R. & M. No. 3126

R. & M. No. 3126
(14,234)
A.R.C. Technical Report

MINISTRY OF AVIATION

AERONAUTICAL RESEARCH COUNCIL
REPORTS AND MEMORANDA

Notes on the Derivation of True Air Temperature from Aircraft Observations

By D. D. CLARK
OF THE METEOROLOGICAL OFFICE

LONDON: HER MAJESTY'S STATIONERY OFFICE
1960
PRICE 4*s*. 6*d*. NET

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1. *Review of Conventional Practice.* If we start with the simple relation connecting the temperature rise with the air speed

$$T_i - T_s = \frac{\lambda V^2}{2c_p}, \tag{1}$$

or its equivalent form

$$T_i - T_s = \frac{\alpha}{k^2}\left(\frac{V}{100}\right)^2, \tag{2}$$

then, given T_i and V, T_s can be found.

T_i is read off directly from the temperature indicator corrected for instrumental error and, for slow aircraft, V is derived from the equation

$$V = V_i \sqrt{\left(\frac{\rho_0}{\rho}\right)} \tag{3}$$

$$= V_i \sqrt{\left(\frac{S_0}{T_0}\right)} \sqrt{\left(\frac{T_s}{S}\right)}, \tag{4}$$

as described in the Meteorological Air Observer's Handbook, M.O. 470, p. 42 (1945). In this case V_i is taken to be identical with the air-speed-indicator reading corrected for instrument and position errors. It is not necessary, however, to extract V separately and T_s is obtained by combining equations (1) and (4) in the form

$$T_i - T_s = \frac{\lambda}{2c_p} \frac{V_i^2 S_0 T_s}{T_0 S} \tag{5}$$

or

$$T_s = \frac{T_i}{\left(1 + \frac{\lambda}{2c_p} \frac{V_i^2 S_0}{T_0 S}\right)}. \tag{6}$$

As speeds increase these simple relationships no longer hold and it is necessary to distinguish between V_i, sometimes called the 'equivalent air speed' and defined as V_i in equations (3) or (4), and V_r which is the reading on the air-speed indicator, corrected for instrumental error.

The energy equation under adiabatic conditions can be written

$$\frac{q}{S} = \left\{1 + \frac{\gamma - 1}{2}\left(\frac{V}{a}\right)^2\right\}^{\frac{\gamma}{\gamma-1}} - 1, \tag{7}$$

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* This is a revised version of C.P. 90, brought up to date for purpose of R. & M.

or using equation (3), where V_i now stands for the 'equivalent air speed',

$$\frac{q}{S} = \left\{1 + \frac{\gamma - 1}{2}\frac{S_0}{S}\left(\frac{V_i}{a_0}\right)^2\right\}^{\frac{\gamma}{\gamma-1}} - 1 . \tag{8}$$

Expanding the right-hand side of equation (8) and remembering that $a_0^2 = \gamma\, S_0/\rho_0$ we get

$$q = \frac{\rho_0 V_i^2}{2}\left\{1 + \frac{S_0}{4S}\left(\frac{V_i}{a_0}\right)^2 + \frac{2-\gamma}{24}\left(\frac{S_0}{S}\right)^2\left(\frac{V_i}{a_0}\right)^4 + \ldots\right\} . \tag{9}$$

Now, in the United Kingdom prior to 1950 air-speed indicators were calibrated according to the formula

$$q = \frac{\rho_0 V_r^2}{2}\left\{1 + \frac{1}{4}\left(\frac{V_r}{a_0}\right)^2\right\} . \tag{10}$$

Since 1950 (Bone (1958)), however, the full energy equation (7), referred to ground level, has been used to calibrate air-speed indicators, namely,

$$\frac{q}{S_0} = \left\{1 + \frac{\gamma - 1}{2}\left(\frac{V_r}{a_0}\right)^2\right\}^{\frac{\gamma}{\gamma-1}} - 1 . \tag{11}$$

In the absence of position error, when V_r would refer to the reading of the air-speed indicator in the free air stream, equations (9) and (10) or (9) and (11) together give the relationship between V_i and V_r.

Many sets of Tables are available giving the values of V_i corresponding to values of V_r, and the conversion from V_r to V_i is termed 'correcting for the compressibility error'.

