Appendix 1

AIR DATA SYSTEM Mk. 1B — COMPUTATION PROCESS

Introduction

1. This appendix gives brief details of the basic formulae associated with the computation of height, speed, etc., and the solution of the associated equations by means of the air data computer, Type B.

TABLE 1

Computer Type B — Variables

Variable	*Source*	*Destination*
log P–S	Pitot-static transducer	Mach number channel
log S	Static transducer	Mach number channel Height channel
Temperature	Temperature probe	T.A.S. channel
Height	Static transducer	Vertical speed channel Height channel

TABLE 2

A.D.S. Mk. 1B — output signals

Signal	*Destination*	*Type*
Height (from static transducer)	Display units	Synchro (CX2)
I.A.S. (from pitot-static transducer)	Display unit	Synchro (CX1)
T.A.S.	Display unit OUE (B) OUE (C)	Synchro (G7/CX1) Potentiometer (G7/RV5) Potentiometer (G7/RV6)
Mach number	Display unit OUE (A)	Synchro (G5/CX1) Potentiometer (G5/RV4)
Reciprocal Mach number	OUE (A)	Potentiometer (G5/RV5)
Rate of change of height (logarithmic)	Display unit	Synchro (G4/TX1)
Rate of change of height (linear)	OUE (C)	Potentiometer (G4/RV5)

HEIGHT

General

2. The maximum height range of the air data system (A.D.S.) is 100000 ft and the system is calibrated in accordance with the Wright Air Development Centre (W.A.D.C.) standard atmosphere, which has a limiting altitude of 140000 ft and was introduced as a supplement to the International Civil Air Organisation (I.C.A.O.) standard atmosphere (maximum altitude, 65800 ft).

Note...
The A.D.S. Mk. 1B is calibrated to 50000 ft.

3. The region above the tropopause (36090 ft) is now known as the stratosphere, with a limiting height of 104986·88 ft called the stratopause. For convenience, it is assumed that the temperature above the tropopause and up to the stratopause is constant at −56·5 degrees C (216·66 degrees K).

Formulae for linear height

4. The W.A.D.C. standard atmosphere is represented by the following equations:—

(1) Up to tropopause

$$P = P_o\left[1 - \frac{aZ}{T_o}\right]^n$$

where P = pressure at altitude Z
P_o = standard sea-level pressure = 1013·25mb
T_o = standard absolute sea-level temperature = 288·16 degrees K
a = temperature lapse rate = 0·00198124 degrees C per foot change in altitude
Z = altitude above sea level
n = constant = 5·2561155

or

$$S = 1013{\cdot}25\left[\frac{288{\cdot}16 - 0{\cdot}00198124 \times H}{288.16}\right]^{5{\cdot}2561155}$$

where S = static pressure in mb
H = height in ft.

(2) Stratosphere

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

where P = pressure at altitude Z
P_a = pressure at the tropopause = 226·318814mb
Z = altitude above sea level
Z_a = altitude at the tropopause = 36089·24 ft

or

$$S = 226{\cdot}318814 \times e^{-[1{\cdot}577688316 \times 10^{-4} \times (0{\cdot}3048 \times H - 11000)]}$$

where S = static pressure
H = height in ft.

SPEED

Indicated air speed (I.A.S.)

5. I.A.S. (V_I) is the reading of the air speed indicator which forms part of the speed display. I.A.S. is provided as a synchro output from the P–S transducer and is linked to drive a moving pointer read against a fixed scale. At standard sea level density, I.A.S. is equal to the true air speed (T.A.S.), but at greater heights the I.A.S. is reduced in the same proportion as the square root of the density, so that at 40000 ft, where the standard density is one quarter of the sea level density, the I.A.S. display will indicate about half the T.A.S.

6. The air loads on an aircraft in level flight or straight dives and climbs are directly proportional to the dynamic pressure and thus to the I.A.S. For example, an aircraft flying at approximately 75000 ft at a T.A.S. of some 1300 knots has a corresponding I.A.S. of 270 knots. Thus, although

the T.A.S. is high, the forces experienced on all parts of the airframe are the same as those which they would experience at sea level at a T.A.S. and I.A.S. of 270 knots, and the air loads on the airframe are therefore determined by the I.A.S.

Formulae for I.A.S.

