PART 3 : SECTION 2

CHAPTER 1

FLYING FOR RANGE

Introduction

1. To cover the greatest air distance on the fuel available, the airframe, engine, and propeller must all operate at their most efficient settings. Since an aircraft is rarely flown to its limit of range, the term "flying for range" is normally used to indicate maximum fuel economy over any flight stage. Although financial economy is desirable, the main requirement is that of a maximum fuel reserve at the end of a flight stage for use during possible stand-offs or diversions.

2. For every aircraft there is an I.A.S. at which the total drag, and the power required from the engine to counteract this drag, is least. The propeller converts power into thrust (equal to total drag), but always with some conversion losses, which are at a minimum when the propeller is operating at its best setting. When these requirements are satisfied, the maximum number of air nautical miles per gallon (A.N.M.P.G.) of fuel is obtained.

3. The pilot may be unable to achieve this ideal condition, for reasons outlined later in this chapter, and maximum fuel economy cannot be obtained. However, guidance is given in Pilot's Notes on handling each type of aircraft, and graphs are supplied from which can be determined the best speed, height, and engine settings for the particular flight.

Derivation of Range Speed

4. The greatest fuel economy is not obtained by flying as slowly as possible, since high power is needed to fly at very low airspeeds owing to the large induced drag. The level flight speed produced by using minimum power is also unsuitable since the resulting low speed is uneconomical in terms of distance travelled per gallon used.

5. It will be shown that maximum range in level flight at a certain A.U.W. is obtained at the I.A.S. at which the total drag is least (provided that the correct engine and propeller settings are used), as follows :—

On a given flight, assuming that the fuel consumption depends on the power setting to obtain the desired I.A.S., and the time during which this setting is used, then for a given I.A.S. :

Fuel used per hour depends on the power :

POWER is proportional to DRAG × T.A.S.

Therefore for a given distance (time) total fuel used depends on :

$$\text{POWER} \times \text{TIME} \propto \text{DRAG} \times \text{T.A.S.} \times \text{TIME}$$
$$\propto \text{Drag} \times \text{DISTANCE}$$

Thus, the less the drag the less the fuel used for a given distance, and also the greater the distance flown on a fixed quantity of fuel. Since the total drag depends on the T.A.S. there is only one speed at which minimum drag is realized in level flight—this is the speed for maximum range.

Variation of Total Drag

6. The total drag for a given aircraft configuration varies with airspeed and the angle of attack, but these are interrelated as shown in Fig. 1 (sea-level total drag curve for a hypothetical aircraft, plotted against T.A.S. which in this case is also I.A.S.). Minimum total drag is obtained at an I.A.S. of 150 knots, which is therefore the optimum range speed for this aircraft. Below this speed the induced drag, associated with the high angle of attack, increases the total drag ; at a higher speed profile drag rises steeply, despite the smaller angle of attack.

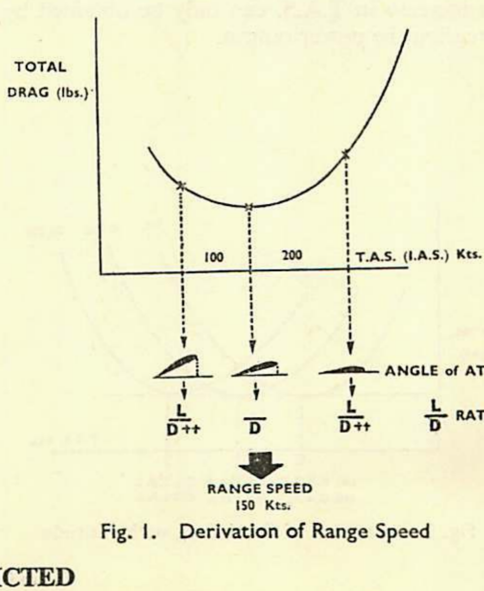

Fig. 1. Derivation of Range Speed

7. Assuming that the A.U.W. remains constant, the lift in level flight follows suit. Although the lift remains constant, the manner in which it is obtained changes with speed. At low speeds the angle of attack is increased, drag rises and produces a poor value of $\frac{\text{Lift}}{\text{Drag}}$(L/D), a ratio which gives a direct indication of the aerodynamic efficiency of the airframe. The ratio also deteriorates at high speeds, and in consequence maximum range is obtained at the angle of attack giving the best ratio of L/D. In flight, the pilot does not know the angle of attack of the aircraft, or the L/D ratio, but by flying at the recommended I.A.S. for best L/D the ideal flight condition is achieved.