If in equation (4), V_r were used as V_i, then the value of V in kt which would be obtained would be too large by an amount ΔV where, if all terms containing $(V_i/a_0)^5$ or smaller be neglected,

$$\Delta V = 0{\cdot}285\sqrt{\left(\frac{\rho_0}{\rho}\right)}\left(\frac{S_0}{S} - 1\right)\left(\frac{V_i}{100}\right)^3 \tag{12}$$

$$= 0{\cdot}285\,\frac{ST_0}{S_0T_s}\left(\frac{S_0}{S} - 1\right)\left(\frac{V}{100}\right)^3 . \tag{13}$$

In Table 1 are given some of the values of ΔV from equation (13) for three selected air speeds and three altitudes, T_s being assumed to have the values corresponding to an I.C.A.N. atmosphere. The Table also shows the errors in T_s which would arise from using V_r for V_i in equation (4), assuming $\lambda = 10^{-4} \times 2c_p/k^2$ (i.e., $\alpha = 1$).

TABLE 1

Pressure altitude (mb)	True air speed in knots					
	200		300		400	
	Error in air speed (kt)	Error in temperature (deg C)	Error in air speed (kt)	Error in temperature (deg C)	Error in air speed (kt)	Error in temperature (deg C)
500	1·28	0·05	4·3	0·26	10·2	0·83
300	2·0	0·08	6·7	0·37	16·0	1·28
150	2·6	0·10	8·6	0·48	20·5	1·61

When the position error has to be taken into account, then, assuming the position error to be in the form of a static-pressure correction ΔS, the value of V_r should first be adjusted by applying the correction ΔV_r corresponding to ΔS obtained, say, by differentiation of equation (10):

$$\Delta V_r = - \frac{\Delta S}{\rho_0 V_r' \left(1 + V_r'^2/2a_0^2\right)} . \tag{14}$$

In this expression accents indicate values referred to the neighbourhood of the static source, *i.e.*, before the position error has been applied. If desired, the Tables or graphs giving V_i in terms of V_r from equation (11) can be modified with the aid of equation (14) to give V_i directly from V_r', thus combining the two steps $V_r' \rightarrow V_r$, $V_r \rightarrow V_i$ into one.

Charnley and Fleming (1949), however, prefer to insert the correction for position error after the correction for compressibility, which means working with elaborate correction formulae but which, since the two steps are finally combined, comes to the same in the end.

In the method of approach to the true air temperature outlined above, the introduction of such terms as the 'indicated air speed' and the 'equivalent air speed' produces artificial errors which have thenceforth to be eliminated by manipulating awkward mathematical formulae. It is therefore more logical and much simpler not to employ the terms V_r and V_i but to use instead the pressure terms from which they are derived, namely q and S. In the method which will now be described this course has been adopted and a much neater analysis is obtained which leads to a more rapid derivation of the true air temperature.

2. *Preferred Method.* Re-writing equation (1)

$$T_i - T_s = \frac{\lambda V^2}{2c_p}$$

and putting $a^2 = \gamma(c_p - c_v)T_s$ we get

$$T_i - T_s = \frac{\lambda V^2(\gamma - 1)T_s}{2a^2} , \tag{15}$$

or

$$T_s = \frac{T_i}{1 + \lambda(\gamma - 1)m^2/2} . \tag{16}$$

It will be seen that equations (15) and (5) and (16) and (6) are equivalent forms. Now from equation (7), remembering that $m^2 = V^2/a^2 = V^2(\rho/\gamma P)$,

$$\frac{\gamma - 1}{2} m^2 = \left(1 + \frac{q}{S}\right)^{\frac{\gamma-1}{\gamma}} - 1 . \tag{17}$$

Equation (16) can now be written

$$T_s = \frac{T_i}{1 + \lambda \left\{ \left(1 + \frac{q}{S}\right)^{\frac{\gamma-1}{\gamma}} - 1 \right\}} . \tag{18}$$

Equation (18) gives a direct expression for T_s in terms of the known quantities q, S and T_i for a thermometer of known λ, and incorporates all the steps represented by equations (5) to (11).

The use of q in these calculations raises the question of whether it is worth having instruments calibrated in terms of q instead of V_r as at present. Meanwhile, however, q can be obtained readily by a straight conversion from V_r using equations (10) or (11) as the case may be.

In Table 2, F is given for a large selection of values of q/S. In Table 3 the values of q are given for readings of air-speed indicators calibrated according to formula (10) and in Table 4, according to formula (11).

The successive steps in both the conventional and preferred methods are compared below, it being assumed that all instrumental readings have been corrected for instrumental errors.

3. *Conventional Method Using* V_i.

(i) Apply the position error correction
(ii) Convert V_r to V_i by applying the compressibility correction
(iii) Using (5) or (6) obtain T_s by slide rule

or

(i) Apply the compressibility correction to V_r'
(ii) Apply the position error correction to the result of (i) to get V_i
(iii) As before.

As already mentioned, steps (i) and (ii) may be combined but, as this means the manipulation of three variables V_r, S and the position error to give V_i, the combination can only be rendered graphically.

