NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
March 1943 as
Restricted Bulletin

A SIMPLIFIED CHART FOR DETERMINING MACH NUMBER AND TRUE AIRSPEED FROM AIRSPEED-INDICATOR READINGS

By Donald D. Baals and Virgil S. Ritchie

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NACA

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESTRICTED BULLETIN

A SIMPLIFIED CHART FOR DETERMINING MACH NUMBER AND TRUE AIRSPEED FROM AIRSPEED-INDICATOR READINGS

By Donald D. Baals and Virgil S. Ritchie

SUMMARY

The determination of flight Mach number from measurements of indicated airspeed and pressure altitude is shown to be relatively simple and leads to direct and accurate computation of true airspeed. A simplified chart is presented for determining flight Mach number and true airspeed for a range of values of indicated airspeed, pressure altitude, and air temperature. A table of standard atmospheric values is included.

INTRODUCTION

The pitot-static type of airspeed indicator in current use does not measure airspeed directly, but measures a pressure difference between a total- and a static-pressure tube. The instrument calibration expresses this differential pressure in terms of airspeed for sea-level standard conditions. In order to determine true airspeed for conditions other than sea-level standard, corrections must be applied to the indicated-airspeed readings. Installation and instrument errors are assumed to be included in the airspeed-indicator calibration.

In order to determine true airspeed for low-speed flight conditions at altitude, the usual density-ratio correction for incompressible flow is sufficient; for high-speed flight at altitude, however, the incompressible-flow relations do not apply and an added factor must be considered. At high speeds, the ratio of the differential pressure between a total- and a static-pressure tube to the dynamic pressure is greater than unity and is a function of the flight Mach number. Because the speed of sound varies with altitude, the flight Mach number for a given true airspeed will correspondingly vary and a correction will be required. Neglect of this correction will produce errors in the determination of true airspeed of the order of 5 percent for high-speed flight at altitude.

The determination of the compressibility correction is difficult and its physical significance is obscure. An analysis by simple compressible-flow relations, as pointed out in reference 1, provides a more direct computation of true airspeed through the evaluation of flight Mach number. A simple chart has been developed for the direct determination of flight Mach number and true airspeed for standard atmospheric conditions. Provisions for obtaining true airspeed for conditions other than standard have been included in the chart.

EQUATIONS FOR DETERMINING FLIGHT MACH NUMBER AND TRUE AIRSPEED

By simple compressible-flow relations, the pressure difference between a total- and a static-pressure tube can be shown to be a function of only two variables, flight Mach number and static pressure; that is,

$$H - p = p\left[\left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{\gamma}{\gamma-1}} - 1\right] \qquad (1)$$

where

H total pressure, pounds per square foot

p static pressure, pounds per square foot

M flight Mach number

γ ratio of specific heats (for air, 1.40)

For values of $H - p$ and p, which are functions of indicated airspeed and pressure altitude, respectively, the flight Mach number can thus be determined explicitly.

The pressure difference $H - p$ of equation (1) may also be expressed in the form

$$H - p = \frac{1}{2}\rho V^2\left(\frac{H-p}{q}\right)\left(\frac{22}{15}\right)^2$$

where

ρ air density, slugs per cubic foot

V true airspeed, miles per hour

$\left(\frac{H-p}{q}\right)$ compressibility factor $\left(1 + \frac{M^2}{4} + \frac{M^4}{40}\right)$

q dynamic pressure $\left(\frac{1}{2}\rho V^2\right)$

and 22/15 is the factor for converting miles per hour to feet per second. Inasmuch as the indicated airspeed V_i depends on only the value of the pressure difference $H - p$, the relation between V_i and $H - p$ may be determined from the airspeed-indicator calibration. The usual calibration, in which the airspeed indicator is indexed to read true airspeed for standard sea-level conditions, is assumed. The static pressure p in equation (1) may be determined from reference 2 for values of the pressure altitude.

By definition, the true airspeed is equal to the flight Mach number times the speed of sound. Because for standard conditions the speed of sound is defined for the various altitudes, the true airspeed is determined for any value of Mach number and standard altitude. For conditions other than standard, the value of the speed of sound a in miles per hour is given by the relation

$$a = \frac{15}{22}\sqrt{\frac{\gamma p}{\rho}} = 33.425\sqrt{T}$$

where T is the air temperature in degrees Fahrenheit absolute.

