C.P. No. 292
(18,162)
A.R.C. Technical Report

C.P. No. 292
(18,162)
A.R.C. Technical Report

MINISTRY OF SUPPLY

AERONAUTICAL RESEARCH COUNCIL
CURRENT PAPERS

An Index of Mathematical Tables for Shock-Tube Flow

By

B. D. Henshall, B.Sc., Ph.D.

LONDON : HER MAJESTY'S STATIONERY OFFICE

1956

Price 1s 6d net

C.P. No. 292

An Index of Mathematical Tables for Shock-Tube Flow

- By -
B. D. Henshall, B.Sc., Ph.D.
of the Aerodynamics Division, N.P.L.

24th January, 1956

1. SUMMARY

A classified index of tables for use in calculations of the flow in shock tubes is presented in this note. Consistent nomenclature in accordance with general usage is adopted.

2. Introduction

The increasing use of shock tubes in aerodynamic research has called attention to the scattered nature of the relevant tables required for calculations of shock-tube flow. It is hoped that the present index of freely-available tables will help to prevent unnecessary duplication of effort. A consistent nomenclature has been adopted which is in accordance with general usage. For convenience a labelled diagram of typical simple shock-tube flow is given in Figure 1 and a list of symbols is given below.

3. Notation

a	velocity of sound
C	length of chamber of shock tube
L	length of channel of shock tube
M	Mach number
p	absolute pressure
R	Reynolds number
s	entropy
t	time
τ	flow duration
T	absolute temperature
u	flow velocity
U	shock velocity; subscript corresponds to flow region *ahead* of shock
x	distance measured along longitudinal axis of shock tube
X	distance parameter $= \frac{x}{C}$
γ	C_p/C_v, the ratio of the specific heats

ρ/

Published with permission of the Director, National Physical Laboratory

ρ	density
$M_{()}$	flow Mach number with respect to the local speed of sound $\left(\text{e.g., } M_2 = \frac{u_2}{a_2}\right)$
$M_{s()}$	shock wave propagation Mach number with respect to the speed of sound in the flow ahead of the shock front $\left(\text{e.g., } M_{s_1} = \frac{U_1}{a_1}\right)$
P_o	Overall pressure ratio across the extreme ends of a simple shock tube
T_o	Overall temperature ratio across extreme ends of a simple shock tube
X_o	Non-dimensional length of channel of shock tube (= L/C).

Subscripts

1,2,3,4,5 etc identify quantities related to the gas in the corresponding region of shock tube flow (see Figure 1)

Special Non-dimensional Notation

$p_{mn} = \frac{p_m}{p_n}$ a pressure ratio

$\rho_{mn} = \frac{\rho_m}{\rho_n}$ a density ratio

etc.

4. Classification of Tables

Independent tables of normal-shock functions and simple wave functions are listed in Sections 4A and 4B respectively. However, in simple shock-tube flow the normal shock and simple wave equations are combined so that the boundary conditions at the contact surface are satisfied, and thus tables which involve assumptions about the initial conditions in the shock tube are listed separately in Section 4C.

As in the index of tables for compressible flow calculations[18], each table is described in the following manner:

Argument - Range of Argument - Respondents

The argument is placed first and underlined, followed by the range of argument tabulated. Figures in brackets indicate the interval of argument, and the flanking figures give the extremities of the range. Next the number of significant figures (S) or decimal places (D) for the respondents are given, and finally the appropriate reference number is noted. For example,

$\underline{M_{s_1}}$	1(.01)5	p_{21}	6S	Ref 1

would denote that in Ref.1 there is a table in which p_{21} is tabulated against M_{s_1} to 6 significant figures, for M_{s_1} varying by intervals

of/

of 0.01 from 1 to 5. In all cases γ = 1.400 unless otherwise stated and perfect gas behaviour is assumed. It is intended from time to time to bring this index up to date, and the author will be grateful to receive details of tables which have been overlooked in the compilation of the present list.

