PART 3 : SECTION 2

CHAPTER 2

FLYING FOR ENDURANCE

Introduction

1. To keep an aircraft airborne for as long as possible on the fuel available, the I.A.S. should be that at which the engine consumes least fuel. Endurance (measured in hours) is obtained by dividing the fuel available (in gallons) by the gross fuel consumption (G.F.C.) in gallons per hour. Since the G.F.C. is assumed to be proportional to the power output, maximum fuel economy is obtained by using the level-flight speed corresponding to the lowest power output from the engine.

2. This speed is determined by the aerodynamic characteristics of the airframe, the S.F.C. of the engine at the power output required, and by propeller efficiency. In practice the speed may be modified by variation in the A.U.W. and by handling considerations.

3. The actual endurance obtained depends on the A.U.W., the altitude, the outside air temperature, and the external condition of the aircraft itself. Wind has no effect on endurance.

Derivation of Endurance Speed

4. By gradually reducing the power during level flight, a speed and power is eventually reached at which the aircraft can just maintain a height at which there is no margin of control for handling purposes. If the total drag and T.A.S. are known, this minimum power may easily be calculated, since the Power = Total Drag × T.A.S. Assuming the fuel consumption in gallons per hour to be proportional to the power output, the speed for minimum power gives maximum endurance.

5. It is interesting to note that at this low speed the drag is greater than when flying at range speed which is higher, while the power output is less. This is because the power depends on two factors (drag and airspeed) which alter when power is reduced, *but not in proportion.* It can be seen from Fig. 1 that an appreciable reduction can be made in the speed for minimum drag without incurring any large increase in drag. The overall effect is a reduction in the product of the two factors, although drag has increased and speed decreased.

6. In practice, flight at the speed for minimum power is not practicable since all ability to manœuvre disappears, and engine handling problems arise. For these reasons a margin of speed is added to improve the manœuvrability, resulting in a recommended endurance speed which should be maintained within plus or minus five knots. Endurance speed may be defined as :

The level flight speed produced by the use of minimum power, plus a margin for control and manoeuvre.

It is stated in Pilot's Notes for each type of piston-engine aircraft.

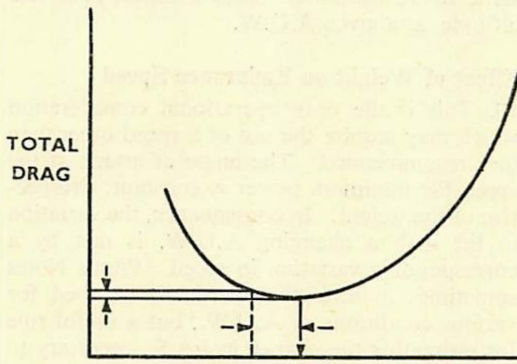

Fig. 1. Variation of Total Drag with Speed

7. From the power-required curve for a typical aircraft (Fig. 2) the best endurance speed would appear to be 95 knots. The recommended endurance speed would be some 10 knots above this speed.

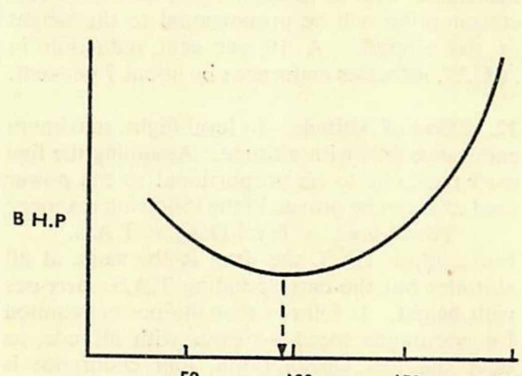

Fig. 2. Derivation of Endurance Speed

8. The recommended I.A.S. for endurance is considerably higher than the minimum possible flight speed, primarily because of the large rate of drag increase at the lower speeds (Fig. 1). Flight at these speeds would entail the use of higher powers than that for maximum endurance, and at full power, level flight is possible on some aircraft at speeds well below the power-off stalling speed.