4. *Preferred Method Using* q.

(i) Apply position error corrections to q' and S'
(ii) Form the function $F(q/S)$ from Tables
(iii) Use (18) and obtain T_s.

5. *Discussion.* In the first method, the application of the position error (if we do not wish to use the multitudinous graphs which result from combining steps (i) and (ii)) entails making some side calculations or using subsidiary graphs or Tables based on equation (14) or similar. Also, in the step to V_i, the pressure occurs as an additional parameter which, even if the applications of position error and compressibility error are separated, means taking account simultaneously of S and V_r, whereas, in the alternative method, the replacement of V_r by q, eliminating V_r from the argument, allows the ratio q/S to appear as an independent variable, thus simplifying the analysis.

Furthermore, step (iii) in the first method still contains the extra variable S, in addition to V_i, and is therefore longer than the corresponding step (ii) in the alternative method which contains only $F(q/S)$.

6. *Acknowledgements.* For Table 2 the author is indebted to Mathematical Services, Royal Aircraft Establishment, who very kindly did the computations. In the preparation of Tables 3 and 4 the author gratefully acknowledges the help of the staff of the Meteorological Research Flight, R.A.E.

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LIST OF SYMBOLS

T_s	True air temperature
T_i	Indicated temperature
S	Static air pressure in the absence of position error (the true air pressure)
P	Total air pressure or the pressure of the air if brought to rest relative to the aircraft
q	$P - S$ (The pressure rise)
V	True air speed
V_i	Indicated air speed if referred to slow aircraft but now called the 'equivalent air speed' if the compressibility of the air is significant
V_r	Reading of the air-speed indicator in the absence of position error
S_0	m.s.l. pressure (1013·2 mb I.C.A.N.)
T_0	m.s.l. temperature (288°A I.C.A.N.)
ρ_0	m.s.l. density ($1{\cdot}226 \times 10^{-3}$ gm/cm^3 I.C.A.N.)
ρ	Air density at the level considered
α	Air-speed correction factor, $T_i - T_s = \frac{\alpha}{k^2}\left(\frac{V}{100}\right)^2$, where k is the factor converting from knots to cm/sec
λ	Defined in the equation $T_i - T_s = \lambda \frac{V^2}{2c_p} \qquad 0 < \lambda < 1$
a	Speed of sound; $a_0 = 3{\cdot}40 \times 10^4$ cm/sec
m	Mach number $= V/a$
k	Conversion factor knots to cm/sec $= 51{\cdot}479$
γ	Ratio of specific heat at constant pressure to specific heat at constant volume for air $= 1{\cdot}402$
C_p	Specific heat of air at constant pressure

Accentuation of a symbol indicates that it has the value corresponding to the immediate neighbourhood of the static source, e.g., S' is the static pressure before the application of position-error correction. All units unless stated are given in cm gm sec.

REFERENCES

No.	*Author*	*Title, etc.*
1	W. J. Charnley and I. Fleming ..	Corrections applied to airspeed indicator and altimeter readings for position error and compressibility effects. R.A.E. Report Aero. 2299. A.R.C. 12,365. February, 1949.
2	A. G. Bone	Aircraft aerodynamic height and speed quantities, their characteristics and co-relation. R.A.E. Tech. Note IAP.1085. 1958.

APPENDIX I

The pressure rise which we have called q could be obtained either directly from the air-speed indicator or else from a second aneroid measuring the total pressure P. The proportional error in the first case (obtained by logarithmic differentiation of (18), assuming $\lambda = 1$ and $\Delta T_i = 0$ to simplify the formulae), is given by

$$\left(\frac{\Delta T_s}{T_s}\right)_q = \frac{\gamma - 1}{\gamma} \frac{q/S}{1 + (q/S)} \left(\frac{\Delta S}{S} - \frac{\Delta q}{q}\right), \tag{19}$$

i.e.,

$$\left|\left(\frac{\Delta T_s}{T_s}\right)_q\right|_{\max} = \frac{\gamma - 1}{\gamma} \frac{q/S}{1 + (q/S)} \left(\left|\frac{\Delta S}{S}\right| + \left|\frac{\Delta q}{q}\right|\right). \tag{20}$$

Likewise in the second case from equation (18) putting $1 + (q/S) = P/S$,

$$\left(\frac{\Delta T_s}{T_s}\right)_P = \frac{\gamma - 1}{\gamma} \left(\frac{\Delta S}{S} - \frac{\Delta P}{P}\right), \tag{21}$$

i.e.,

$$\left|\left(\frac{\Delta T_s}{T_s}\right)_P\right|_{\max} = \frac{\gamma - 1}{\gamma} \left(\left|\frac{\Delta S}{S}\right| + \left|\frac{\Delta P}{P}\right|\right). \tag{22}$$