4A. Normal Shock Tables

M_{S_1}	1(.01)5	$p_{21},\ \rho_{21},\ T_{21}$	6S	Ref.1
M_{S_1}	1(.01)5	$M_2,\ \{M_{S_1}\cdot a_{12} - M_2\}$	6S	Ref.1
M_{S_1}	1(.05)5	$[\gamma = 1.405]$ $p_{21},\ \rho_{21},\ T_{21}$	4S	Ref.7
M_{S_1}	1(.01)4	$p_{21},\ \{M_{S_1}\cdot a_{12} - M_2\}$	4S	Ref.6
M_{S_1}	1(.01)3	$p_{21},\ \left\{1 - a_{21}\cdot\frac{M_2}{M_{S_1}}\right\}$	5D	Ref.3
M_{S_1}	1(.01)10	$p_{21},\ \rho_{21},\ \left\{1 - a_{21}\cdot\frac{M_2}{M_{S_1}}\right\},\ \{M_{S_1}\cdot a_{12} - M_2\}$	4S	Ref.4
M_{S_1}	1(.01)3(.5)5(1)10	$p_{21},\ \rho_{21},\ T_{21}$	5S	Ref.5
M_{S_1}	1(.01)2(.1)5(1)25	$p_{21},\ \rho_{21},\ T_{21},\ a_{21}$ $\{M_{S_1},\ a_{12} - M_2\}\ .\ \left\{1 - a_{21}\cdot\frac{M_2}{M_{S_1}}\right\}$	5S	Ref.8
M_{S_1}	1(.05)3.5(.1)5	$p_{21},\ \rho_{21},\ T_{21},\ a_{21},\ \{M_{S_1}\cdot a_{12} - M_2\}$	4S	Ref.9
M_{S_1}	1(.1)8(1)20	$p_{51},\ T_{51}$	5S	Ref.16
M_{S_1}	1(.1)2	$p_{21},\ p_{12},\ \{M_{S_1}\cdot a_{12} - M_2\}$	4S	Ref.12
M_{S_1}	1(.01)10(.02)20(.2)50(1)100	$p_{21},\ \rho_{21},\ T_{21},\ \{M_{S_1}\ .\ a_{12} - M_2\}$	4S	Ref.13
M_{S_1}	1(.01)5	$p_{21},\ \rho_{21},\ T_{21},\ a_{21},$ $\{M_{S_1}\cdot a_{12} - M_2\},\ \left\{1 - a_{21}\cdot\frac{M_2}{M_{S_1}}\right\}$	5D	Ref.2
M_{S_1}	1(.01)3(.5)5(1)10, ∞	$p_{21},\ \rho_{21},\ T_{21},\ \{M_{S_1}\cdot a_{12} - M_2\}$	5S	Ref.10
M_{S_1}	1(.05)2(.1)3(.2)4	$p_{21},\ \rho_{21},\ T_{21},\ a_{21},\ \frac{u_2}{a_1},\ \frac{u_2}{U_1},\ U_{21},\ M_2,\ \frac{S_2 - S_1}{C_v}$	4S	Ref.11
p_{21}	1(.1)1.5(.25)2(.5)4(1)6(2)10(2.5)20(5)30(10)60(20)100(50)300, 400, 600, 800, 1,000, 2,000, 3,000 and ∞; γ_1 = 1.0, 1.1, 1.2, 1.4, and 5/3.	$T_{21},\ \rho_{21},\ a_{21},\ M_{S_1},\ M_2,\ \frac{u_2}{a_1},\ \frac{s_2 - s_1}{C_v}$	3 or 4D	Ref.15

p_{21}

$\underline{p_{21}}$ 1(.1)1.5(.25)2(.5)4(1)6(2)10(2.5)20(5)30(10)60(20)100(50)300

400, 600, 800, 1,000 and ∞

γ_1 = 1.0, 1.1, 1.2, 1.4 and 5/3

p_{52}, T_{52}, ρ_{52}, U_{21} 3 or 4D Ref.15

$\underline{p_{21}}$	1(1)21(2)43	M_{s_1}, T_{21}, M_2, ρ_{21}, a_{21}, $\frac{u_2}{a_1}$	4S	Ref.14
$\underline{p_{21}}$	1(2)35	M_{s_1}, p_{52}, ρ_{52}, T_{52}, M_{32}	4S	Ref.14
$\underline{p_{21}}$	1(.2)6.4	p_{51}, M_{s_1}, U_{21}, $M_{s_2}.a_{21}$,	4 or 5S	Ref.17
$\underline{p_{21}}$	1(.2)2(.1)6.4	M_{s_1}, M_2, a_{21}, $\frac{u_2}{a_1}$	4S	Ref.17

4B. Simple Wave Tables

$\underline{p_{34}}$	1.0(.1)0.8(.2)0.4	T_{64}, ρ_{64}, p_{64}	4S	Ref.14
$\underline{M_3}$	0(.05)1.0	γ_4 = 1.1, 1.2, 1.4 and 5/3 p_{64}	4S	Ref.15

$\underline{M_3}$ 0(.1)0.2(.2)2(.5)10(2)20(5)30 and ∞

For γ_4 = 1.1, 1.2, 1.4, and 5/3

a_{34}, T_{34}, p_{34}, ρ_{34} $\frac{u_3}{a_4}$ 4 or 5S Ref.15

4C. Shock Tube Tables

(a) A general double entry table $\gamma_4 = \gamma_1 = 1.4$

$\underline{M_{s_1}}$ 1(.1)8, $\underline{T_0}$ 1(1)15 } P_0 5S Ref.16

(b) Tables with $T_0 = 1$ ($T_{41} = a_{41} = 1$)

