

CONVERSION OF AIR-DATA SYSTEM PRESSURE ERRORS INTO HEIGHT AND SPEED CORRECTIONS

1. NOTATION, UNITS, CONSTANTS AND CONVERSION FACTORS

Most of the numerical expressions in this Item are presented in non-dimensional form so that correct results are obtained using any consistent set of units. The exceptions are the expressions for height and its correction.

1.1 Notation and Units

		SI	British
a	speed of sound	m/s, kn	ft/s, kn
H_p	pressure height	m	ft
H_{p_i}	indicated* (registered) height	m	ft
M	Mach number, V/a		
M_i	indicated* (registered) Mach number		
p	pressure (absolute) in a pressure system	N/m ² , mb	lbf/ft ²
p_a	ambient static pressure	N/m ² , mb	lbf/ft ²
p_p	fully corrected value of pitot (absolute) pressure in pitot system in steady level-flight conditions	N/m ² , mb	lbf/ft ²
p_p'	pitot (absolute) pressure corrected for non-steady flight effects	N/m ² , mb	lbf/ft ²
p_s	static (absolute) pressure in static system in steady level-flight conditions	N/m ² , mb	lbf/ft ²
q_c	impact pressure, $(p_p - p_a)$	N/m ² , mb	lbf/ft ²
V	true airspeed	m/s, kn	ft/s, kn
V_c	calibrated airspeed	m/s, kn	ft/s, kn
V_e	equivalent airspeed, $V\sigma^{0.5}$, $a_0(p_a/p_{a_0})^{0.5}M$	m/s, kn	ft/s, kn
V_i	indicated* (registered) airspeed	m/s, kn	ft/s, kn
$\epsilon_1, \epsilon_2, \epsilon_3$	pressure ratios defined in Appendix B		

For footnote refer to end of Notation Section.

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ΔH_p	correction to indicated* value of height, $(H_p - H_{p_i})$	m	ft
ΔM	correction to indicated* value of Mach number, $(M - M_i)$		
ΔV	correction to indicated* value of airspeed, $(V_c - V_i)$	m/s, kn	ft/s, kn
δp	contribution to pressure error in a pressure system, $(p_i - p)$	N/m ² , mb	lbf/ft ²
ρ	ambient air density	kg/m ³	slug/ft ³
$\Sigma(\delta p)$	summation of pressure system errors	N/m ² , mb	lbf/ft ²
σ	relative ambient density, ρ/ρ_0		
$ x $	absolute value of any parameter, x		

Subscripts

i	the indicated* (registered) value of a pressure parameter that is subject to corrections to arrive at a true value
ns	denotes non-steady flight conditions
p	denotes pitot-pressure system
s	denotes static-pressure system
sf	denotes steady level-flight conditions
TOT	denotes total of a number of individual pressure errors
0	denotes conditions at sea-level in International Standard Atmosphere, ISA

* The definition of an indicated or registered parameter is given in Section 1.2.

1.2 Definitions of Height and Speed Parameters

Definitions of and relationships between height, Mach number and airspeed are given in Data Item No. 69026 (Reference 1).

1.2.1 Indicated or registered quantities

“Indicated” or “registered” values of height, Mach number and airspeed are those provided by transducers (instruments) which are assumed to be free of any calibration or other inherent errors. The transducers (instruments) are responding to the registered or output pressure(s) of the static and/or pitot pressure system(s). True values of height, Mach number and calibrated airspeed may be derived by making corrections for

- (i) air-data system pressure errors due to non-steady flight effects – see Data Item No. 85011, (Reference 6),
- (ii) aerodynamic errors due to the aircraft flow field at the sensor and, on occasions, due also to the orientation of the sensor (see Data Item No. 86006, Reference 7).

1.2.2 Airspeeds

When airspeed is obtained from readings of a mechanical instrument the following definitions apply.

- ASIR (Airspeed Indicator Reading) is the reading of an airspeed indicator before corrections for reading error, instrument calibration error and, when appropriate, instrument lag errors.
- IAS (Indicated Airspeed) is the reading of an airspeed indicator not subject to any of the above errors. In this Item IAS is denoted by V_i .
- CAS (Calibrated Airspeed, V_c) is the value of airspeed resulting after corrections for the air-data system and aerodynamic pressure errors (see Section 1.2.1). (An obsolete name is Rectified Airspeed.)

1.2.3 Other notations

Appendix A, Section A2 presents a comparison of the notation used in this Item with those used in References 2, 3 and 5 together with some implied definitions.