Effect of Altitude on Drag

8. By plotting the total drag against T.A.S. for various altitudes, curves similar to those in Fig. 2 are obtained. For the comparatively low performance of piston-engine aircraft (*i.e.* neglecting compressibility drag) it can be said that *for a given I.A.S. the drag remains the same at all heights*, although the T.A.S. corresponding to this I.A.S. increases progressively. As far as the airframe is concerned, the recommended range I.A.S. holds good at any altitude ; and while the higher T.A.S. results in more air miles for a given time at high altitude than at sea level, this advantage is not gained without cost. *The power required for a given I.A.S. increases with altitude.* It has been shown that power required = total drag × T.A.S., and since the drag at the equivalent I.A.S. remains constant with altitude, any increase in T.A.S. can only be obtained by increasing the power output.

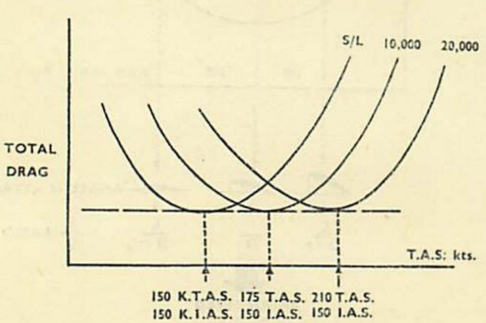

Fig. 2. Variation of Total Drag with Altitude

Summary of Airframe Considerations

9. (*a*) Maximum range is obtained at a certain I.A.S.

(*b*) This I.A.S. realizes the minimum total drag.

(*c*) Total drag at a given I.A.S. is constant at all altitudes.

(*d*) The T.A.S. corresponding to the range I.A.S. increases with altitude.

(*e*) The power required for a given I.A.S. increases with altitude.

(*f*) The I.A.S. is the pilot's guide to the attitude giving the best angle of attack and L/D ratio.

Engine Considerations

10. Fuel consumption may be measured in two ways :—

(*a*) *Gross Fuel Consumption* (*G.F.C.*) (*Gallons per Hour*). The G.F.C. varies directly with the power output, and therefore, with a fixed-pitch propeller, with r.p.m. The case of the constant-speed propeller is more involved, since the power output depends on both throttle and propeller setting. In general, for a given throttle setting, the power output is proportional to the r.p.m. A certain power output may be obtained, for instance, by using :—

(i) High r.p.m., low boost, and hence a small throttle opening.

(ii) Medium r.p.m. and boost, giving a larger throttle opening.

(iii) Low r.p.m., high boost, and full throttle. (Full throttle refers to engine and altitude conditions where the desired boost is obtained with the throttle butterfly fully open.)

The best fuel economy would result from the last case, owing to the reduced number of engine working strokes per minute, associated with the higher volumetric efficiency gained with high boost. Other mechanical considerations, such as a possibly improved propeller efficiency at low r.p.m., add to this effect. Operating data for a hypothetical aircraft are given in the table below.

Condition	*Boost* (*lb.*)	*R.P.M.*	*Mixture*
Take-off ...	12	2,850	Rich
Climb, maximum continuous	9	2,850	Rich
Maximum weak continuous	7	2,650	Weak
Range flying ...	Full throttle	2,000	Weak

If a cruising speed of 175 knots were desired, it might for instance be possible to use :—

1 lb. boost, 2,850 r.p.m. ;

3 lb. boost, 2,400 r.p.m. ;

5 lb. boost, 2,000 r.p.m. with full throttle.

The last setting would give best fuel economy. In general, consumption increases with r.p.m. and the effect of certain mechanical considerations mentioned in para. 26 *et seq*. The G.F.C. gives little indication of the efficiency of the aircraft in making use of the power obtained, and to ascertain the most economical setting for a required speed it is necessary to determine the amount of fuel used per hour at various power outputs.

(*b*) *Specific Fuel Consumption* (*S.F.C.*) (*lb. fuel used per B.H.P. per hour*). If the fuel consumption in pounds per hour is plotted for each point throughout the power range of the engine, a curve is obtained similar to that in Fig. 3. The best S.F.C. is obtained at a moderate power setting, by the use of full throttle and minimum r.p.m. ; if it can be arranged that this setting also propels the aircraft at the correct I.A.S., maximum fuel economy results.

