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PART 1 : SECTION 1

CHAPTER 1

THE ATMOSPHERE

Introduction

1. The atmosphere is an ocean of air surrounding the earth and extending upwards for about 500 miles. The flight of all objects using fixed or moving wings to sustain them is confined to the lower layers of the atmosphere. The ability of a body to fly successfully is therefore closely associated with the atmosphere, its properties and peculiarities.

2. The earth's atmosphere can be said to consist of four concentric gaseous layers. Commencing from the earth's surface these are the troposphere, stratosphere, ionosphere, and exosphere. The boundary of the troposphere, known as the tropopause, is not at a constant height but varies from about 25,000 feet at the poles to about 54,000 feet at the equator. Above the tropopause the stratosphere extends to about 40 miles. At greater heights various authorities have at some time divided the remaining atmosphere into further regions but for descriptive purposes the terms ionosphere and exosphere, which are of German origin, are used here.

3. Through these four layers the atmosphere undergoes a gradual transition from its characteristics at sea level to those at the fringes of the exosphere which merges with the completely airless outer space. The weight of the atmosphere is about one-millionth of that of the earth, and an air column of one square foot in section, extending vertically through the atmosphere, weighs a little over 2,000 lb. Of the total atmospheric weight about three-quarters is concentrated in the troposphere, slightly less than one-quarter in the stratosphere, one three-thousandth ($\frac{1}{3,000}$) in the ionosphere and one hundred-thousand-millionth ($\frac{1}{100,000,000,000}$) in the exosphere. Fig. 1 shows average representative values of the atmospheric characteristics ; the figures for the ionosphere are calculated from natural laws and it should be noted that although very high temperatures are shown as occurring at great altitudes, the temperature of a body at these heights would be about 30°C. Although individual air molecules have the temperatures shown in Fig. 1 their extremely rarefied nature would result in a negligible heat transfer to any body that was present.

Physical Properties of Air

4. Air is a compressible fluid, and as such it is able to flow or change its shape when subjected even to minute pressures. At normal temperatures metals such as iron and copper are highly resistant to deformation by pressure, but in liquid form they flow readily. In solids the molecules adhere so strongly that large forces are needed to change their position with respect to other molecules. In fluids, however, the degree of cohesion of the molecules is so small that very small forces suffice to move them in relation to each other. Imagine a fluid in which there is no cohesion between the molecules, and therefore no internal friction, and which is incompressible ; such a fluid would be an "ideal" fluid if it were obtainable. In practice, within certain limitations, the internal friction of some fluids is so low that for normal purposes they can be regarded as ideal fluids.

5. **Fluid Pressure.** At any point in a fluid the pressure is the same in all directions, and if a body is immersed in a stationary fluid the pressure on any point of the body acts at right angles to the surface at that point irrespective of the shape or position of the body.

6. **Composition of Air.** Since air is a fluid having a very low internal friction it can be considered, within limits, as an ideal fluid. Air is a physical mixture of a number of separate gases, the proportions of which are :—

<i>Element</i>	<i>Percentage</i>
Nitrogen	78.0784
Oxygen	20.94
Argon94
Carbon dioxide03
Hydrogen... ..	.01
Neon0012
Helium0004

