compressible Fluid Flow, Vol. 1, Wiley; 1st edition (January 16, 1991). This work is used subject to the fair use doctrine of Article 52, 65 Taiwan Copyright Act.