

## AIRSPEED DATA FOR PERFORMANCE CALCULATIONS

## 1. NOTATION, UNITS, CONSTANTS AND CONVERSION FACTORS

## 1.1 Notation and Units

|          |                                                 | SI                    | British              |
|----------|-------------------------------------------------|-----------------------|----------------------|
| $a$      | speed of sound*                                 | m/s, kn               | ft/s, kn             |
| $H_p$    | pressure height (defined in References 2, 4, 6) | m                     | ft                   |
| $M$      | Mach number, $V/a$                              |                       |                      |
| $p$      | static pressure†                                | N/m <sup>2</sup> , mb | lbf/ft <sup>2</sup>  |
| $p_p$    | pitot pressure†                                 | N/m <sup>2</sup> , mb | lbf/ft <sup>2</sup>  |
| $p_t$    | total pressure†                                 | N/m <sup>2</sup> , mb | lbf/ft <sup>2</sup>  |
| $q$      | kinetic pressure                                | N/m <sup>2</sup> , mb | lbf/ft <sup>2</sup>  |
| $q_c$    | impact pressure, $(p_p - p)$                    | N/m <sup>2</sup> , mb | lbf/ft <sup>2</sup>  |
| $R$      | gas constant for air                            | N m/kg K              | lbf ft/slug K        |
| $T$      | ambient temperature                             | K                     | K                    |
| $T_t$    | total, or stagnation, temperature               | K                     | K                    |
| $V$      | true airspeed*                                  | m/s, kn               | ft/s, kn             |
| $V_c$    | calibrated airspeed*                            | m/s, kn               | ft/s, kn             |
| $V_e$    | equivalent airspeed*                            | m/s, kn               | ft/s, kn             |
| $\gamma$ | ratio of specific heat capacities of air        |                       |                      |
| $\delta$ | relative pressure, $p/p_0$                      |                       |                      |
| $\theta$ | relative temperature, $T/T_0$                   |                       |                      |
| $\rho$   | density                                         | kg/m <sup>3</sup>     | slug/ft <sup>3</sup> |
| $\sigma$ | relative density, $\rho/\rho_0$                 |                       |                      |

\* The knot (kn) is one international nautical mile per hour, see Section 1.2.

† Note that these pressures are absolute.

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### Subscripts

|            |                                                                               |
|------------|-------------------------------------------------------------------------------|
| <i>std</i> | denotes conditions in International Standard Atmosphere, ISA, see Reference 4 |
| 0          | denotes conditions at sea-level in International Standard Atmosphere, ISA     |
| 1          | denotes value upstream of normal shock                                        |
| 2          | denotes value downstream of normal shock                                      |

## 1.2 Constants and Conversion Factors

Constants (**bold characters denote exact values**)

|          |                                                     |                                                 |
|----------|-----------------------------------------------------|-------------------------------------------------|
| $a_0$    | 340.294 m/s, 661.479 kn                             | 1116.45 ft/s, 661.479 kn                        |
| $p_0$    | <b>101 325</b> N/m <sup>2</sup> , <b>1013.25</b> mb | <b>2116.22</b> lbf ft <sup>2</sup>              |
| $R$      | <b>287.052 87</b> N m/kg K                          | <b>3089.8114</b> lbf ft/slug K                  |
| $T_0$    | <b>288.15</b> K                                     | <b>288.15</b> K                                 |
| $\rho_0$ | <b>1.225</b> kg/m <sup>3</sup>                      | $2.376\ 89 \times 10^{-3}$ slug/ft <sup>3</sup> |
| $\gamma$ | 1.4                                                 | 1.4                                             |

Values of constants in British Units have been obtained by conversion from the SI values, are correct to the number of figures quoted, and are adequate for most calculation purposes. However, while the value of  $\rho_0$  can be obtained by direct conversion from the SI value, the need for  $p_0$ ,  $R$ ,  $T_0$  and  $\rho_0$  to satisfy Equation (2.1) can only be met if an exceptionally large number of significant figures is used, as follows:  $p_0 = 2116.216\ 624$  lbf/ft<sup>2</sup>,  $R = 3089.811\ 378$  lbf ft/slug K, giving,  $\rho_0 = 0.002\ 376\ 892\ 44$  slug/ft<sup>3</sup>.