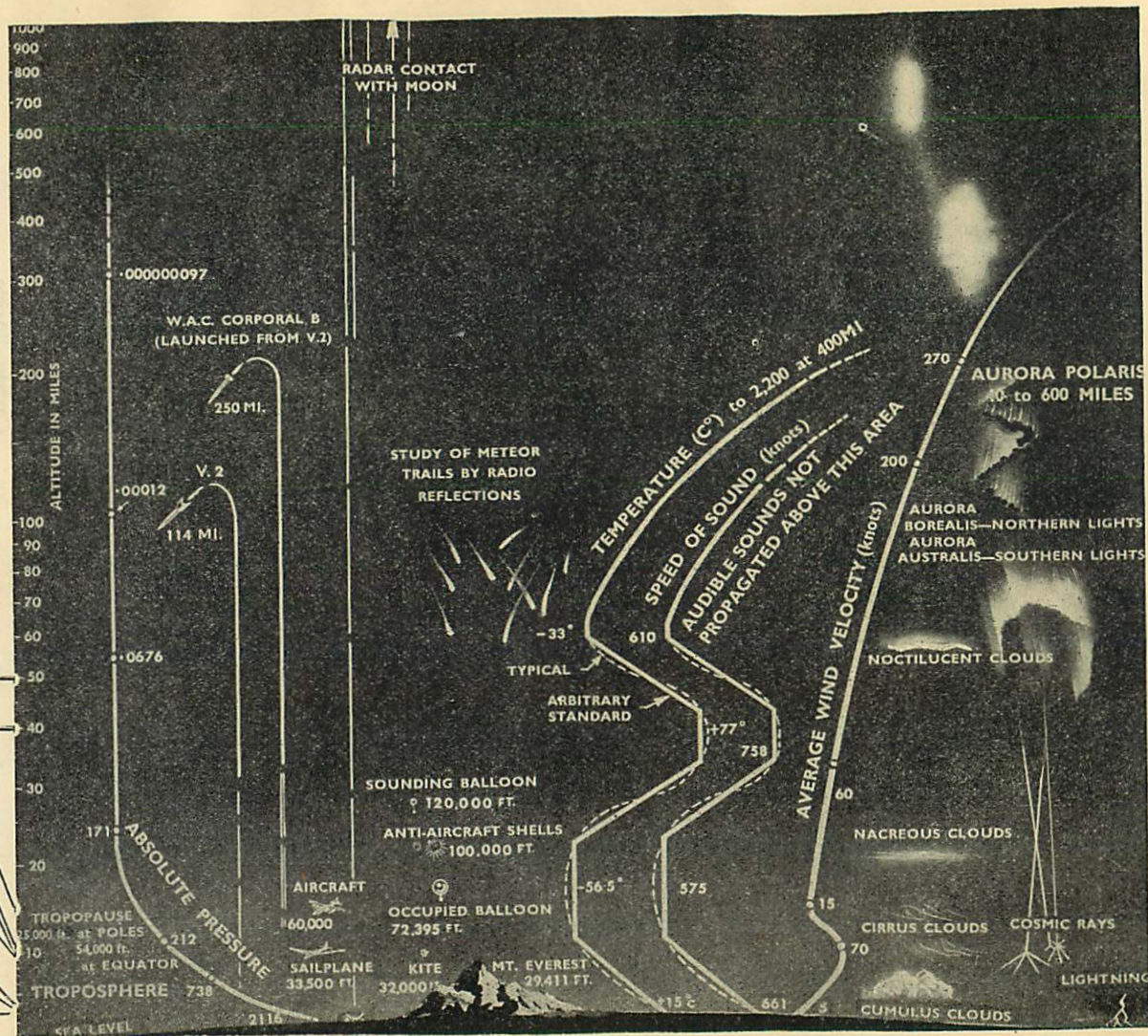
For all practical purposes the atmosphere can be regarded as consisting of 21 per cent. oxygen and 79 per cent. nitrogen, with dust particles suspended in it at the lower levels. Up to a height of some five to six miles water vapour is found in varying quantities ; the amount of water vapour in a given mass of air depends on the temperature and whether the air is, or has recently been, over large

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Fig. 1.
Atmospheric Characteristics

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- Average size of Meteorites is that of a pea.
- Twilight limits; first magnitude stars visible directly overhead when sun sets.
- Ozone layer; concentration of ozone in this region absorbs large part of sun's ultra-violet radiation.
- Blood at normal body temperature (98°F), boils at this pressure altitude (63,000 feet).
- Reciprocating engine power output falls to zero between 55,000 and 60,000 feet.
- Water vapour in body boils at pressure altitude of 55,000 feet, causing inflation of body.
- Highest altitude at which atmospheric oxygen is able to sustain life. Depends on physical condition and duration of stay (15,000 to 20,000 feet).
- Highest known community of human beings: Andes mountains, South America (18,000 feet).
- Pain not noticed by unacclimatized man at greater pressure altitude than 16,000 feet.



areas of water. The higher the temperature the greater the amount of water vapour that the air can hold.