1.3 Constants and Conversion Factors

Constants

a_0	340.294 m/s	1116.45 ft/s	661.479 kn
p_{a_0}	101325 N/m ²	1013.25 mb	2116.22 lbf/ft ²

Exact Conversion Factors used or implied

- 1 ft = 0.3048 m
- 1 n.mile = 1852 m
- 1 bar = 10⁵ N/m²

2. INTRODUCTION

“Registered” anemometric pressures: pitot pressure, p_{p_i} , and static pressure, p_{s_i} , are subject to error in general so that neither stagnation pressure nor ambient pressure is measured directly. As a result indicated height, H_{p_i} , indicated Mach number, M_i , and indicated airspeed, V_i , must be corrected to obtain true values.

This Data Item is concerned primarily with approximate methods for converting errors in pitot and static pressures into corrections to height, Mach number and indicated airspeed. Such methods are useful for “quick-look” purposes and, provided the pressure errors are not large, may give acceptable accuracy for the construction of charts and tables of height and speed corrections for flight and operating manuals. However, for the analysis of air-data system pressures recorded at extreme altitude or during flight tests (including non-steady flight conditions) and for cases where pressure errors are large the methods presented in Item No. 83029 (Reference 4) are more appropriate. Exact methods of conversion of pressure errors are given in Appendix B of the present Item for cases where these are needed and the approach of Item No. 83029 is not appropriate.

Section 3 gives the approximate correction to indicated height due to an error in static pressure.

Section 4 gives approximate corrections to indicated Mach number. Section 4.1 deals with pitot-pressure error; Section 4.2 with static-pressure error and Section 4.3 with combined pitot- and static-pressure errors.

Section 5 gives approximate corrections to indicated airspeed. Sections 5.1 to 5.3 consider the same errors as Sections 4.1 to 4.3.

Section 6 deals with the derivation of equivalent airspeed, V_e , and hence the scale-altitude correction, $(V_e - V_c)$.

Section 8 presents worked examples of the use of the approximate methods given in Sections 3 to 6, with comparisons with the exact methods of Appendix B.

Appendix A gives alternative forms of notation that may be used in the correction processes. Also shown is the comparison of the notation used in this Data Item with those of References 2, 3 and 5.

Appendix B gives exact methods of correcting height, Mach number and airspeed for errors in pitot and static pressure.

Appendix C deals with correction processes necessary for analysis of non-steady flight conditions where any of the errors is sensitive to height, Mach number or airspeed.

2.1 General Form of Errors and Associated Corrections

The summations of the pitot and static system errors, as derived for steady level-flight conditions in Data Item No. 86006 (Reference 7) and in Data Item No. 85011 (Reference 6) for non-steady flight, may be combined to give total errors as follows

$$(\delta p_p)_{TOT} = \Sigma(\delta p_p)_{ns} + \Sigma(\delta p_p)_{sf} = p_{p_i} - p_p \quad (2.1)$$

$$(\delta p_s)_{TOT} = \Sigma(\delta p_s)_{ns} + \Sigma(\delta p_s)_{sf} = p_{s_i} - p_a \quad (2.2)$$

These total errors may be converted into corrections to height, Mach number and calibrated airspeed as described in Sections 3, 4 and 5. The corrected parameters then become,

$$H_p = H_{p_i} + \Delta H_p \quad (2.3)$$

$$M = M_i + \Delta M \quad (2.4)$$

$$V_c = V_i + \Delta V. \quad (2.5)$$

However, where any of the steady-flight errors is sensitive to height, Mach number or airspeed, it is usually necessary to carry out the conversions in two stages, as described in Appendix C.

In this Item the pitot and static pressures and their corrections are considered independently. However, in sources such as Reference 3, corrections to Mach number and indicated airspeed are given in terms of the quantities q_c or q_{c_i} , where q_c may be derived from q_{c_i} after the application of either or both of pitot and static pressure errors (see Equation (A1.1)). Appendix A defines these quantities and shows their relationship to the parameters used in this Item.

3. HEIGHT CORRECTION, ΔH_p , DUE TO STATIC PRESSURE ERROR, $(\delta p_s)_{TOT}$

An approximate correction to the indicated (registered) value of height, H_{p_i} , is obtained using the following identities within the quoted limits. True height is then calculated using Equation (2.3). When H_{p_i} is greater than the maximum value quoted, the exact method of Appendix B is recommended.