### Exact conversion factors implied

$$1\ \text{ft} = \mathbf{0.3048}\ \text{m};\ 1\ \text{International n.mile} = \mathbf{1852}\ \text{m};$$

$$1\ \text{bar} = \mathbf{10^5}\ \text{N/m}^2;\ 1\ \text{Pa} = 1\ \text{N/m}^2;\ (T\ \text{or}\ T_t\ ^\circ\text{C}) = (T\ \text{or}\ T_t\ \text{K}) - 273.15$$

## 2. INTRODUCTION

This Item presents analytical and graphical relationships between the airspeeds\* and associated pressure\* parameters used in aircraft performance work.

**Section 3** presents those airspeed\* parameters ( $V$ ,  $M$ ,  $q$ ,  $V_e$ ) that are defined independently of the pressure quantities from which flight (or wind tunnel) values are deduced. Figures 1a and 1b present relationships between  $V_e$ ,  $M$ ,  $H_p$  (and  $V$  for ISA conditions).

**Section 4** and Figures 4a to 4e and 5a to 5e present relationships between airspeeds\* ( $M$  and  $V_c$ ) and pressure\* and temperature parameters.

**Sections 5 and 6** present particular relationships between  $V_c$  and  $M$  and between  $V_c$  and  $V_e$  (including the “scale altitude correction”,  $(V_e - V_c)$ ). Figures 2a and 2b and 3a and 3b give the general relationships between  $V_c$ ,  $M$  and  $H_p$  and between  $(V_e - V_c)$ ,  $V_c$ ,  $M$  and  $H_p$  respectively.

**Table 9.1** summarises the various calculation sequences possible using the equations and graphs. In general, equations are presented in non-dimensional form so that any system of units can be used. Some of the graphical data are also in non-dimensional form but the reduced emphasis on graphical data, and relatively widespread use of knots for airspeed and feet for height, has led to a decision not to duplicate the dimensional figures.

### 2.1 Equation of State

The various airspeed relationships presented in this Item are based on the premise that the atmosphere consists of air that is a perfect gas, so that local static values of pressure,  $p$ , density,  $\rho$ , and temperature,  $T$ , are related by the equation of state,

$$p = \rho RT. \quad (2.1)$$

In additions, the speed of sound,  $a$ , in undisturbed air is given (for consistent units) by

$$a = (\gamma p / \rho)^{0.5} = (\gamma RT)^{0.5} = a_0 \theta^{0.5}. \quad (2.2)$$

\* Equations and graphical data are expressed in notation corresponding to true values of the various parameters. For practical aspects of correcting air-data-system measurements to obtain such values, see Reference 6 for Items on, “Air Data (Flight Test Measurement)”.

### 3. DEFINITIONS OF AIRSPEED PARAMETERS $V$ , $M$ , $q$ , $V_e$

These airspeed parameters are defined independently of the pressure quantities from which flight (or wind tunnel) values are deduced.

#### 3.1 True Airspeed and Mach Number

**True airspeed (TAS),  $V$** , is the magnitude of the velocity vector of an aircraft relative to undisturbed air.

**Mach number,  $M$** , is the ratio of true airspeed to speed of sound in undisturbed air,

$$M = V/a, \quad (3.1)$$

where values of the speed of sound are obtained from Equation (2.2).

For most **calculations** of aircraft instantaneous (or “point”) performance,  $V$  and/or  $M$  provides a sufficient description of motion relative to air. For **flight** purposes,  $V$  has obvious navigational significance but is rarely used in specifying operational performance data and (even if known) is not the preferred means of identifying airspeed to the pilot. When compressibility effects are significant, Mach number is the primary means of displaying airspeed information and is widely used in specifying operational data.

#### 3.2 Kinetic Pressure and Equivalent Airspeed

**Kinetic pressure,  $q$** , is defined (for coherent units) by

$$q = \rho V^2/2 \quad (3.2)$$

$$\text{or, for } V \text{ in kn, } \rho \text{ in kg/m}^3, \quad q = \left[ \frac{1852}{3600} \right]^2 \times \frac{\rho V^2}{2} = 0.132 \, 33 \rho V^2 \text{ N/m}^2,$$

$$\text{or, for } V \text{ in kn, } \rho \text{ in slug/ft}^3, \quad q = \left[ \frac{1852}{0.3048 \times 3600} \right]^2 \times \frac{\rho V^2}{2} = 1.424 \, 35 \rho V^2 \text{ lbf/ft}^2.$$

Alternatively, by combining Equations (2.2) and (3.2),

$$q = \gamma p M^2/2. \quad (3.3)$$

Kinetic pressure is widely used in expressing aerodynamic forces and moments in coefficient form.