(i) $\gamma_4 = \gamma_1 = 1.4$

$\underline{P_0}$ 1(1)100 and ∞ M_{s_1}, M_2, M_3, a_{21}, a_{34}, p_{21}, p_{34}, $\frac{u_2}{a_1}$, $T_{23}^{\frac{1}{4}}$ 3 or 4S Ref.17

$\underline{p_{21}}$	1(.2)2(.1)6.4	P_0, p_{34}, a_{34}, M_3, $T_{23}^{\frac{1}{4}}$	4S	Ref.17
$\underline{p_{21}}$	1(1)21(2)43	P_0, P_0^{-1}, a_{34}, T_{34}, p_{34} $\left\{\frac{u_3}{a_4} - a_{34}\right\}$	4S	Ref.14

$\underline{M_{s_1}}$/

M_{S_1}	1(.05)2(.1)3(.2)4	M_{32}, a_{23}, T_{23} ρ_{23}, R_{32} X_o, X_2, X_3, $\frac{X_o}{X_2}$, $\frac{X_o}{\frac{a_1 \tau_2}{C}}$, P_o, M_3, $\frac{\tau_2}{\tau_3}$, $\frac{a_1 \tau_2}{C}$, $\frac{a_1 \tau_3}{C}$, $\frac{a_1 t_2}{C} = \frac{2a_1 t_3}{C}$	4S	Ref.11
	(ii) $\gamma_4 = 1.665$, $\gamma_1 = 1.402$ (Helium/Air)			
p_{21}	1(1)30	ρ_{34}, a_{34}, T_{34}, p_{34}	4S	Ref.14
p_{21}	1(1)33(2)57	P_o	4S	Ref.14

REFERENCES

No.	Author(s)	Title, etc.
1	A.R.C. Compressible Flow Tables Panel	Compressible airflow: Tables Clarendon Press Oxford 1952.
2	-	Handbook of Supersonic Aerodynamics Applied Physics Laboratory, Johns Hopkins University, U.S.A. Navord Report 1488 Vol.2.
3	R. Harrop and P. I. Bright	Tables for compressible air flow calculations Part IV. R.A.E. Technical Note No.Aero.1738c A.R.C.10,910 - F.M.950b July, 1947.
4	M. A. Burcher	Compressible flow tables for air N.A.C.A. TN 1592 August, 1948
5	J. H. Keenan and J. Kaye	Gas tables Wiley and Sons, New York, 1948
6	A. Ferri	Elements of aerodynamics of supersonic flows. Macmillan. New York 1949
7	F. Schubert	On the theory of stationary compression shocks. Z.A.M.M. Vol.23 No.3 June, 1943.
8	H. W. Emmons	Gas dynamics tables for air Dover Publications, New York, 1947.
9	R. C. Pankhurst and D. W. Holder	Wind tunnel technique Pitman. London, 1952.