Limits for H_{p_i} ft		$\Delta H_p / (\delta p_s)_{TOT}$		Equation Numbers
Lower	Upper	ft/(lbf/ft ²)	ft/(N/m ²)	
–	36089.24	$13.076 / [1 - 6.87559 \times 10^{-6} H_{p_i}]^{4.25588}$	$0.27310 / [1 - 6.87559 \times 10^{-6} H_{p_i}]^{4.25588}$	(3.1a)
36089.24	65616.8	$7.7675 / [\exp(-48.0635 \times 10^{-6} H_{p_i})]$	$0.16223 / [\exp(-48.0635 \times 10^{-6} H_{p_i})]$	(3.1b)
65616.8	104987	$9.0266 [0.988626 + 1.5323 \times 10^{-6} H_{p_i}]^{35.16319}$	$0.18853 [0.988626 + 1.5323 \times 10^{-6} H_{p_i}]^{35.16319}$	(3.1c)

Limits for H_{p_i} ft		$\Delta H_p / (\delta p_s)_{TOT}$	Equation Numbers
Lower	Upper	m/(N/m ²)	
–	11000	$0.083241 / [1 - 22.558 \times 10^{-6} H_{p_i}]^{4.2558}$	(3.2a)
11000	20000	$0.049448 / [\exp(-14.6498 \times 10^{-6} H_{p_i})]$	(3.2b)
20000	32000	$0.057464 [0.988626 + 467.05 \times 10^{-9} H_{p_i}]^{35.16319}$	(3.2c)

For a more rapid assessment, approximate values for the correction (in feet) are shown in Figure 1 and tabulated at the end of this section. Since all of the corrections are approximate, values of the limits on static error corresponding to some suggested uncertainties in height are given below. These limits are, of course, arbitrary as there are no firm values for the uncertainties that may be acceptable when using an approximate method.

Indicated height, H_{p_i}	ft m	0 0	36000 11000	65000 20000	100000 30000
Height uncertainty* assumed to be acceptable using approximations, $\pm(\Delta H_p)$	ft m	2 0.6	11 3.4	50 16	167 50.9
Limits on static pressure error corresponding to height uncertainty quoted above, $\pm(\delta p_s)_{TOT}$	lbf/ft ² N/m ²	27 1300	18 880	12 550	3 160

* The uncertainties in height are given, approximately, by

$$\pm \left[2 + 0.0003 \left(H_{p_i} / 10^3 \right)^{2.87} \right] \text{ ft or}$$

$$\pm \left[0.61 + 0.0029 \left(H_{p_i} / 10^3 \right)^{2.87} \right] \text{ m.}$$

Approximate correction, ΔH_p , to height due to static pressure[†] error, $(\delta p_s)_{TOT}$

H_{p_i} ft	0	10 000	20 000	30 000	34 000	36089
$\frac{\Delta H_p}{(\delta p_s)_{TOT}} \left\{ \begin{array}{l} \text{ft/(lbf/ft}^2\text{)} \\ \text{ft/(N/m}^2\text{)} \end{array} \right.$	13.076 0.27310	17.707 0.36982	24.542 0.51257	34.951 0.72997	40.610 0.84816	44.016 0.91929
H_{p_i} ft	38 000	40 000	50 000	60 000	64 000	65 617
$\frac{\Delta H_p}{(\delta p_s)_{TOT}} \left\{ \begin{array}{l} \text{ft/(lbf/ft}^2\text{)} \\ \text{ft/(N/m}^2\text{)} \end{array} \right.$	48.248 1.0077	53.117 1.1094	85.895 1.7940	138.90 2.9010	168.34 3.5159	181.95 3.8001
H_{p_i} ft	70 000	80 000	90 000	100 000	103 000	105 000
$\frac{\Delta H_p}{(\delta p_s)_{TOT}} \left\{ \begin{array}{l} \text{ft/(lbf/ft}^2\text{)} \\ \text{ft/(N/m}^2\text{)} \end{array} \right.$	225.85 4.7170	368.01 7.6861	595.67 12.441	957.91 20.006	1103.3 23.043	1211.8 25.309

† The uncertainties in static pressure error corresponding to the quoted height uncertainties are given, approximately, by

$$\pm(\delta p_s)_{TOT} = \left[27 - 0.237 \left(H_{p_i} / 10^3 \right) \right] \text{ lbf/ft}^2 \text{ for } H_{p_i} \text{ in ft, or}$$

$$\pm(\delta p_s)_{TOT} = \left[1290 - 37.2 \left(H_{p_i} / 10^3 \right) \right] \text{ N/m}^2 \text{ for } H_{p_i} \text{ in m.}$$

4. MACH NUMBER CORRECTIONS

4.1 Mach Number Correction, ΔM_p , Due to Pitot Pressure Error, $(\delta p_p)_{TOT}$

An approximate correction to the indicated value of Mach number, M_i , is obtained as follows (note that if p_{s_i} is not known, values may be obtained from Equations (B1.1a) to (B1.1d) using H_{p_i}).