**Equivalent Airspeed (EAS),  $V_e$** , is the (true) airspeed at sea-level in the International Standard Atmosphere that will give the same kinetic pressure,  $q$ , as exists at the aircraft flight conditions.

$$\begin{aligned} V_e &= [q/(\rho_0/2)]^{0.5} = [(\rho V^2/2)/(\rho_0/2)]^{0.5} = V \sigma^{0.5} = V[p/\rho_0 RT]^{0.5} \\ &= a M \sigma^{0.5} = [(\gamma p M^2/2)/(\rho_0/2)]^{0.5} = a_0 M \delta^{0.5}. \end{aligned} \quad (3.4)$$

The graphical relationship between  $V_e$ ,  $M$  and  $H_p$  is given in Figures 1a and 1b. Equivalent airspeed is most often encountered in the specification of flight loads such as in gust or manoeuvre envelopes. The close relationship of  $V_e$  and  $q$  means that the former is a convenient means of relating wind tunnel tests to flight speeds, but see Section 6.1.

## 4. RELATIONSHIPS BETWEEN AIRSPEEDS AND PRESSURE AND TEMPERATURE PARAMETERS

In-flight methods of obtaining airspeed information customarily rely on pressure sensors, so it is necessary to define relationships between various airspeed and pressure parameters, see Sections 4.2 and 4.3. In addition, and to provide a link with the underlying flow phenomena, Section 4.1 quotes expressions derived from one-dimensional flow theory.

### 4.1 Relationships from One-Dimensional-Flow Theory

#### 4.1.1 One dimensional isentropic flow

**Total pressure,  $p_t$ ,** is the pressure of air brought to rest isentropically

$$p_t = p \left[ 1 + \frac{(\gamma - 1)}{2} M^2 \right]^{\gamma/(\gamma - 1)} \quad (4.1)$$

Flows that are reversible and adiabatic will be isentropic. In practical terms, Equation (4.1) may be applied to flows where no shock waves are present.

#### 4.1.2 One dimensional adiabatic flow

Adiabatic flows are those involving no overall heat transfer but possibly including irreversible processes such as shock waves.

**Normal-shock relationships** given by Equations (4.2), (4.3) and (4.4) apply to the flow of a perfect gas through a shock wave positioned normal to the local flow direction. Flow conditions on the upstream (supersonic) side of the shock are denoted by subscript “1”, and on the downstream (subsonic) side of the shock by subscript “2”.

$$\text{Ratio of static pressures across shock, } \frac{p_2}{p_1} = 1 + \frac{2\gamma}{(\gamma + 1)} (M_1^2 - 1) \quad (4.2)$$

Ratio of total pressures across shock,

$$\frac{p_{t_2}}{p_{t_1}} = \left[ \frac{(\gamma + 1)M_1^2}{(\gamma - 1)M_1^2 + 2} \right]^{\gamma/(\gamma - 1)} \left[ 1 + \frac{2\gamma}{(\gamma + 1)} (M_1^2 - 1) \right]^{1/(1 - \gamma)} \quad (4.3)$$

$$\text{Mach number downstream of shock, } M_2 = \left[ \frac{1 + \frac{(\gamma - 1)}{2} M_1^2}{\gamma M_1^2 - \frac{(\gamma - 1)}{2}} \right]^{0.5} \quad (4.4)$$

**Total temperature,  $T_t$ ,** is the temperature of air brought to rest adiabatically. It is a measure of total energy in the flow and this is conserved – even in supersonic flows with irreversible compression through shocks

$$T_t = T \left[ 1 + \frac{(\gamma - 1)}{2} M^2 \right] \quad (4.5)$$

The relationship of Equation (4.5) is presented in Figure 6.

## 4.2 Pitot Pressure and its Relationship to Mach Number, $M$

**Pitot pressure,  $p_p$** , is the stagnation pressure sensed by a pitot tube not subject to any sensing errors\*. In subsonic flow this pressure is equal to total pressure,  $p_t$ . In supersonic flow it is the stagnation pressure behind a normal shock, given by the “normal-shock” relationship.