Effect of Altitude on Endurance Speed

9. The effect of increasing altitude on the curve of Fig. 2 would be to shift the power-required curve upwards and to the right, thus increasing the T.A.S. corresponding to minimum power; this increase in the T.A.S. is obtained automatically by maintaining the same recommended I.A.S. regardless of the altitude. Therefore the same I.A.S. should be used, irrespective of the altitude, at a given A.U.W.

Effect of Weight on Endurance Speed

10. This is the only operational consideration which may require the use of a speed other than that recommended. The angle of attack at the speed for minimum power is constant, irrespective of the weight. In consequence, the variation in lift with a changing A.U.W. is met by a corresponding variation in speed. Pilot's Notes sometimes indicate the speeds to be used for various conditions of A.U.W., but a useful rule for estimating the change in I.A.S., necessary to compensate for a change in A.U.W. up to 20 per cent., is to vary the speed by half the percentage variation in weight.

Factors Affecting the Endurance

11. **Variation in A.U.W.** Since speed changes are obtained by varying the power, it follows that less power is required for the reduced I.A.S. associated with a lower weight, and that fuel consumption will be proportional to the weight of the aircraft. A 10 per cent. reduction in A.U.W. increases endurance by about 7 per cent.

12. **Effect of Altitude.** In level flight, maximum endurance falls with altitude. Assuming the fuel used per hour to be proportional to the power used, this can be proved in the following manner:

Power used = Total Drag × T.A.S.

For a given I.A.S. the drag is the same at all altitudes but the corresponding T.A.S. increases with height. It follows that the power required for endurance speed increases with altitude, as does the fuel consumption, and endurance is therefore reduced. Although maximum endurance is obtained at sea level, a safety limit is imposed in practice; if flying in cloud, the local safety height must be used and in clear conditions a height of at least 1,000 feet above ground is recommended. The approximate decrease of endurance time with altitude is as follows:

At 10,000 feet: 85 per cent. of that at sea level
At 20,000 feet: 75 ,, ,, ,,
At 30,000 feet: 60 ,, ,, ,,

This relationship may be modified slightly by the changing S.F.C., as the power required varies with change of altitude. If the necessity to fly for endurance arises when at altitude, a descent should be made to the lowest safe and practicable altitude.

13. **Effect of Additional Drag.** Since the recommended speed must be maintained to provide adequate control and manœuvrability, more power must be used to counteract extra drag arising from the carriage of external stores. Endurance will be improved by any measures the pilot can take to ensure that the aircraft is aerodynamically clean; however, with a large increase in drag, the best I.A.S. is obtainable only at a higher power setting, thus reducing the endurance.

14. **Effect of Temperature Variation.** At high atmospheric temperatures, the air density, the weight of the induction charge, and therefore the power output, are all reduced. To maintain a given I.A.S., an increase in boost and/or r.p.m. is necessary, and there may be a considerable loss in endurance. When flying for range the less dense air at altitude gives a greater T.A.S. for a given I.A.S. and the effect of temperature increase is slight.

Handling the Aircraft for Maximum Endurance

15. Maximum fuel economy is obtained only if full consideration is given to the following factors:—

(*a*) *Boost and r.p.m.* While the ideal combination for fuel economy is high boost and low r.p.m., it may be impossible to maintain the correct endurance speed without reducing throttle opening. At low r.p.m. settings this may cause the r.p.m. to fall below the lower constant-speeding limit, and they are therefore directly controlled by throttle movement. The speed may therefore have to be obtained by a medium throttle setting and a low acceptable r.p.m. It may also happen that the lower r.p.m. limit is dictated by the generator charging r.p.m. In very low atmospheric temperatures, sustained cruising at low power may give rise to engine temperature problems, while on some aircraft it may not be possible to use weak mixture at very low throttle settings. The pilot should make the choice of engine settings in the light of circumstances at the time.