Range of M_i	$\Delta M_p / [(\delta p_p)_{TOT} / p_{s_i}]$	Equation No.
$M_i \leq 1.0$	$-(1 + 0.2M_i^2)^{-2.5} / (1.4M_i)$	(4.1a)
$M_i > 1.0$	$-(7M_i^2 - 1)^{3.5} / (1168.45 M_i^6 (2M_i^2 - 1))$	(4.1b)

For a more rapid assessment, values are shown in Figure 2 and tabulated below. The corrections are within $|\Delta M_p / M_i| \leq 1$ per cent

for $|(\delta p_p)_{TOT} / p_{s_i}| \leq 0.2M_i^2$, when $M_i \leq 1.0$, or,
for $|(\delta p_p)_{TOT} / p_{s_i}| \leq (1.16M_i - 1)$, when $M_i > 1.0$.

Approximate correction, ΔM_p , to Mach number due to pitot pressure error, $(\delta p_p)_{TOT}$

M_i	0.2	0.4	0.6	0.8	1.0	1.4	1.8	2.2	2.6	3.4	4.2	5.0
$-(\delta p_p)_{TOT} / p_{s_i} \Delta M$	0.2856	0.6059	0.9995	1.514	2.208	3.500	4.590	5.642	6.681	8.749	10.81	12.87

If, in addition, static pressure errors are to be corrected, then refer to Section 4.3, otherwise $\Delta M = \Delta M_p$, and true Mach number is obtained from Equation (2.4).

4.2 Mach Number Correction, ΔM_s , Due to Static Pressure Error, $(\delta p_s)_{TOT}$

An approximate correction to the indicated value of Mach number is obtained as follows.

Range of M_i	$\Delta M_s / [(\delta p_s)_{TOT} / p_{s_i}]$	Equation No.
$M_i \leq 1.0$	$(1 + 0.2M_i^2) / (1.4M_i)$	(4.2a)
$M_i > 1.0$	$M_i(7M_i^2 - 1) / (7(2M_i^2 - 1))$	(4.2b)

For a more rapid assessment, values are shown in Figure 3 and tabulated below. The corrections are within $|\Delta M_s / M_i| \leq 1$ per cent

for $(\delta p_s)_{TOT} / p_{s_i} \leq 0.24M_i^2$, when $M_i \leq 1.0$, or,
for $(\delta p_s)_{TOT} / p_{s_i} \leq 0.24 / M_i^{0.5}$, when $M_i \geq 1.0$.

Approximate correction, ΔM_s , to Mach number due to static pressure error, $(\delta p_s)_{TOT}$

M_i	0.2	0.4	0.6	0.8	1.0	1.4	1.8	2.2	2.6	3.0	3.4	4.2	5.0
$\frac{(\delta p_s)_{TOT}}{(p_{s_i} \Delta M_s)}$	0.2778	0.5426	0.7836	0.9929	1.167	1.148	0.9830	0.8400	0.7277	0.6398	0.5700	0.4665	0.3943

If, in addition, pitot pressure errors are to be corrected, then refer to Section 4.3, otherwise $\Delta M = \Delta M_s$ and true Mach number is obtained from Equation (2.4).

4.3 Mach Number Correction Due to Combined Pitot and Static Pressure Errors

Where the pitot and static pressure errors occur in combination, the approximate value of the resultant correction is

$$\Delta M \approx \Delta M_p + \Delta M_s. \quad (4.3)$$

5. AIRSPEED CORRECTIONS

5.1 Airspeed Correction, ΔV_p , Due to Pitot Pressure Error, $(\delta p_p)_{TOT}$

An approximate correction to the indicated value of airspeed, V_i , is obtained as follows.