If ΔS represents a position error then $\Delta S = -\Delta q$, $\Delta P = 0$, which makes equations (19) and (21) identical. If, however, ΔP is an instrumental error then $\left|\frac{\Delta S}{S}\right| = \left|\frac{\Delta P}{P}\right|$, whereas to the same order also $\left|\frac{\Delta q}{q}\right|$ is small, so that the ratio

$$\left|\left(\frac{\Delta T_s}{T_s}\right)_q\right|_{\max} \Big/ \left|\left(\frac{\Delta T_s}{T_s}\right)_P\right|_{\max} \approx \frac{\frac{1}{2}q/S}{1 + (q/S)} < 1 .$$

It follows that it is advantageous to measure q directly in preference to P.

Present types of aneroid altimeters, after correction for instrumental errors, are accurate to one per cent and if great care is taken and corrections applied also for changes with temperature, then one half per cent can be obtained. For our purpose we will take the figure one per cent as representing the accuracy of altimeters. Air-speed indicators are much more accurate and after application of corrections, give a true reading to ½ kt which is small compared to the altimeter error.

Now for any small variation in q/S of value $\Delta(q/S)$ the corresponding proportional variation in T, namely, $\Delta T_s/T_s$ is, from equation (18) by differentiation, assuming $\lambda = 1$, and omitting any variation in T_i for the moment,

$$\frac{\Delta T}{T} = -\frac{\gamma - 1}{\gamma} \frac{\Delta(q/S)}{1 + (q/S)}. \tag{23}$$

Also

$$\Delta\left(\frac{q}{S}\right) = \frac{q}{P}\left(\frac{\Delta q}{q} - \frac{\Delta S}{S}\right), \tag{24}$$

so that

$$\left|\Delta\left(\frac{q}{S}\right)\right|_{\max} = \frac{q}{S}\left(\left|\frac{\Delta q}{q}\right| + \left|\frac{\Delta S}{S}\right|\right). \tag{25}$$

If we take $\left|\frac{\Delta S}{S}\right| = 0{\cdot}01$ and neglect $\left|\frac{\Delta q}{q}\right|$ in comparison, then from equation (24)

$$\left|\Delta\left(\frac{q}{S}\right)\right|_{\max} \approx \frac{q}{S}(0{\cdot}01)\,,$$

and hence

$$\left|\frac{\Delta T}{T}\right|_{\max} \approx 0{\cdot}01\,\frac{\gamma - 1}{\gamma}\,\frac{q/S}{1 + (q/S)}$$

$$= 0{\cdot}003\,\frac{q/S}{1 + (q/S)}\,. \qquad (26)$$

The values of $|\Delta(q/S)|_{\max}$ and $|\Delta T/T|_{\max}$ for different values of q/S are given below:

q/S	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9
$\lvert\Delta(q/S)\rvert_{\max}$	0·001	0·002	0·003	0·004	0·005	0·006	0·007	0·008	0·009
$\lvert\Delta T/T\rvert_{\max} \times 10^3$	0·26	0·47	0·66	0·81	0·95	1·07	1·17	1·27	1·35

As would be expected, the accuracy falls off at the higher speeds and higher altitudes which correspond to larger values of q/S. At a m.s.l. temperature of 15 deg C (288 deg A) and $q/S = 0{\cdot}1$, $\Delta T = 0{\cdot}07$ deg C and at $-$ 53 deg C (220 deg A) and $q/S = 0{\cdot}8$, $\Delta T = 0{\cdot}28$ deg C.

The values for $|\Delta(q/S)|_{\max}$ in the second line suggest that in a Table for $F(q/S)$ it would be sufficient for entries of q/S to be made at intervals of 0·001, which would then provide values of T to within the limits of instrumental accuracy.

The limits of accuracy in the derived value of the true air temperature also depend, of course, on the accuracy in the reading of T_i. With a good aircraft thermometer using a null-reading type indicator the reading, provided T remains constant, can be made to 0·1 deg C, but, with pointer indicators or with recorders, the best accuracy that can be expected from existing equipment is ± 0·5 deg C. Adding these errors to the others arising from the pressure instruments gives, with null-reading-type indicators, for $q/S = 0{\cdot}1$ and $T = 15$ deg C, an accuracy to about ± 0·2 deg C, and at the other end of the scale for $q/S = 0{\cdot}8$ and $T = -$ 53 deg C, an accuracy to about ± 0·4 deg C, while with pointer indicators or recorders these figures would be larger by 0·5 deg C. In all cases it is assumed that λ is known and that no error arises from variations in λ.