Effect of Pressure on Density

7. As distinct from other characteristics of the earth's atmosphere, the vertical pressure distribution behaves in a regular manner and decreases steadily with altitude. At the upper limit of the troposphere, the pressure falls to a quarter of its sea-level value.

8. Under standard sea-level conditions (see para. 29) a cubic foot of dry air has a mass of .002378 slugs, *i.e.* the density of air under standard sea-level conditions is .002378 slugs per cubic foot. (The weight of a cubic foot of air under the same conditions is about .08 lb. or 1.75 ounces.) The slug is the unit of mass used in aerodynamics. The mass of a body in terms of slugs is found by dividing the weight (lb.) by the acceleration due to gravity. Therefore if a cubic foot of air weighs .08 lb., measured at a position on the earth where g is 32.17 feet per second, then its mass is .08/32.17 or .0024 slugs approximately.

9. The symbol used to denote density is ρ (the Greek letter rho). Subscripts are used to denote special conditions, *e.g.* ρ_0 means the density at sea level and $\rho_{10,000}$ denotes the density at an altitude of 10,000 feet.

10. Standard conditions for sea level are an atmosphere of 15°C. (59°F.) and a pressure of 14.7 lb. per square inch (29.92 inches Hg. or 1013.2 millibars).

11. Since air is a gas, it can be compressed or expanded. When air is compressed, a greater amount of air can occupy a given volume, *i.e.* there is a greater mass and hence a greater density. Conversely, when the pressure on a given volume of air is decreased the air expands and occupies a greater space, *i.e.* the original volume at a lower pressure contains a smaller mass of air, in other words the density is decreased.

12. The last paragraph can be summarized by saying that density is directly proportional to pressure. If the pressure is doubled the density is doubled, and if the pressure is halved so is the density. The new density is the same fractional part of the standard density as is the new pressure of the standard pressure. This statement holds good only at a constant temperature and may be

expressed thus :

$$\rho_1/\rho_2 = P_1/P_2 \text{ or } \rho_1 \frac{P_2}{P_1} = \rho_2$$

where P is pressure in lb. per square inch.

Measurement of Temperature

13. Temperature in the troposphere decreases steadily with increasing altitude. In the stratosphere the temperature is at first constant, then increases to a maximum at a height of about 14 miles, after which it starts to decrease again and reaches freezing point at about 50 miles, then increases yet again to a maximum of about 2,200°C. at about 150 miles.

14. The Fahrenheit scale of temperature is that most commonly used for general purposes ; but it is not entirely suitable, as the Fahrenheit zero has no special significance. On this scale, at sea level, water freezes at 32° and boils at 212°.

15. In scientific measurement of temperature *absolute zero* has a special significance ; for at this temperature a body is said to have no heat whatsoever. On the Fahrenheit scale this occurs at -459.4°.

16. The Centigrade scale is generally used in the R.A.F. for the recording of atmospheric temperatures and the working temperatures of engines and other equipment. On this scale, at sea level, water freezes at 0° and boils at 100°. Absolute zero occurs at -273°C.

17. To convert a temperature from °F. to °C. subtract 32° from the Fahrenheit temperature and divide the remainder by 1.8.

18. To convert a temperature from °C. to °F. multiply the Centigrade reading by 1.8 and add 32°.

19. To convert t°C. to T°K (Absolute), add 273° ; to convert t°F. to T°K (Absolute) add 459.4°.

Effect of Temperature on Density

20. The effect of increasing the temperature of a body is to decrease its density ; conversely, decreasing the temperature has the effect of increasing the density. Thus the density of air varies inversely as the absolute temperature. This statement holds good only at a constant pressure, and may be expressed thus :

$$\rho_1 \frac{T_1}{T_2} = \rho_2$$

where T is temperature in ° Absolute.

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21. In the atmosphere the fairly rapid drop in pressure as altitude is increased has the dominating effect on density, as against the effect of the fall in temperature which tends to increase the density.