7. Indicated air speed as a function of P–S pressure is represented by the following equations :—

(1) I.A.S. less than speed of sound

$$V_1 = C_o \sqrt{5\left[\left(\left(\frac{P-S}{1013{\cdot}25}\right)+1\right)^{2/7}-1\right]}$$

(2) I.A.S. greater than speed of sound

$$\frac{P-S}{1013{\cdot}25} = 166{\cdot}92158 \left\{ \frac{\left[\frac{V_1}{C_o}\right]^7}{\left[7\left[\frac{V_1}{C_o}\right]^2-1\right]^{5/2}} \right\} -1$$

where C_o = Speed of sound at sea level = 661·03088 knots
S = Static pressure, mb
P = Pitot, pressure, mb
V_1 = Indicated airspeed

Speed of sound in air

8. The Mach number display indicates the ratio of T.A.S. to sonic speed when both are measured under the same atmospheric conditions. Variations in sonic speed with atmospheric conditions are given by :—

$$C = \sqrt{\Upsilon RT}$$

where Υ (gamma) = coefficient of adiabatic expansion (ICAN standard atmosphere = 1·400)
R = gas constant for unit mass of air
T = temperature of air degrees Absolute ($15^\circ C + 273{\cdot}16 = 288{\cdot}16^\circ A$)
C = Speed of sound in air (metres/sec)

Then C (knots) = $38{\cdot}94\sqrt{T}$

9. The speed of sound varies from 660·6 knots at sea level to 573·1 knots at the tropopause (36090 ft). Above this height it will remain constant, since the ICAN and WADC atmospheric temperature is constant at −56·5 degrees C.

Mach number

10. The relation between Mach number, static pressure and pitot-static pressure may be defined as

(1) Mach number less than 1

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

(2) Mach number greater than 1

$$\frac{P-S}{S} = \frac{166{\cdot}9215\,M^7}{(7M^2-1)^{2{\cdot}5}} - 1$$

where M = Mach number
P = Pitot pressure in mb
S = Static pressure in mb

Mach number computation

11. The simplified formula for the derivation of Mach number is as follows :—

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

where M = Mach number
P = pitot pressure
S = static pressure

and f denotes "a function of"

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

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

Log (P–S) (VI, phase X) and log S (V2, phase Y) are obtained from the pitot-static and static transducers respectively, and are supplied to the log Mach number servo system G1 at the summation point of SA2. V1 and V2 are out of phase, so that :

$$\log(P-S) - \log S = V1 - V2$$

A constant voltage V3 (phase X) which is the equivalent of V2 at sea level (S_o), is fed from the preset potentiometer RV1 to the summation point of SA2, so that :—

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

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

$$= V1 - V2 + V3$$

True air speed computation

12. The formula for T.A.S. is derived as follows :—

$$T.A.S. = M\ C_o$$

where M = Mach number
C_o = Speed of sound
$C_o = 38{\cdot}94\sqrt{T}$
where T = absolute temperature

$$\therefore T.A.S. = 38{\cdot}94\, M\sqrt{T}$$

Indicated temperature, T_1, is measured at the temperature probe

$$T_1 = T\,(1 + 0{\cdot}2\,KM^2)$$

where K = recovery factor (assumed equal to unity)

$$\therefore \log T.A.S. = \frac{38{\cdot}94\, M\sqrt{T_1}}{\sqrt{1+0{\cdot}2\,KM^2}}$$

The inputs to SA7 are as follows :—

(1) V4 (phase X), log M from G1
(2) V10 (phase X), ($\frac{1}{2}\log T_1$) from G6
(3) V7 (phase Y), $\frac{1}{2}\log(1+0{\cdot}2\,KM^2)$ from G1

$$T.A.S. = \frac{38{\cdot}94\, M\sqrt{T_1}}{\sqrt{1+0{\cdot}2\,KM^2}} = \frac{CM\sqrt{T_1}}{\sqrt{1+0{\cdot}2\,KM^2}}$$

$$\log T.A.S. = \log C + \log M + \tfrac{1}{2}\log T_1 - \tfrac{1}{2}\log(1+0{\cdot}2\,KM^2)$$

$$\text{and } \log T.A.S. = V11 + V4 + V10 - V7$$

Where V11 (phase Y) is fed from the preset potentiometer RV2 to the summation point of SA7.

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FIG. 1

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