APPENDIX II

It has been suggested that Mach number read from a Mach-meter could be used to reduce the indicated temperature to true temperature, using equation (16).

The Mach-meter is accurate to M, 0·005, whence from equation (16) putting $\lambda = 1$,

$$\frac{\delta T_s}{T_s} = \frac{(\gamma - 1)m\,\delta m}{1 + \frac{\gamma - 1}{2}m^2}$$

$$= \frac{0{\cdot}002m}{1 + 0{\cdot}2m^2}\,. \qquad (27)$$

Compare this with equation (26), namely,

$$\frac{\Delta T_s}{T_s} = \frac{0{\cdot}003(q/S)}{1 + (q/S)}\,,$$

which gives the equivalent error in T_s obtained from q and S readings.

The values of $\delta T_s/T_s$ obtained from both (26) and (27) are given below against Mach number:

Mach number	$\frac{q}{S}$	$\left(\frac{\delta T}{T}\right)_m \times 10^4$	$\left(\frac{\delta T}{T}\right)_{q/s} \times 10^4$
0·1	0·008	2·00	0·24
0·2	0·029	3·97	0·84
0·3	0·066	5·89	1·86
0·4	0·118	7·75	3·17
0·5	0·187	9·52	4·73
0·6	0·276	11·19	6·49
0·7	0·387	12·75	8·37
0·8	0·524	14·18	10·31
0·9	0·690	15·23	12·25
1	0·891	16·67	14·13

It is seen from the above Table that, whereas there is much advantage in using q and S at low Mach numbers, the use of the Mach number itself at the higher Mach numbers is almost as good. The slight advantage shown in the Table in favour of q and S would be easily lost with a falling off in accuracy of the air-speed indicator or if the accuracy of Mach-meters could be improved.

TABLE 2

Formula $F = (1 + q/S)^{\frac{\gamma-1}{\gamma}} - 1$

Explanation: Each value of F is valid for the opposite value of q/S and all lower values until the next lower entry in the Table, *e.g.*,

$q/S = 0{\cdot}118$ $F = 0{\cdot}032$
$q/S = 0{\cdot}115$ $F = 0{\cdot}032$
$q/S = 0{\cdot}114$ $F = 0{\cdot}031$

q/S	F	q/S	F	q/S	F	q/S	F
0·001	0·000	0·207	0·055	0·441	0·110	0·705	0·165
0·005	0·001	0·211	0·056	0·445	0·111	0·711	0·166
0·008	0·002	0·215	0·057	0·450	0·112	0·716	0·167
0·012	0·003	0·219	0·058	0·454	0·113	0·721	0·168
0·015	0·004	0·223	0·059	0·459	0·114	0·726	0·169
0·019	0·005	0·227	0·060	0·464	0·115	0·731	0·170
0·022	0·006	0·231	0·061	0·468	0·116	0·736	0·171
0·026	0·007	0·235	0·062	0·473	0·117	0·741	0·172
0·029	0·008	0·239	0·063	0·477	0·118	0·747	0·173