(*b*) *Mixture*. Wherever possible weak mixture should be used, since the excess fuel in rich mixture is expended only on reducing combustion temperatures. Cruising in high atmospheric temperatures may cause overheating in weak mixture, which may be alleviated by the periodic use of rich mixture at appropriate intervals.

(*c*) *Supercharger Gear*. At the low altitudes at which the aircraft is flown for endurance, low gear is invariably in use. If it becomes necessary to fly at high altitude the best fuel economy is obtained by using full throttle for the boost required, with r.p.m. reduced to give the required speed. Low gear usually provides enough power even at the highest altitudes.

(*d*) *Carburettor Air-Intake Shutter*. Unless in icing conditions, "COLD" air should be used, since pre-heating of the intake gases results in reduced power output and impaired fuel economy. The degree to which endurance is affected depends on the type of carburettor, and instructions on the use of the intake shutter are included in Pilot's Notes.

(*e*) *Air Filter*. Better fuel economy results if the air filter is out of operation in flight, since least restriction is caused to the airflow into the engine. However, when at the low altitude selected for endurance, sustained cruising with the filter out of operation may cause excessive engine wear, and it may be advisable to bring the filter in. This applies especially in tropical countries where dust may extend some distance into the atmosphere.

16. **Technique for Endurance Flying.** The technique for flying for endurance may be summarized as follows :—

(*a*) Fly at the lowest safe practicable altitude.

(*b*) Adjust the throttle and r.p.m. to give the recommended speed for the prevailing A.U.W. Maintain this speed within five knots.

(*c*) Use weak mixture, carburettor cold air, air filter out of operation.

(*d*) Trim the aircraft correctly, and reduce all additional drag such as that caused by hatches, flaps, radiator shutters, etc.

(*e*) Jettison any excess load possible if maximum endurance is required.

Comparison of Range and Endurance Speeds

17. Since endurance implies minimum power and range implies minimum drag, comparison of the two speeds is not easy. However, the endurance speed may be identified by referring to Fig. 3, which plots power required against T.A.S. for a certain aircraft. The speed requiring minimum power is found at the base of the power curve. The range speed for this aircraft would be that giving the highest ratio of $\frac{\text{Speed}}{\text{Power}}$, and may be found by drawing a tangent from the origin of the graph to the power curve. The range speed occurs at the point of tangency.

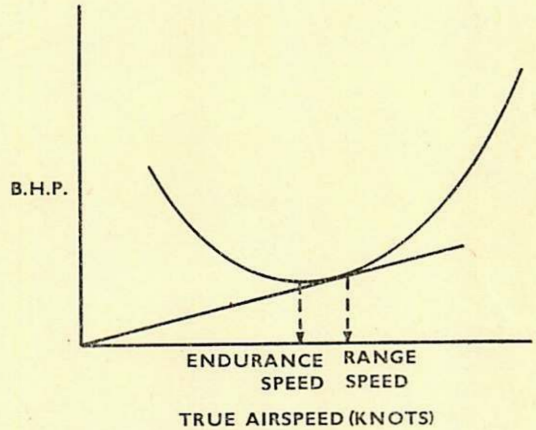

Fig. 3. Relationship between Range and Endurance Speeds

18. Range and endurance speeds differ for each type of aircraft, but in general the endurance speed is about 80 per cent. of the range speed.

Endurance on Asymmetric Power

19. Endurance is decreased by failure of an engine on twin or multi-engine aircraft. The reduction in endurance is smaller, however, than the reduction in range under the same conditions. This is because, while the range speed cannot usually be maintained without the use of rich mixture, endurance speed can often be maintained by the use of a higher weak mixture power. The main cause of the increased fuel consumption is the higher G.F.C. of the live engine, which exceeds the G.F.C. of both engines in normal endurance conditions.