Figure 1 gives the variation of flight Mach number with indicated airspeed for various values of pressure altitude. Lines of true airspeed for standard atmospheric conditions have been superimposed on the basic plot of M against V_i. Provisions are included for determining true airspeed for conditions other than standard. Additional copies of figure 1 may be obtained upon request from the National Advisory Committee for Aeronautics.

Table I gives the values of the standard atmosphere derived from reference 2 for general use in altitude computations.

USE OF AIRSPEED-MACH NUMBER CHART

An example will serve to illustrate the use of the airspeed-Mach number chart (fig. 1) in the determination of flight Mach number and true airspeed. The following conditions will be assumed:

Indicated airspeed, V_i, miles per hour.........	360
Pressure altitude, h_p, feet.....................	25,000

Flight Mach number is determined by following the V_i value (360 mph) vertically upward to the h_p curve for 25,000 feet and reading this point of intersection horizontally to the Mach number scale at the left, where a value of 0.745 is indicated. The determination of flight Mach number by this method is independent of air temperature.

True airspeed for standard conditions (−30.15° F at 25,000 ft) is obtained by reading from the intersection of the given V_i with the h_p curve diagonally downward to the V_{std} scale where a value of 516 miles per hour is obtained. (See (a) on fig. 1.)

True airspeed for the assumed values of indicated airspeed and pressure altitude, but for a nonstandard temperature – of 10° F, for example – is obtained by reading from the intersection of the given V_i with the h_p curve horizontally to the 0, or sea-level, pressure-altitude curve. From this intersection, the reading is taken vertically downward to the 10° F temperature line and then horizontally to the V scale where a true-airspeed value of 540 miles per hour is obtained. (See (b) on fig. 1.)

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., March 2, 1943.

REFERENCES

1. Kotcher, Ezra: The Compressibility Factor in Converting Indicated to True Air Speed. A.C.T.R., ser. no. 4515, Matériel Div., Army Air Corps, 1940.