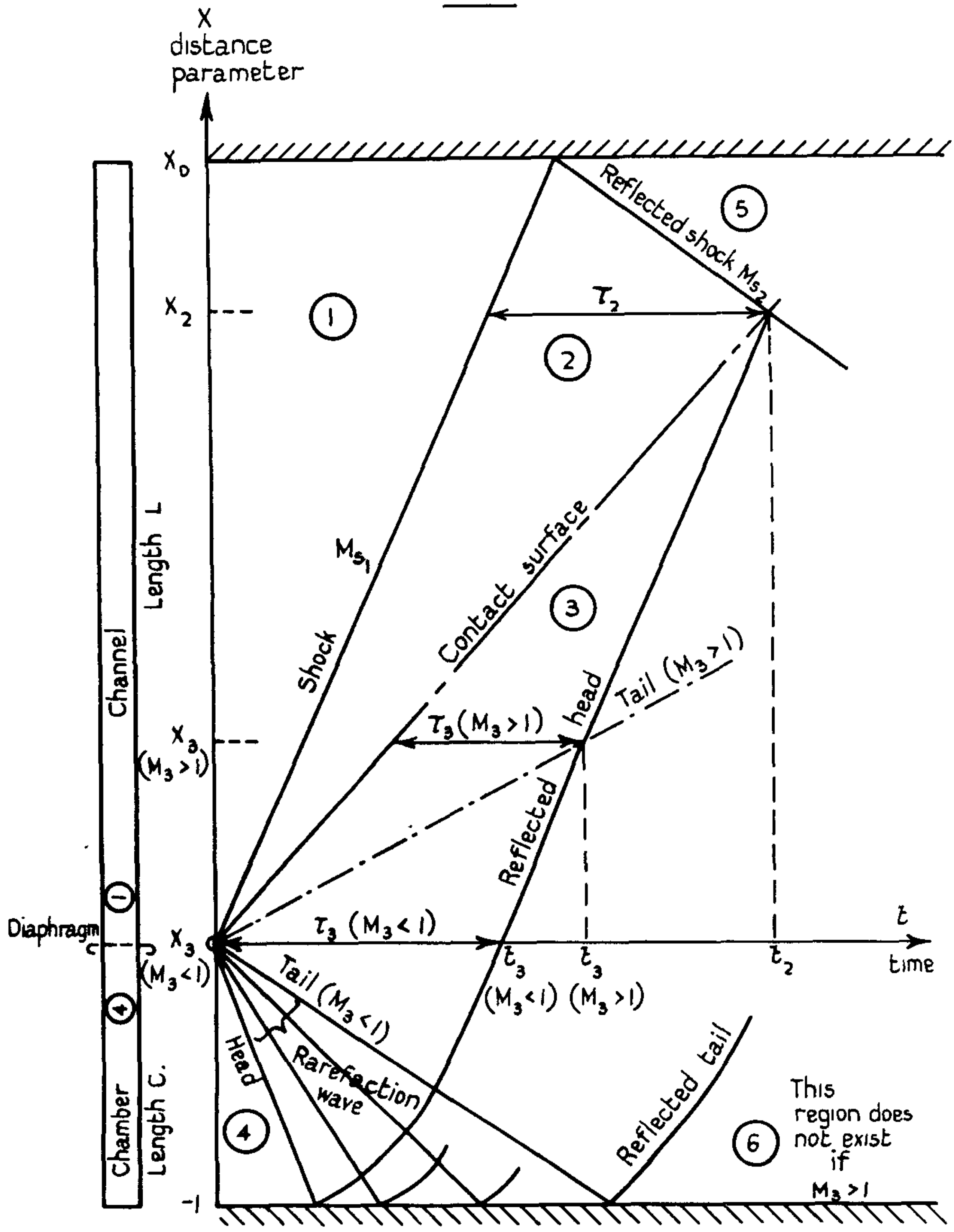
10/

REFERENCES (Continued)

No.	Author(s)	Title, etc.
10	A. H. Shapiro	The dynamics and thermodynamics of compressible fluid flow. Ronald Press. New York, 1953.
11	B. D. Henshall	On some aspects of the use of shock tubes in aerodynamic research. University of Bristol, Dept. of Aeronautical Engineering Report No.P.4. Communicated by Prof. A. R. Collar. A.R.C.17,407 - T.P.449 24th February, 1955. And Corrigendum - 13th July, 1955.
12	J. S. Thompson	A short summary of formulae and tables for calculations of compressible air flow. R.A.E. Technical Note No. Aero 1613 (March 1945). A.R.C.8635 - F.M.804 March 1945.
13	Ames Research Staff	Equations, tables and charts for compressible flow. N.A.C.A. Report 1135, 1953.
14	I. I. Glass, W. Martin and G. N. Patterson	A theoretical and experimental study of the shock tube. University of Toronto U.T.I.A. Rep. No.2. A.R.C.17,243 - T.P.441 17th December, 1954.
15	J. Lukasiewicz	Shock tube theory and applications. N.A.E. Canada, Report 15, 1952. A.R.C.15,653 - T.P.385 - F.M.1963 18th February, 1953.
16	B. D. Henshall	The use of multiple diaphragms in shock tubes. A.R.C.18,062 - F.M.2337 - T.P.469 3rd December, 1955.
17	J. Kestin and J. Wagstyl	On the use of shock tubes as high-speed wind tunnels. A.R.C.13,492 - T.P.319 6th November, 1950.
18	R. C. Tomlinson	A revised index of mathematical tables for compressible flow. R. & M.2691 December, 1949.

HD
LT

FIG 1.



Flow in a simple shock tube

C.P. No. 292
(18,162)
A.R.C Technical Report

Printed and published by
HER MAJESTY'S STATIONERY OFFICE
To be purchased from
York House, Kingsway, London W.C.2
423 Oxford Street, London W.1
P.O. Box 569, London S.E.1
13A Castle Street, Edinburgh 2
109 St. Mary Street, Cardiff
39 King Street, Manchester 2
Tower Lane, Bristol 1
2 Edmund Street, Birmingham 3
80 Chichester Street, Belfast
or through any bookseller

Printed in Great Britain

S.O. Code No. [illegible]-009 92

C.P. No. 292