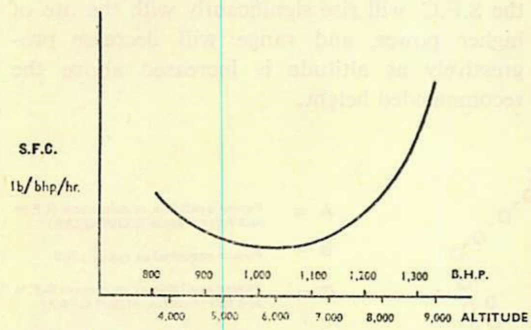

Fig. 3. Variation of S.F.C. with Power

Airframe/Engine Combination

11. By calculating the total drag at the minimum-drag speed the designer can determine the thrust horse-power (T.H.P.) required to obtain this speed. A propeller is then selected which absorbs least brake horse-power (B.H.P.) from the engine in producing the T.H.P. required, but, even under ideal conditions, the propeller efficiency rarely exceeds about 80 per cent. Next, the designer selects an engine which gives :—

(*a*) Sufficient power for the take-off and flight performance required.

(*b*) The required power for range speed, when using full throttle and minimum r.p.m.

(*c*) The lowest S.F.C. when using range power.

The airframe and engine are carefully matched to provide the best combination possible, within their individual limitations, but this may not always be practicable on aircraft with specific roles and a compromise must be made.

Determination of Best Altitude to Obtain Maximum Range

12. The two factors concerned with the determination of best altitude to obtain maximum range are :—

(*a*) The power required at range I.A.S.

(*b*) The power available, at various altitudes, using full throttle and minimum r.p.m.

Fig. 4 shows the relationship between the B.H.P. available and altitude, for a certain aircraft ; the engine has a two-speed supercharger which can maintain the weight of the induction charge up to the low-gear rated altitude of 9,000 feet. In constant temperature conditions at altitude, the sea-level power output would therefore be maintained up to rated altitude ; but assuming a decreasing temperature lapse rate, the lower temperature at altitude results in a heavier and denser charge, which causes the power output to increase to some extent with height up to the rated altitude, as shown by Fig. 4. Certain mechanical factors, such as decreased exhaust back-pressure at the higher altitudes, add to this effect.

13. Above this altitude the power available falls off steadily until the supercharger high gear is cut in. Prior to this an altitude is found at which the power available is just equal to the power required to give range I.A.S. The power required has been rising steadily with altitude, owing to the factors outlined in para. 8 ; but at this altitude the requirement is just fulfilled. Therefore this is the range height for these conditions ; it is defined as :—

> **"The full-throttle height for the power required to give the recommended range speed, using minimum r.p.m., weak mixture, and supercharger low gear."**

Referring to Fig. 3, it can be seen that as altitude is gained the S.F.C. at first falls, until range height is reached, after which it again increases. On some aircraft it may be necessary to use the maximum weak-mixture boost to maintain range speed, especially at a high A.U.W. To some extent this may restrict the altitude at which the aircraft can be flown for range ; but usually a boost setting less than maximum weak mixture may be used. The effect of increased weight is to move the power required curve to the right, the intersection with the power available curve occurring at a lower altitude in Fig. 4. At full throttle the extra power is obtained by using higher r.p.m., so that in extreme cases it may be necessary to use high r.p.m. and rich mixture initially, reducing r.p.m. as the weight decreases until weak-mixture maximum boost can supply the required power.

Factors Affecting the Choice of Range Speed

14. With the information given up to this point, the pilot should be able to climb the aircraft to the recommended height, set full throttle, and reduce r.p.m. to the low value required for range speed, as given in Pilot's Notes for the particular flight condition. The final choice of range speed may be influenced by one or more of the five additional considerations outlined below.

Recommended Range Speed

15. On most aircraft, the *optimum range speed* is a comparatively low I.A.S., and unless maximum range is essential the range speed can be increased by about 10 per cent. in the interests of control with only a slight fall in fuel economy. This is made possible by the shallow slope of the total drag curve in the region of minimum drag; the new speed is known as the *recommended range speed.*