2. Diehl, Walter S.: Standard Atmosphere - Tables and Data. Rep. No. 218, NACA, 1925.

TABLE I

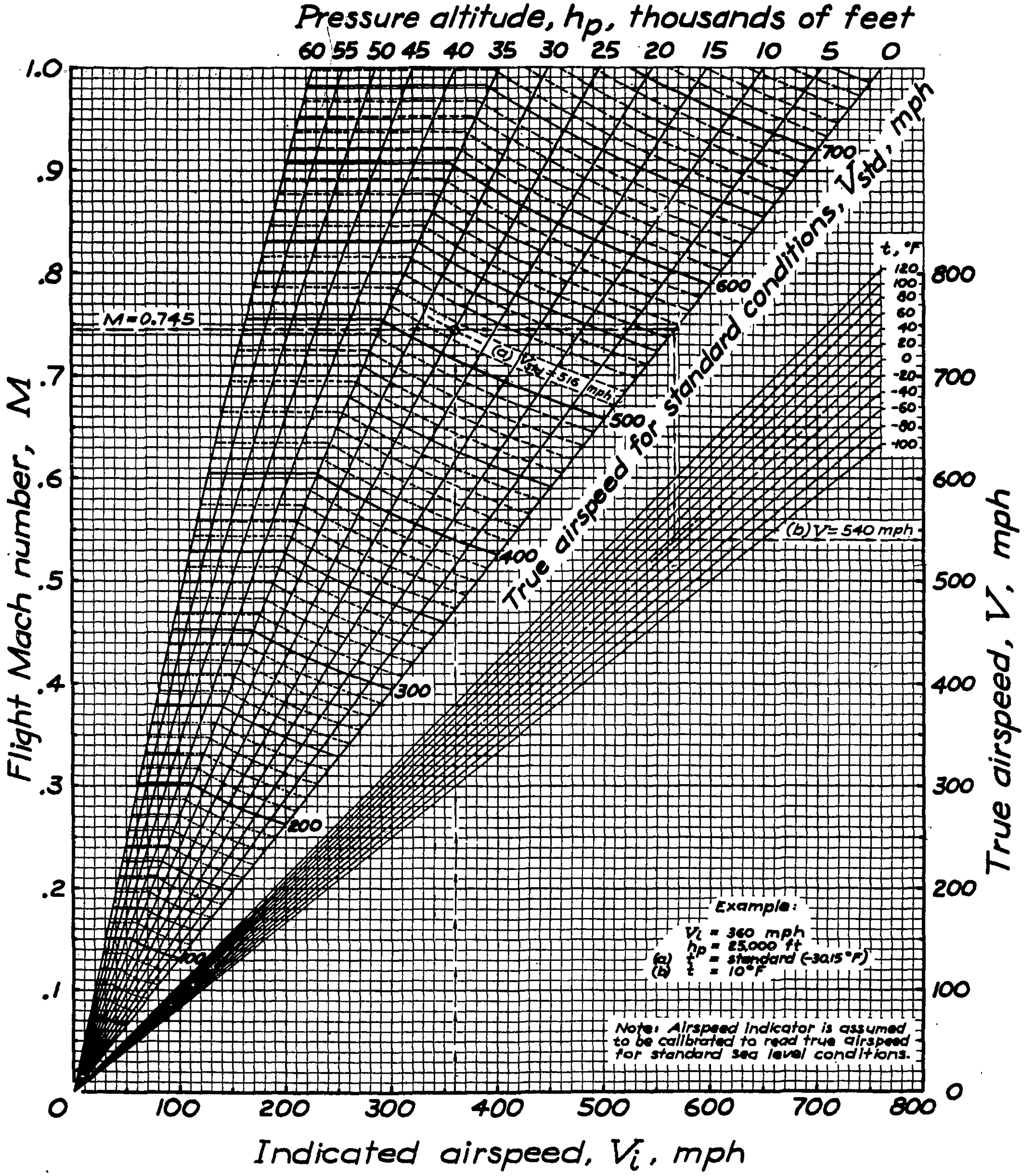
STANDARD ATMOSPHERIC CONDITIONS

Altitude h (ft)	Pressure, p (lb/sq ft)	Pressure, p (in. Hg)	p/p_{SL} (1)	Temperature t (°F)	Temperature T (°F abs.)	$\sqrt{T}$	T/T_{SL} (1)	Speed of sound a (mph)	Speed of sound a (fps)	Density ρ (slugs/cu ft)	Density ratio, σ, ρ/ρ_{SL} (1)	$\sqrt{1/\sigma}$
-2,000	2273.9	32.15	1.0745	66.13	525.53	22.924	1.0138	766.2	1123.8	0.002520	1.0599	0.9713
-1,000	2193.9	31.02	1.0367	62.57	521.96	22.846	1.0069	763.6	1120.0	.002448	1.0296	.9855
0	2116.2	29.92	1.0000	59.00	518.40	22.768	1.0000	761.0	1116.2	.002378	1.0000	1.0000
1,000	2041.2	28.86	.9644	55.43	514.83	22.690	.9931	758.4	1112.3	.002309	.9710	1.0148
2,000	1967.6	27.82	.9298	51.87	511.27	22.611	.9862	755.8	1108.5	.002242	.9428	1.0299
3,000	1896.2	26.81	.8962	48.30	507.70	22.532	.9794	753.1	1104.6	.002176	.9151	1.0454
4,000	1827.6	25.84	.8636	44.74	504.14	22.453	.9725	750.5	1100.7	.002112	.8881	1.0611
5,000	1760.4	24.89	.8320	41.17	500.57	22.373	.9656	747.8	1096.8	.002049	.8616	1.0773
6,000	1696.0	23.98	.8013	37.60	497.00	22.293	.9587	745.1	1092.9	.001988	.8358	1.0938
7,000	1633.1	23.09	.7716	34.04	493.44	22.214	.9518	742.5	1089.0	.001928	.8106	1.1107
8,000	1571.5	22.22	.7427	30.47	489.87	22.133	.9450	739.8	1085.0	.001869	.7859	1.1280
9,000	1512.1	21.38	.7147	26.90	486.30	22.052	.9381	737.1	1081.1	.001812	.7619	1.1456
10,000	1455.6	20.58	.6876	23.34	482.74	21.971	.9312	734.4	1077.1	.001756	.7384	1.1637
11,000	1399.7	19.79	.6614	19.77	479.17	21.890	.9243	731.7	1073.1	.001702	.7154	1.1823
12,000	1345.9	19.03	.6359	16.21	475.61	21.808	.9175	728.9	1069.1	.001648	.6931	1.2012
13,000	1293.6	18.29	.6112	12.64	472.04	21.726	.9106	726.2	1065.1	.001596	.6712	1.2206
14,000	1242.7	17.57	.5873	9.07	468.47	21.644	.9037	723.5	1061.1	.001545	.6499	1.2404
15,000	1193.9	16.88	.5642	5.51	464.91	21.562	.8968	720.7	1057.0	.001496	.6291	1.2608
16,000	1146.5	16.21	.5418	1.94	461.34	21.479	.8899	717.9	1053.0	.001448	.6088	1.2816
17,000	1100.5	15.56	.5202	-1.63	457.78	21.396	.8831	715.2	1048.9	.001401	.5891	1.3029
18,000	1056.7	14.94	.4992	-5.19	454.21	21.312	.8762	712.4	1044.8	.001355	.5698	1.3248
19,000	1013.5	14.33	.4790	-8.76	450.64	21.228	.8693	709.6	1040.7	.001311	.5509	1.3473
20,000	972.5	13.75	.4594	-12.32	447.08	21.144	.8624	706.7	1036.6	.001267	.5327	1.3701
21,000	932.2	13.18	.4405	-15.89	444.51	21.083	.8555	704.7	1033.6	.001225	.5148	1.3937
22,000	893.3	12.63	.4222	-19.46	439.94	20.975	.8487	701.1	1028.3	.001183	.4974	1.4179
23,000	855.8	12.10	.4045	-23.02	436.38	20.890	.8418	698.3	1024.1	.001143	.4805	1.4426
24,000	819.7	11.59	.3874	-26.59	432.81	20.804	.8349	695.4	1019.9	.001103	.4640	1.4681