Expressions relating pitot pressure and freestream Mach number are derived from Equations given in Sections 4.1.1 and 4.1.2; the corresponding graphical relationship is given in Figures 5a to 5c.

**For  $M \leq 1$** ,  $p_p = p_t$ , so that, from Equation (4.1),

$$\frac{p_p}{p} = \left[ 1 + \frac{(\gamma - 1)}{2} M^2 \right]^{\gamma/(\gamma - 1)} \quad (4.6)$$

**For  $M > 1$** ,  $p_p \neq p_t$ , because in supersonic flow a normal shock is positioned at the mouth of the pitot tube (i.e., in notation of Section 4.1.2,  $p_p = p_{t_2}$ ). The expression for pitot pressure in terms of freestream Mach number, derived from Equations (4.1) and (4.3), is

$$\frac{p_p}{p} = \frac{p_{t_2}}{p_1} = \frac{p_{t_2}}{p_{t_1}} \times \frac{p_{t_1}}{p_1} = \left[ \frac{(\gamma + 1)}{2} M^2 \right]^{\gamma/(\gamma - 1)} \left[ 1 + \frac{2\gamma}{(\gamma + 1)} (M^2 - 1) \right]^{1/(1 - \gamma)} \quad (4.7)$$

Note that for  $M = 1$ , Equations (4.6) and (4.7) give  $p_p/p = 1.892\,93$ .

### 4.2.1 Inverse relationships for Mach number and pitot pressure

**For†  $p_p/p \leq 1.892\,93$** , Equation (4.6) is inverted to give

$$M = \left\{ \frac{2}{(\gamma - 1)} \left[ \left( \frac{p_p}{p} \right)^{(\gamma - 1)/\gamma} - 1 \right] \right\}^{0.5} \quad (4.8)$$

**For†  $p_p/p > 1.892\,93$** , an inverse form of Equation (4.7) is required, but this cannot be obtained explicitly and a solution must be obtained by successive approximation. An alternative is to make use of the following approximate, but direct, relationship

$$M \approx \left[ 0.417\,26 + 0.7767 \left( \frac{p_p}{p} - 1 \right) - \frac{0.0989}{\left( \frac{p_p}{p} - 1 \right)} \right]^{0.5} \quad (4.9)$$

Equation (4.9) is taken from Reference 1, applies for  $\gamma = 1.4$  only, and gives results to better than  $\pm 0.01$  per cent in the range  $1 < M < 6.0$ .

\* Equations and graphical data are expressed in notation corresponding to true values of the various parameters. For practical aspects of correcting air-data-system measurements to obtain such values, see Reference 6 for Items on, “Air Data (Flight Test Measurement)”.

† For derivation of value 1.892 93 see last line of Section 4.2.

### 4.3 Impact Pressure and Definition of Calibrated Airspeed, $V_c$

**Impact pressure,  $q_c$ ,** is the stagnation pressure increment above ambient static pressure, *i.e.*

$$q_c = p_p - p. \quad (4.10)$$

**Calibrated Airspeed (CAS),  $V_c$ ,** is the value of (true) airspeed which at Standard Sea Level conditions will give the same impact pressure as exists at the aircraft flight conditions (and is the airspeed resulting after all corrections have been made for air data system and aerodynamic pressure errors, see Reference 6). Relationships between  $q_c$  and  $M$  are obtained by deducting unity from both sides of Equations (4.6) and (4.7). Calibrated airspeed is obtained when the expressions for  $q_c$  are solved to give airspeed in ISA, sea level conditions ( $p = p_0$ ,  $a = a_0$ ).

**For  $V_c/a_0 \leq 1.0$ ,**

$$\frac{q_c}{p_0} = \frac{p_p - p}{p_0} = \left[ 1 + \frac{(\gamma - 1)}{2} \left( \frac{V_c}{a_0} \right)^2 \right]^{\gamma/(\gamma - 1)} - 1. \quad (4.11)$$

**For  $V_c/a_0 > 1.0$ ,**

$$\frac{q_c}{p_0} = \frac{(p_p - p)}{p_0} = \left[ \left\{ \frac{(\gamma + 1)}{2} \left( \frac{V_c}{a_0} \right)^2 \right\}^{\frac{\gamma}{(\gamma - 1)}} \left\{ 1 + \frac{2\gamma}{(\gamma + 1)} \left[ \left( \frac{V_c}{a_0} \right)^2 - 1 \right] \right\}^{\frac{1}{(1 - \gamma)}} - 1 \right]. \quad (4.12)$$