Limit for (V_i/a_0)	$(\Delta V_p/a_0)/[(\delta p_p)_{TOT}/p_{a_0}]$	Equation No.
$V_i/a_0 \leq 1.0$	$-1/[1.4(V_i/a_0)[0.2(V_i/a_0)^2 + 1]^{2.5}]$	(5.1a)
$V_i/a_0 > 1.0$	$-1/[1168.451(V_i/a_0)[2 - (a_0/V_i)^2]/[7 - (a_0/V_i)^2]^{3.5}]$	(5.1b)

For a more rapid assessment, values are shown in Figure 4 and tabulated below. The corrections are within $|\Delta V_p/V_i| \leq 1$ per cent

for $|(\delta p_p)_{TOT}/p_{a_0}| \leq 0.2(V_i/a_0)^2$, when $(V_i/a_0) \leq 1.0$, or,

for $|(\delta p_p)_{TOT}/p_{a_0}| \leq (1.2(V_i/a_0) - 1)$, when $(V_i/a_0) > 1.0$.

Approximate correction, ΔV_p , to airspeed due to pitot pressure error

V_i/a_0	0.1	0.15	0.2	0.4	0.6	0.8	1.0	1.2	1.6	2.0	2.4	3.2
$\frac{-(\Delta V_p/a_0)}{(\delta p_p)_{TOT}/p_{a_0}}$	7.107	4.709	3.501	1.651	1.005	0.6607	0.4528	0.3439	0.2467	0.1954	0.1662	0.1215

If, in addition, static pressure errors are to be corrected, then refer to Section 5.3, otherwise $\Delta V = \Delta V_p$, and calibrated airspeed is obtained from Equation (2.5).

5.2 Airspeed Correction, ΔV_s , Due to Static Pressure Error, $(\delta p_s)_{TOT}$

An approximate correction to the indicated value of airspeed, V_i , is obtained as follows.

Range of values for (V_i/a_0)	$\frac{(\Delta V_s/a_0)}{(\delta p_s)_{TOT}/p_{a_0}}$	Equation No.
$V_i/a_0 \leq 1.0$	$1/[1.4(V_i/a_0)[0.2(V_i/a_0)^2 + 1]^{2.5}]$	(5.2a)
$V_i/a_0 > 1.0$	$1/[1168.451(V_i/a_0)[2 - (a_0/V_i)^2]/[7 - (a_0/V_i)^2]^{3.5}]$	(5.2b)

For a more rapid assessment, values are shown in Figure 4 and tabulated below. The corrections are within $|\Delta V_s/V_i| \leq 1$ per cent

for $|(\delta p_s)_{TOT}/p_{a_0}| \leq 0.2(V_i/a_0)^2$, when $(V_i/a_0) \leq 1.0$, or,

for $|(\delta p_s)_{TOT}/p_{a_0}| \leq (1.2(V_i/a_0) - 1)$, when $V_i/a_0 > 1.0$.

Approximate correction, ΔV_s , to calibrated airspeed due to static pressure error

V_i/a_0	0.1	0.15	0.2	0.4	0.6	0.8	1.0	1.2	1.6	2.0	2.4	3.2
$\frac{\Delta V_s/a_0}{(\delta p_s)_{TOT}/p_{a_0}}$	7.107	4.709	3.501	1.651	1.005	0.6607	0.4528	0.3439	0.2467	0.1954	0.1662	0.1215

If, in addition, pitot pressure errors are to be corrected, then refer to Section 5.3, otherwise $\Delta V = \Delta V_s$ and calibrated airspeed is obtained from Equation (2.5).

5.3 Airspeed Correction Due to Combined Pitot and Static Pressure Errors

Where the pitot and static pressure errors occur in combination, the approximate value of the resultant correction is

$$\Delta V \approx \Delta V_p + \Delta V_s. \quad (5.3)$$

6. EQUIVALENT AIRSPEED AND SCALE-ALTITUDE CORRECTION

6.1 Equivalent Airspeed

Equivalent airspeed is obtained using

$$V_e = a_0 [p_a / p_{a_0}]^{0.5} M \quad (6.1)$$

$$\text{where } p_a = p_{s_i} - (\delta p_s)_{TOT} \quad (6.2)$$

and M is given by Equation (2.4) with Equation (4.3) or is obtained exactly using Equations (B2.2a), (B2.3a), (B2.3b) or (B2.4a) and (B2.4b).

6.2 Scale-altitude Correction

Scale-altitude correction is defined by the difference $(V_e - V_c)$, where V_c is given by Equation (2.5) with Equation (5.3).

For a rough assessment, Figure 5 shows the relationship between $(V_e - V_c)$ in knots and calibrated airspeed, Mach number, and pressure height.

7. REFERENCES

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