Appendix 1

COMPUTATION PROCESS

Introduction

1. This appendix gives brief details of the basic formulae used in the computation of height and speed within the air data computer to enable the air data system to resolve the mathematical equations presented to it.

HEIGHT

General

2. The maximum height range of the air data system is 100 000 ft and the system is calibrated in accordance with the Wright Air Development Centre (W.A.D.C.) standard atmosphere. This atmosphere is based upon a limiting altitude of 140 000 ft and it was introduced as a supplement to the earlier International Civil Air Organization (I.C.A.O.) standard atmosphere, which has a limiting altitude of 65 800 ft.

3. The W.A.D.C. standard atmosphere assumes that throughout the stratosphere the temperature is constant at $-56\cdot5$ degrees C (216·66°K). The stratosphere is defined as the range of altitude between the tropopause (36 090 ft) and the stratopause (104 986·88 ft).

Formulae for linear height

4. For altitudes up to 36 090 ft the W.A.D.C. standard atmosphere is represented by the following equation:—

$$P = P_o \left(1 - \frac{a}{T_o}Z\right)^n$$

In this equation,

P = pressure at altitude Z

P_o = standard sea level pressure (1013·25 mb)

T_o standard absolute sea level temperature (288·16 degrees K)

a = temperature lapse rate (0·00198 degrees C per foot change of altitude)

Z = altitude above sea level

n = constant value of 5·25

The equation can therefore be stated as

$$S = 1013\cdot25\left(\frac{288\cdot16 - 0\cdot00198 \times H}{288\cdot16}\right)^{5\cdot25}$$

where S = static pressure in mb

H = altitude in ft.

5. For altitudes throughout the stratosphere range, the W.A.D.C. standard atmosphere is represented by the following equations:—

$$\log_e P = n \log_e P_a - (Z - Z_a)$$

in this equation

P = pressure at altitude Z

n = constant value of 5·25

P_a = pressure at tropopause (226·318mb)

Z = altitude above sea level

Z_a = altitude at tropopause (36 089 ft)

The equation can therefore be stated as

$$S = 226\cdot318 \times \exp-(1\cdot577 \times 10^{-4} \times (0\cdot3048 \times H - 11000))$$

where S = static pressure in mb

H = altitude in ft.

SPEED

Indicated air speed (I.A.S.)

6. In the A.D.S. Mk. 1A, the I.A.S. output is taken directly from the pitot-static transducer for use in the flight control system and is not computed in its passage through the computer unit.

7. At standard sea level density, indicated air speed is equal to true air speed (T.A.S.); with increasing altitude, I.A.S. decreases, for all practical purposes, in the same proportion as the square root of the density. For example, at 40 000 ft the standard density is one quarter of the sea level density and the displayed I.A.S. will be approximately half the T.A.S.

8. The air loads on aircraft in level flight or straight dives and climbs are proportional to the dynamic pressure and, in turn, to the I.A.S. For example, an aircraft flying at approximately 75 000 ft at a T.A.S. of about 1300 kt has a corresponding I.A.S. of 270 kt. Although the T.A.S. is high, the forces bearing on all parts of the aircraft are only the same as those that would be experienced if the aircraft were flying at sea level at a coincident I.A.S. and T.A.S. of 270 kt. The air loads are therefore determined by I.A.S.

Formulae for I.A.S.

9. Indicated air speed, as a function of pitot minus static (P—S) pressure, is represented by the following equation for an I.A.S. less than the speed of sound:—

$$V_i = C_o \sqrt{5\left[\left(\frac{P-S}{1013\cdot25}+1\right)^{\frac{2}{7}} - 1\right]}$$

In this equation

C_o = speed of sound at sea level (661·03kt)

S = static pressure in mb

P = pitot pressure in mb

Vi = indicated air speed.

10. Where the I.A.S. is greater than the speed of sound the following equation is employed:—

$$\frac{P-S}{1013\cdot 25} = 166\cdot 921 \frac{\left[\frac{V_i}{C_o}\right]^7}{7\left[\left(\frac{V_i}{C_o}\right)^2 - 1\right]^{\frac{5}{2}}} - 1$$

where the significance of the various symbols is as stated in para. 9.

Speed of sound in air

11. Variations in sonic speed with atmospheric conditions are given by the formula

$$C = \sqrt{YRT}$$

where Y (gamma) = coefficient of adiabatic expansion (I.C.A.N. standard atmosphere = 1·400)

R = gas constant for unit mass of air

T = temperature of air in degrees Kelvin (15 degrees C = 288·16 degrees K)

C = speed of sound in air (metres/sec)

then $C(kt) = 38\cdot 94\ \sqrt{T}$

12. The speed of sound varies from 661 kt at sea level to 573 kt at the tropopause (36 090 ft). Above this height, it will remain constant since both the I.C.A.N. and W.A.D.C. atmospheres assume a constant temperature of −56·5 degrees C.

Mach number

13. The indication, or display of Mach number, results from the comparison of T.A.S. with sonic speed when both are measured under the same atmospheric conditions. The relationship between Mach number, static pressure and pitot minus static pressure is shown by the two following formulae:—

(1) Mach number less than 1

$$\frac{P-S}{S} = \left[(1 + 0\cdot 2M^2)^{3\cdot 5} - 1\right]$$

(2) Mach number greater than 1

$$\frac{P-S}{S} = \left[\frac{166\cdot 921\ M^7}{(7M^2 - 1)^{2\cdot 5}} - 1\right]$$

where, in both equations,

M = Mach number

P = pitot pressure (mb)

S = static pressure (mb)

Mach number computation

14. A simplified formula for the derivation of Mach number is as follows:—

$$f(M) = \frac{P-S}{S}$$

where M = Mach number

P = pitot pressure

S = static pressure

and f denotes " a function of ".

By conversion to logarithmic form, the formula can be expressed as

$$\log\left(\frac{P-S}{S}\right) = \log f(M)$$

$$\therefore \log(P-S) - \log S = \log f(M).$$