#### 4.3.1 Inverse relationships for calibrated airspeed and impact pressure

**For\*  $q_c/p_0 = (p_p - p)/p_0 \leq 0.892\ 93$ ,**

$$\frac{V_c}{a_0} = \left\{ \frac{2}{(\gamma - 1)} \left[ \frac{(p_p - p)}{p_0} + 1 \right]^{(\gamma - 1)/\gamma} - \frac{2}{(\gamma - 1)} \right\}^{0.5}. \quad (4.13)$$

**For\*  $q_c/p_0 = (p_p - p)/p_0 > 0.892\ 93$**  an inverse form of Equation (4.12) is required but this cannot be obtained explicitly and a solution must be obtained by successive approximation. An alternative is to make use of the following approximate, but direct, relationship

$$\frac{V_c}{a_0} \approx \left[ 0.417\ 26 + 0.7767 \frac{(p_p - p)}{p_0} - \frac{0.0989 p_0}{(p_p - p)} \right]^{0.5}. \quad (4.14)$$

Equation (4.14) is taken from Reference 1, applies for  $\gamma = 1.4$  only, and gives results to better than  $\pm 0.02$  per cent in the range  $1 < (V_c/a_0) < 6.0$ .

\* For derivation of value 0.892 93 see last line of Section 4.2.

## 5. RELATIONSHIP BETWEEN CALIBRATED AIRSPEED AND MACH NUMBER

Relationships between  $V_c$  and  $M$  are deduced from Equations (4.6), (4.7), (4.11), (4.12) by solving for constant values of  $q_c (= p_p - p)$ . Because, in general,  $V_c/a_0 \neq M$ , three separate equations result, as follows.

For  $V_c/a_0 \leq 1.0$  and  $M \leq 1.0$

$$\left\{ \left[ 1 + \frac{(\gamma-1)}{2} \frac{V_c^2}{a_0^2} \right]^{\frac{\gamma}{(\gamma-1)}} - 1 \right\} = \delta \left\{ \left[ 1 + \frac{(\gamma-1)}{2} M^2 \right]^{\frac{\gamma}{(\gamma-1)}} - 1 \right\}. \quad (5.1)$$

For  $V_c/a_0 \leq 1.0$  and  $M > 1.0$

$$\left\{ \left[ 1 + \frac{(\gamma-1)}{2} \frac{V_c^2}{a_0^2} \right]^{\frac{\gamma}{(\gamma-1)}} - 1 \right\} = \delta \left\{ \left[ \frac{(\gamma+1)}{2} M^2 \right]^{\frac{\gamma}{(\gamma-1)}} \left[ 1 + \frac{2\gamma}{(\gamma+1)} (M^2 - 1) \right]^{\frac{1}{(1-\gamma)}} - 1 \right\}. \quad (5.2)$$

For  $V_c/a_0 > 1.0$  and  $M > 1.0$

$$\left\{ \left[ \frac{(\gamma+1)}{2} \frac{V_c^2}{a_0^2} \right]^{\frac{\gamma}{(\gamma-1)}} \left[ 1 + \frac{2\gamma}{(\gamma+1)} \left( \frac{V_c^2}{a_0^2} - 1 \right) \right]^{\frac{1}{(1-\gamma)}} - 1 \right\} = \delta \left\{ \left[ \frac{(\gamma+1)}{2} M^2 \right]^{\frac{\gamma}{(\gamma-1)}} \left[ 1 + \frac{2\gamma}{(\gamma+1)} (M^2 - 1) \right]^{\frac{1}{(1-\gamma)}} - 1 \right\}. \quad (5.3)$$

Equations (5.1) to (5.3) provide a relationship between  $V_c$ ,  $M$  and  $\delta$  and, since  $H_p$  is a function of  $\delta$  (or  $p$ , see Table 9.1) only, there is a unique relationship between  $V_c$ ,  $M$  and  $H_p$  (*i.e.* applicable to all temperature conditions), which is shown in Figures 2a and 2b.