25,000	785.1	11.10	.3709	-30.15	429.25	20.718	.8280	692.5	1015.7	.001065	.4480	1.4940
26,000	751.1	10.62	.3550	-33.72	425.68	20.632	.8211	689.6	1011.5	.001028	.4323	1.5209
27,000	718.6	10.16	.3397	-37.29	422.11	20.545	.8143	686.7	1007.2	.000992	.4171	1.5484
28,000	687.5	9.720	.3248	-40.85	418.55	20.458	.8074	683.8	1002.9	.000957	.4023	1.5766
29,000	657.3	9.293	.3106	-44.42	414.98	20.371	.8005	680.9	998.7	.000922	.3879	1.6056
30,000	628.1	8.880	.2968	-47.99	411.42	20.283	.7936	678.0	994.3	.000889	.3740	1.6352
31,000	600.0	8.483	.2834	-51.55	407.85	20.195	.7867	675.0	990.0	.000857	.3603	1.6660
32,000	573.0	8.101	.2707	-55.12	404.28	20.107	.7799	672.1	985.7	.000826	.3472	1.6971
33,000	546.9	7.732	.2583	-58.68	400.72	20.018	.7730	669.1	981.4	.000795	.3343	1.7295
34,000	521.8	7.377	.2465	-62.25	397.15	19.929	.7661	666.1	977.0	.000765	.3218	1.7628
35,000	497.6	7.036	.2352	-65.82	393.58	19.839	.7592	663.1	972.6	.000736	.3098	1.7966
35,332	489.8	6.925	.2314	-67.00	392.40	19.809	.7569	662.1	971.1	.000727	.3058	1.8083
36,000	474.4	6.708	.2242	-67.00	392.40	19.809	.7569	662.1	971.1	.000704	.2962	1.8374
37,000	452.3	6.395	.2137	-67.00	392.40	19.809	.7569	662.1	971.1	.000671	.2824	1.8818
38,000	431.2	6.096	.2037	-67.00	392.40	19.809	.7569	662.1	971.1	.000640	.2692	1.9274
39,000	411.1	5.812	.1943	-67.00	392.40	19.809	.7569	662.1	971.1	.000610	.2566	1.9741
40,000	391.9	5.541	.1852	-67.00	392.40	19.809	.7569	662.1	971.1	.000582	.2447	2.0215
41,000	373.6	5.283	.1765	-67.00	392.40	19.809	.7569	662.1	971.1	.000554	.2332	2.0708
42,000	356.2	5.036	.1683	-67.00	392.40	19.809	.7569	662.1	971.1	.000529	.2224	2.1205
43,000	339.6	4.802	.1605	-67.00	392.40	19.809	.7569	662.1	971.1	.000504	.2120	2.1719
44,000	323.8	4.578	.1530	-67.00	392.40	19.809	.7569	662.1	971.1	.000481	.2021	2.2244
45,000	308.7	4.364	.1458	-67.00	392.40	19.809	.7569	662.1	971.1	.000459	.1926	2.2786
46,000	294.2	4.160	.1391	-67.00	392.40	19.809	.7569	662.1	971.1	.000437	.1837	2.3332
47,000	280.5	3.966	.1325	-67.00	392.40	19.809	.7569	662.1	971.1	.000417	.1751	2.3898
48,000	267.4	3.781	.1264	-67.00	392.40	19.809	.7569	662.1	971.1	.000397	.1669	2.4478
49,000	254.9	3.604	.1205	-67.00	392.40	19.809	.7569	662.1	971.1	.000379	.1591	2.5071
50,000	243.0	3.436	.1149	-67.00	392.40	19.809	.7569	662.1	971.1	.000361	.1517	2.5675
51,000	231.7	3.276	.1095	-67.00	392.40	19.809	.7569	662.1	971.1	.000344	.1447	2.6289
52,000	220.9	3.123	.1044	-67.00	392.40	19.809	.7569	662.1	971.1	.000328	.1380	2.6919
53,000	210.6	2.978	.0996	-67.00	392.40	19.809	.7569	662.1	971.1	.000312	.1314	2.7587
54,000	200.8	2.839	.0949	-67.00	392.40	19.809	.7569	662.1	971.1	.000298	.1253	2.8250
55,000	191.5	2.707	.0905	-67.00	392.40	19.809	.7569	662.1	971.1	.000284	.1195	2.8928
56,000	182.5	2.581	.0863	-67.00	392.40	19.809	.7569	662.1	971.1	.000271	.1140	2.9617
57,000	174.0	2.460	.0822	-67.00	392.40	19.809	.7569	662.1	971.1	.000258	.1087	3.0331
58,000	165.9	2.346	.0784	-67.00	392.40	19.809	.7569	662.1	971.1	.000246	.1035	3.1083
59,000	158.2	2.237	.0747	-67.00	392.40	19.809	.7569	662.1	971.1	.000234	.0987	3.1830
60,000	150.8	2.132	.0713	-67.00	392.40	19.809	.7569	662.1	971.1	.000224	.0941	3.2594