0·033	0·009	0·243	0·064	0·482	0·119	0·752	0·174
0·037	0·010	0·247	0·065	0·487	0·120	0·757	0·175
0·040	0·011	0·251	0·066	0·491	0·121	0·762	0·176
0·044	0·012	0·255	0·067	0·496	0·122	0·768	0·177
0·047	0·013	0·259	0·068	0·500	0·123	0·773	0·178
0·051	0·014	0·264	0·069	0·505	0·124	0·778	0·179
0·055	0·015	0·268	0·070	0·510	0·125	0·783	0·180
0·058	0·016	0·272	0·071	0·515	0·126	0·789	0·181
0·062	0·017	0·276	0·072	0·519	0·127	0·794	0·182
0·066	0·018	0·280	0·073	0·524	0·128	0·799	0·183
0·069	0·019	0·284	0·074	0·529	0·129	0·804	0·184
0·073	0·020	0·288	0·075	0·533	0·130	0·810	0·185
0·077	0·021	0·293	0·076	0·538	0·131	0·815	0·186
0·080	0·022	0·297	0·077	0·543	0·132	0·820	0·187
0·084	0·023	0·301	0·078	0·548	0·133	0·826	0·188
0·088	0·024	0·305	0·079	0·552	0·134	0·831	0·189
0·091	0·025	0·309	0·080	0·557	0·135	0·837	0·190
0·095	0·026	0·314	0·081	0·562	0·136	0·842	0·191
0·099	0·027	0·318	0·082	0·567	0·137	0·847	0·192
0·102	0·028	0·322	0·083	0·572	0·138	0·853	0·193
0·106	0·029	0·326	0·084	0·576	0·139	0·858	0·194
0·110	0·030	0·331	0·085	0·581	0·140	0·864	0·195
0·114	0·031	0·335	0·086	0·586	0·141	0·869	0·196
0·118	0·032	0·339	0·087	0·591	0·142	0·874	0·197
0·121	0·033	0·344	0·088	0·596	0·143	0·880	0·198
0·125	0·034	0·348	0·089	0·601	0·144	0·885	0·199
0·129	0·035	0·352	0·090	0·606	0·145	0·891	0·200
0·133	0·036	0·357	0·091	0·610	0·146	0·896	0·201
0·136	0·037	0·361	0·092	0·615	0·147	0·902	0·202
0·140	0·038	0·365	0·093	0·620	0·148	0·907	0·203
0·144	0·039	0·370	0·094	0·625	0·149	0·913	0·204
0·148	0·040	0·374	0·095	0·630	0·150	0·919	0·205
0·152	0·041	0·378	0·096	0·635	0·151	0·924	0·206
0·156	0·042	0·383	0·097	0·640	0·152	0·930	0·207
0·160	0·043	0·387	0·098	0·645	0·153	0·935	0·208
0·163	0·044	0·392	0·099	0·650	0·154	0·941	0·209
0·167	0·045	0·396	0·100	0·655	0·155	0·946	0·210
0·171	0·046	0·400	0·101	0·660	0·156	0·952	0·211
0·175	0·047	0·405	0·102	0·665	0·157	0·958	0·212
0·179	0·048	0·409	0·103	0·670	0·158	0·963	0·213
0·183	0·049	0·414	0·104	0·675	0·159	0·969	0·214
0·187	0·050	0·418	0·105	0·680	0·160	0·975	0·215
0·191	0·051	0·423	0·106	0·685	0·161	0·980	0·216
0·195	0·052	0·427	0·107	0·690	0·162	0·986	0·217
0·199	0·053	0·432	0·108	0·695	0·163	0·992	0·218
0·203	0·054	0·436	0·109	0·700	0·164	0·997	0·219