In solving Equations (5.1) to (5.3) particular care is required to identify which of the three possible relationships between  $V_c$  and  $M$  applies. The sequence of “tests” used to identify the appropriate equation is presented in Section 4 of Data Item No. 81046 (Reference 5) together with an iteration sequence for the solution of Equations (5.2) and (5.3). An alternative to the iterative solution of Equation (5.3) (or of Equation (5.2), if  $M$  is to be evaluated) is to utilise the separate expressions for  $V_c$  and  $M$  in Sections 4.2 and 4.3 – in particular the approximate expressions of Equations (4.9) and (4.14).

## 6. RELATIONSHIP BETWEEN CALIBRATED AND EQUIVALENT AIRSPEEDS

Relationships between  $V_c$  and  $V_e$  are obtained by equating the expressions for impact pressure in terms of  $V_c$  and  $V_e$  (i.e. from Equations (5.1) to (5.3) by substituting,  $V_e = a_0 M \delta^{0.5}$ , from Equation (3.4) and  $\gamma = 1.4$ ).

For  $(V_c/a_0) \leq 1$ ,  $(V_e/a_0 \delta^{0.5}) \leq 1$

$$\left[ \left( 1 + 0.2 \frac{V_c^2}{a_0^2} \right)^{3.5} - 1 \right] = \delta \left[ \left( 1 + 0.2 \frac{V_e^2}{\delta a_0^2} \right)^{3.5} - 1 \right]. \quad (6.1)$$

For  $(V_c/a_0) \leq 1 < (V_e/a_0 \delta^{0.5})$

$$\left[ \left( 1 + 0.2 \frac{V_c^2}{a_0^2} \right)^{3.5} - 1 \right] = \delta \left\{ \frac{1.2^6 \times 5^{2.5} \frac{V_e^2}{a_0^2}}{\left( 7 - \frac{\delta a_0^2}{V_e^2} \right)^{2.5}} - 1 \right\}, \quad (6.2)$$

For  $(V_c/a_0) > 1$ ,  $(V_e/a_0 \delta^{0.5}) > 1$

$$\left\{ \frac{1.2^6 \times 5^{2.5} \frac{V_c^2}{a_0^2}}{\left( 7 - \frac{a_0^2}{V_c^2} \right)^{2.5}} - 1 \right\} = \delta \left\{ \frac{1.2^6 \times 5^{2.5} \frac{V_e^2}{a_0^2}}{\left( 7 - \delta \frac{a_0^2}{V_e^2} \right)^{2.5}} - 1 \right\}. \quad (6.3)$$

Equations (6.1) to (6.3) provide a relationship between  $V_c$ ,  $V_e$  and  $\delta$  and, since  $H_p$  is a function of  $\delta$  (or  $p$ , see Table 9.1) only, there is a unique relationship, between  $V_c$ ,  $V_e$  and  $H_p$  (i.e. applicable to all temperatures). The remarks given in Section 5 regarding solution of Equations (5.1) to (5.3), also apply to Equations (6.1) to (6.3).

### 6.1 Scale-Altitude Correction, $(V_e - V_c)$

The quantity  $(V_e - V_c)$  is referred to as the “scale-altitude correction” or “calibration-compressibility correction” and values are presented in Figures 3a and 3b. These values are derived from Equations (6.1) to (6.3) and, as indicated in Section 6, are expressed as functions of  $V_c$  and  $H_p$  only (i.e. they are applicable at all temperatures). The term, “scale-altitude correction”, is associated with aneroid/mechanical airspeed indicators. Such instruments are calibrated using Equations (4.11) and (4.12) and so, in the absence of errors\*, have a unique relationship between impact pressure,  $q_c (= p_p - p)$ , and the “scale” reading,  $V_c$ .

At sea level ( $\delta = 1$ ) Equation (6.1) shows that  $V_c$  and  $V_e$  are identical, while for low speeds and altitudes, Equation (4.11) gives values of  $V_c$  which are so close to the corresponding values of  $V_e$  that the two speed

\* See Reference 6 regarding calibration of air data systems and correction of errors.

parameters have sometimes been regarded as synonymous. However, as altitude increases (and  $\delta$  decreases) and as Mach number (compressibility) increases, it is essential that the difference between  $V_c$  and  $V_e$  is acknowledged. Historically, one method of doing this was to add to the “scale” reading (of  $V_c$ ) a correction,  $(V_e - V_c)$ , to obtain  $V_e$ . Thus, the operational parameter,  $V_c$ , could be related to parameters more appropriate to the expression of aerodynamic forces, *i.e.*  $V_e$  and  $q$  – see Section 3.2.

## 7. REFERENCES

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