22. **Combined Effect of Temperature and Pressure on Density.** To obtain the density when neither the pressure nor the temperature is standard, the formulae of paras. 20 and 12 are combined, thus :

$$\rho_1 \times \frac{P_2}{P_1} \times \frac{T_1}{T_2} = \rho_2$$

Effect of Humidity on Density

23. (a) The preceding paragraphs have assumed that the air was perfectly dry ; in practice it is never completely dry. The small amount of water vapour held in suspension in the atmosphere may be almost negligible in certain conditions, but in other conditions the humidity may become an important factor in the performance of an aircraft.

(b) Water vapour is lighter than air ; consequently moist air is lighter than dry air. It is lightest (or least dense) when, in a given set of conditions, it contains the maximum amount of water vapour. Under standard sea-level conditions the density of water vapour is .001476 slugs per cubic foot. Therefore water vapour can be seen to weigh .001476/.002378 as much as air, or roughly $\frac{5}{8}$ as much as air at sea level. This means that under standard sea-level conditions the portion of a mass of air which holds water vapour weighs $(1 - \frac{5}{8})$ or $\frac{3}{8}$ less than it would if it were dry.

Characteristics of the Atmosphere

24. The standard sea-level pressure is 14.7 lb. per square inch. Thus a column of air one square inch in section, extending from the earth's surface to the extremities of the atmosphere, weighs 14.7 lb. Therefore air at the earth's surface is subjected to this pressure and so has a density proportional to it.

25. A column of air of the same cross-section, but extending from a point one mile above the earth's surface, exerts a pressure of only 12.1 lb. per square inch. Therefore at an altitude of one mile the air pressure is 12.1 lb. per square inch.

26. As altitude is increased, the air becomes less and less dense owing to the fall in pressure. While at the earth's surface the pressure is 14.7 lb. per square inch and at one mile is only 12.1 lb. per square inch, the pressure at two miles is 9.9 lb.

per square inch and the pressure at three miles is 8 lb. per square inch. This means that in the assumed column of air reaching from the surface to the fringe of the atmosphere, the first mile of air weighs 2.6 lb., the second mile 2.2 lb., and the third mile only 1.9 lb.

27. An important factor affecting the atmosphere is the temperature. The air in contact with the earth is heated by conduction and radiation. As a result the density becomes less and the air therefore rises. In rising, the pressure drop allows the air to expand, and the expansion in turn causes a fall in temperature. Both on account of expansion and because of the greater distance from the heating effect of the earth, the temperature is lower than at sea level.

28. Experience has revealed the requirement for a *standard atmosphere* for the comparison of aircraft performances, calibration of altimeters, and other practical uses. Such a standard has been evolved and is known variously as the I.S.A. (International Standard Atmosphere) or I.C.A.N. Standard Atmosphere.

29. **The I.S.A. or I.C.A.N. Standard Atmosphere.** The I.S.A. or I.C.A.N. Standard Atmosphere, laid down by the International Commission for Aerial Navigation, assumes a mean sea-level pressure and temperature of 1013.2 millibars and 15°C. respectively, with a uniform temperature lapse rate of 1.98°C./1,000 ft. up to 36,090 ft., above which the temperature is assumed to be constant at -56.5°C.

30. As stated, the standard atmosphere is based on average figures. In fact, at a height of about 20 miles the temperature begins to increase, as shown in Fig. 1.

Altitude (feet)	Tem- perature (°C.)	Pressure lb./sq. in.	Density (Slugs/ cu. ft.)	Speed of Sound	
				f.p.s.	kts.
0	15	14.7	.002378	1,117	662
5,000	5	12.22	.002049	1,097	648
10,000	- 5	10.11	.001756	1,078	638
15,000	-14½	8.29	.001496	1,058	627
20,000	-24½	6.75	.001267	1,037	614
25,000	-34½	5.45	.001065	1,016	601
30,000	-44½	4.36	.000889	995	589
35,000	-54½	3.46	.000736	973	576
36,000	-56½	3.29	.000704	969	574
40,000	-56½	2.72	.000582	969	574
45,000	-56½	2.15	.000459	969	574
50,000	-56½	1.68	.000361	969	574

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