TABLE 3

$$\text{Formula } q = \frac{\rho_0 V_r^2}{2}\left[1 + \frac{1}{4}\left(\frac{V_r}{a_0}\right)^2\right]$$

q (*mb*)

V_r(kt)	0	1	2	3	4	5	6	7	8	9
100	16·34	16·67	17·00	17·34	17·68	18·02	18·37	18·72	19·07	19·43
110	19·79	20·15	20·52	20·89	21·26	21·64	22·02	22·41	22·80	23·19
120	23·58	23·98	24·38	24·78	25·19	25·60	26·02	26·44	26·86	27·29
130	27·72	28·15	28·59	29·03	29·47	29·91	30·36	30·81	31·27	31·73
140	32·20	32·67	33·14	33·61	34·09	34·57	35·05	35·54	36·03	36·52
150	37·02	37·52	38·03	38·54	39·05	39·57	40·09	40·61	41·13	41·66
160	42·19	42·73	43·27	43·81	44·46	45·01	45·57	46·13	46·69	47·15
170	47·72	48·29	48·86	49·44	50·03	50·62	51·21	51·81	52·41	53·01
180	55·61	54·22	54·83	55·45	56·07	56·69	57·31	57·94	58·57	59·21
190	59·85	60·49	61·14	61·79	62·45	63·11	63·77	64·44	65·11	65·79
200	66·47	67·15	67·83	68·51	69·20	69·89	70·59	71·29	72·00	72·72
210	73·44	74·16	74·89	75·62	76·35	77·08	77·82	78·56	79·30	80·05
220	80·80	81·56	82·32	83·08	83·85	84·62	85·39	86·17	86·95	87·74
230	88·53	89·32	90·12	90·92	91·73	92·54	93·35	94·17	94·99	95·82
240	96·65	97·48	98·32	99·16	100·01	100·86	101·71	102·57	103·43	104·29
250	105·16	106·03	106·91	107·79	108·68	109·57	110·46	111·35	112·25	113·15
260	114·06	114·97	115·88	116·80	117·72	118·65	119·58	120·52	121·46	122·41
270	123·36	124·31	125·27	126·23	127·20	128·17	129·14	130·12	131·10	132·08
280	133·07	134·06	135·06	136·06	137·07	138·08	139·09	140·11	141·13	142·16
290	143·19	144·22	145·26	146·30	147·35	148·40	149·46	150·52	151·59	152·66
300	153·73	154·80	155·88	156·96	158·05	159·14	160·24	161·34	162·45	163·57
310	164·69	165·81	166·94	168·07	169·20	170·34	171·48	172·62	173·77	174·92
320	176·08	177·24	178·41	179·58	180·76	181·94	183·13	184·32	185·52	186·72
330	187·92	189·13	190·34	191·55	192·77	193·99	195·22	196·46	197·70	198·95
340	200·20	201·45	202·71	203·97	205·23	206·50	207·77	209·05	210·34	211·63
350	212·93	214·23	215·53	216·84	218·15	219·47	220·79	222·12	223·45	224·79
360	226·13	227·47	228·82	230·17	231·53	232·89	234·26	235·64	237·02	238·41
370	239·80	241·19	242·59	243·99	245·40	246·81	248·23	249·65	251·08	252·51
380	253·94	255·38	256·82	258·27	259·72	261·18	262·65	264·12	265·60	267·08
390	268·57	270·06	271·55	273·05	274·55	276·06	277·57	279·09	280·62	282·15
400	283·69	285·23	286·78	288·33	289·89	291·45	293·02	294·59	296·16	297·74
410	299·32	300·91	302·50	304·10	305·71	307·32	308·94	310·56	312·19	313·82
420	315·46	317·10	318·75	320·40	322·06	323·73	325·40	327·07	328·75	330·43
430	332·12	333·81	335·51	337·22	338·93	340·65	342·37	344·10	345·83	347·57
440	349·31	351·06	352·81	354·57	356·33	358·10	359·87	361·65	363·44	365·24
450	367·04	368·85	370·66	372·48	374·30	376·12	377·95	379·78	381·62	383·47
460	385·32	387·18	389·04	390·91	392·79	394·67	396·56	398·45	400·35	402·26
470	404·17	406·09	408·01	409·94	411·87	413·81	415·75	417·70	419·65	421·61
480	423·58	425·56	427·54	429·53	431·52	433·52	435·52	437·53	439·54	441·56
490	443·58	445·61	447·65	449·69	451·74	453·80	455·86	457·93	460·00	462·08
500	464·16	466·25	468·35	470·45	472·56	474·68	476·80	478·93	481·07	483·21
510	485·36	487·52	489·68	491·85	494·02	496·20	498·38	500·57	502·76	504·96
520	507·17	509·39	511·61	513·84	516·07	518·31	520·55	522·80	525·06	527·33
530	529·60	531·88	534·16	536·45	538·75	541·05	543·36	545·68	548·00	550·33
540	552·67	555·01	557·36	559·71	562·07	564·44	566·82	569·20	571·59	573·99
550	576·39	578·80	581·22	583·64	586·07	588·50	590·94	593·39	595·84	598·30
560	600·77	603·25	605·73	608·22	610·72	613·22	615·73	618·25	620·77	623·30
570	625·83	628·37	630·92	633·48	636·04	638·61	641·19	643·77	646·36	648·96
580	651·57	654·19	656·81	659·44	662·08	664·72	667·37	670·02	672·68	675·35
590	678·02	680·70	683·39	686·09	688·80	691·51	694·23	696·96	699·69	702·43
600	705·18									

(79479) Wt. 54/8210 K.6 9/60 Hw.

TABLE 4

Formula $q/S_0 = \left[1 + \frac{\gamma - 1}{2}\left(\frac{V_r}{a_0}\right)^2\right]^{\frac{\gamma}{\gamma-1}} - 1$

For values of V_r less than 200 kt the Table is the same as Table 3

q(mb)