Effect of Variation in Cruising Altitude on Range

16. **Flight Above Recommended Altitude.** As altitude is increased above the recommended height for maximum range, the power available will fall, while the power required for range I.A.S. will rise steadily. It will be necessary to increase power by using additional r.p.m., since the throttle is already fully open. At a fixed throttle setting, the power is proportional to the r.p.m. and, in fact, at the absolute ceiling of the aircraft, full throttle and maximum r.p.m. are in use. The behaviour of the boost pressure during this change of altitude will depend on the increase of r.p.m. required to obtain the desired speed at the new altitude. A limit is imposed by the maximum weak-mixture boost setting, for while it may be possible to maintain the desired speed by using rich mixture, this will cause a marked drop in range. The pilot may be obliged to accept the speed produced by maximum weak-mixture boost, provided it does not fall too far below the best range speed. A further complication is introduced by the use of high supercharger gear, for the boost will rise appreciably when this is engaged. In all cases, the S.F.C. will rise significantly with the use of higher power, and range will decrease progressively as altitude is increased above the recommended height.

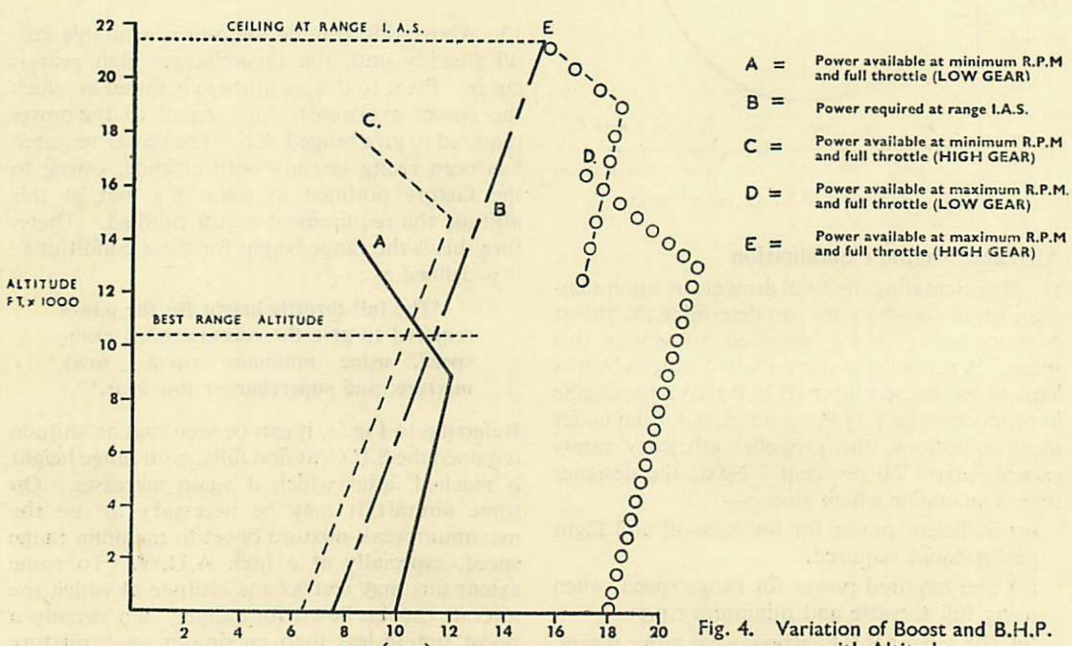

Fig. 4. Variation of Boost and B.H.P. with Altitude

17. **Flight Below Recommended Altitude.** Descending from the recommended altitude, the power available first increases (Fig. 4) until the rated altitude is reached, after which it falls steadily. Power required, on the other hand, falls steadily with decreasing altitude, resulting in a growing power surplus. The pilot may either accept the higher speed obtained (with increased drag and deterioration in L/D ratio), or close the throttle to maintain the recommended range I.A.S. The first is much more acceptable, since not only is a higher cruising speed obtained, so reducing the time during which these adverse conditions apply, but the loss in range experienced is far less than that which would result from running the engine for a longer period at a severely throttled, and therefore uneconomical, setting. Using full throttle and minimum r.p.m., the boost rises as altitude is reduced, and must not be allowed to exceed the maximum weak mixture limitation ; the speed obtained at this power setting may be the acceptable maximum, further reduction in altitude being met by closing the throttle to keep the boost within limits.