[1] Subscript SL denotes "sea level."

Figure 1.



Airspeed — Mach number chart.

ATI- 7619
REVISION (None)
ORIG. AGENCY NO. RB-L-473
PUBLISHING AGENCY NO. --

TITLE: A Simplified Chart for Determining Mach Number and True Airspeed from Airspeed-Indicator Readings

AUTHOR(S): Baals, D. D.; Ritchie, V. S.
ORIGINATING AGENCY: National Advisory Committee for Aeronautics, Washington, D. C.

PUBLISHED BY: (Same)

DATE	DOC. CLASS.	COUNTRY	LANGUAGE	PAGES	ILLUSTRATIONS
Mar '43	Unclass.	U.S.	Eng.	8	tables, graphs

ABSTRACT:

Determination of flight Mach numbers from measurements of indicated air speed and pressure altitude is shown to be relatively simple and leads to direct and accurate computation of true air speed. Simplified chart is presented for determining flight Mach number and true air speed for a range of values of indicated air speed, pressure altitude, and air temperature. Table of standard atmospheric values is included.

DISTRIBUTION: Request copies of this report only from Originating Agency

DIVISION: Guided Missiles (1)
SECTION: Instrumentation (9)

SUBJECT HEADINGS: Airspeed indicators (09700)

ATI SHEET NO.: R-1-9-5