V_r(kt)	0	1	2	3	4	5	6	7	8	9	V_r(kt)	0	1	2	3	4	5	6	7	8	9
200	66·47	67·15	67·84	68·52	69·21	69·90	70·61	71·32	72·02	72·73	480	426·09	428·11	430·13	432·14	434·16	436·18	438·24	440·30	442·35	444·41
210	73·44	74·17	74·90	75·63	76·36	77·09	77·84	78·58	79·33	80·07	490	446·47	448·55	450·62	452·70	454·77	456·85	458·97	461·08	463·20	465·31
220	80·82	81·58	82·33	83·09	83·84	84·60	85·39	86·17	86·96	87·74	500	467·43	469·57	471·70	473·84	475·97	478·11	480·34	482·58	484·81	487·05
230	88·53	89·32	90·11	90·91	91·70	92·49	93·32	94·16	94·99	95·82	510	489·28	491·40	493·51	495·63	497·74	499·86	502·15	504·45	506·74	509·04
240	96·66	97·51	98·36	99·21	100·06	100·91	101·75	102·60	103·44	104·29	520	511·33	513·62	515·91	518·21	520·50	522·79	525·10	527·41	529·73	532·04
250	105·13	106·01	106·89	107·78	108·66	109·54	110·46	111·38	112·30	113·22	530	534·35	536·64	538·93	541·23	543·52	545·81	548·20	550·59	552·99	555·38
260	114·14	115·06	115·98	116·90	117·82	118·74	119·68	120·62	121·57	122·51	540	557·77	560·16	562·55	564·94	567·33	569·72	572·21	574·70	577·18	579·67
270	123·45	124·41	125·37	126·33	127·29	128·25	129·23	130·21	131·19	132·17	550	582·16	584·65	587·14	589·62	592·11	594·60	597·09	599·58	602·07	604·56
280	133·15	134·15	135·15	136·14	137·14	138·14	139·16	140·18	141·20	142·22	560	607·05	609·73	612·42	615·10	617·79	620·47	622·96	625·45	627·93	630·42
290	143·24	144·30	145·36	146·41	147·47	148·53	149·59	150·65	151·70	152·76	570	632·91	635·59	638·28	640·96	643·65	646·33	649·02	651·70	654·39	657·07
300	153·82	154·92	156·02	157·11	158·21	159·31	160·43	161·54	162·66	163·77	580	659·76	662·44	665·13	667·81	670·50	673·18	675·96	678·74	681·53	684·31
310	164·89	166·01	167·13	168·24	169·36	170·48	171·64	172·79	173·95	175·10	590	687·09	689·85	692·62	695·38	698·15	700·91	703·79	706·67	709·55	712·43
320	176·26	177·43	178·61	179·78	180·96	182·13	183·35	184·56	185·78	186·99	600	715·31	718·17	721·03	723·89	726·75	729·61	732·49	735·37	738·26	741·14
330	188·21	189·42	190·64	191·85	193·07	194·28	195·52	196·75	197·99	199·22	610	744·02	747·00	749·98	752·95	755·93	758·91	761·87	764·83	767·78	770·74
340	200·46	201·73	203·00	204·28	205·55	206·82	208·11	209·41	210·70	212·00	620	773·70	776·76	779·81	782·87	785·92	788·98	792·06	795·14	798·21	801·29
350	213·29	214·60	215·92	217·23	218·54	219·85	221·19	222·52	223·86	225·19	630	804·37	807·52	810·68	813·83	816·99	820·14	823·29	826·45	829·60	832·76
360	226·52	227·89	229·26	230·63	232·00	233·37	234·74	236·11	237·49	238·86	640	835·91	839·16	842·42	845·67	848·93	852·18	855·45	858·72	862·00	865·27
370	240·23	241·66	243·09	244·52	245·95	247·38	248·81	250·24	251·68	253·11	650	868·54	871·79	875·04	878·30	881·55	884·80	888·15	891·50	894·86	898·21
380	254·54	256·01	257·48	258·94	260·41	261·88	263·35	264·82	266·29	267·76	660	901·56	905·11	908·65	912·20	915·74	919·29	922·76	926·23	929·69	933·16
390	269·23	270·74	272·25	273·76	275·27	276·78	278·33	279·88	281·42	282·97	670	936·63	940·16	943·69	947·21	950·74	954·27	957·84	961·40	964·97	968·53
400	284·52	286·07	287·62	289·16	290·71	292·26	293·87	295·47	297·08	298·68	680	972·10	975·67	979·23	982·80	986·36	989·93	993·50	997·06	1000·63	1004·19
410	300·29	301·90	303·50	305·12	306·71	308·32	309·97	311·61	313·26	314·90	690	1007·76	1011·44	1015·13	1018·81	1022·50	1026·18	1029·88	1033·59	1037·29	1041·00
420	316·55	318·22	319·88	321·55	323·21	324·88	326·59	328·29	330·00	331·70	700	1044·70	1048·52	1052·34	1056·16	1059·98	1063·80	1067·58	1071·36	1075·15	1078·93
430	333·41	335·13	336·86	338·58	340·31	342·03	343·77	345·52	347·26	349·00	710	1082·71	1086·55	1090·39	1094·23	1098·07	1101·91	1105·81	1109·71	1113·61	1117·51
440	350·75	352·53	354·31	356·10	357·88	359·66	361·48	363·30	365·13	366·95	720	1121·41	1125·45	1129·48	1133·52	1137·55	1141·59	1145·31	1149·04	1152·76	1156·49
450	368·77	370·61	372·45	374·30	376·14	377·98	379·84	381·70	383·57	385·43	730	1160·21	1164·23	1168·24	1172·26	1176·27	1180·29	1184·44	1188·60	1192·75	1196·91
460	387·29	389·19	391·09	393·00	394·90	396·80	398·72	400·64	402·56	404·48	740	1201·06	1205·10	1209·14	1213·17	1217·21	1221·25	1225·31	1229·36	1233·42	1237·47
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