Effect of Variation in All-Up Weight on Range

18. The angle of attack for minimum drag is constant, regardless of any variation in A.U.W. ; consequently any change in lift, due to the changing weight, must be met by an alteration in speed. The best speed is proportional to the square root of the A.U.W. A practical and useful rule for estimating changes of I.A.S., necessary to compensate for changes in A.U.W. up to 20 per cent., is to vary the I.A.S. by half the percentage variation in A.U.W. ; *e.g.* A.U.W. reduced by 10 per cent., I.A.S. reduced by 5 per cent., giving an increase of 7 per cent. to 8 per cent. in the range. The fact that fuel consumption is not proportional to the A.U.W., as might be expected, is due to the variation in S.F.C. through the power range of the engine ; the power setting producing the lowest S.F.C. being suitable only at a particular A.U.W. In practice many short-range aircraft may be flown without varying the speed, while on larger aircraft it may be sufficient to use one speed on the outward journey and a modified speed on the return flight. Para. 34 *et seq.* examine the various methods of cruise control for range, including the effect of variation in A.U.W. on the speeds to be used ; once the pilot has decided which method to adopt, reference may be made to Pilot's Notes for practical details of handling.

Effect of Increased Drag on Range

19. Any increase in total drag impairs the L/D ratio and increases the power required for range speed. Anything a pilot can do to eliminate excess drag improves range, especially with such excrescences as radiator gills, flaps, and hatches. Many aircraft carry external stores, causing extra drag which must be accepted ; in such cases, if the effect on performance is marked, Pilot's Notes include the figures for these configurations. The best I.A.S. may be considerably reduced if the extra drag is appreciable, but this may be preferable to the still greater consumption resulting from misguided attempts to maintain range speed at all costs.

Effect of Wind on Range

20. During an "out-and-home" flight in given wind conditions, the total fuel used is greater than that used on the same flight in still air. *This is due to the greater number of air miles flown*, which are proportional to the strength of the wind component. The effect may be explained by taking a hypothetical aircraft with the following operating data :—

Cruising I.A.S. ...	120 kts.
Cruising T.A.S. ...	130 kts.
Cruising altitude ...	5,000 ft.
Flight distance ...	2×100 n.m. (out and home)
Fuel consumption	42 galls./hr.
Flight conditions:—	(*a*) Still air
	(*b*) 50 kts. headwind
	(*c*) 50 kts. tailwind

(*a*) *Still Air* (*Out and Home*)

Flight distance ...	200 n.m. total
Ground speed ...	130 kts.
Flight time ...	92 mins. (1·53 hr.)
Fuel used	64 galls. approx.
Air miles covered	200 n.m.

(*b*) *Into* 50 *kts. Headwind* (*Out*)

Flight distance ...	100 n.m.
Ground speed ...	80 kts.
Flight time ...	75 mins. (1·25 hr.)
Fuel used	52 galls.
Air miles covered	162·5 (130×1·25) n.m.

(*c*) *In* 50 *kts. Tailwind* (*Home*)

Flight distance ...	100 n.m.
Ground speed ...	180 kts.
Flight time ...	33 mins. (0·55 hr.)
Fuel used	23 galls.
Air miles covered	71·5 (130×0·55) n.m.

During the flight in 50-knot wind conditions, the air miles increase from 200 to 234 (162·5 + 71·5); the fuel consumption from 64 to 75 (52 + 23) gallons. A heavier aircraft, which has a higher fuel consumption per air mile than a lighter aircraft, is affected to a greater extent than a lightly loaded one. To reduce the air miles flown it may seem advisable to fly the aircraft faster in a headwind and vice versa ; but in practice it is not worth making any change in I.A.S. unless the wind is very strong—of the order of 50 knots or more. In this case the I.A.S. should be increased by 3 per cent. to 4 per cent., if it can be done without the use of rich mixture. For a tailwind, there will be a three-fold gain in reducing the I.A.S. by as much as 10 per cent. The recommended range speed is usually some 10 per cent. greater than the best speed ; the latter may be used while still maintaining a high cruising speed. Greater fuel economy results at the reduced power setting used at the lower speed ; finally, a greater time is spent in the beneficial effect of the tailwind component. There is no question of control difficulty at this lower speed, for it lies in the medium speed range of the aircraft, being some 20 per cent. higher than the minimum-power level flight speed at which control difficulty may be experienced. Engine handling presents no problem, for while the throttle is fully open power can still be reduced by decreasing the r.p.m. If this proves impracticable, it may be advantageous to leave the engine and propeller at optimum settings and reduce output by climbing slightly ; some advantage may then accrue from the increased wind velocities normally found aloft.

Factors Affecting Range Obtained

21. Since maximum fuel economy is obtained when flying at range speed, it follows that the factors which affect the choice of speed used also affect the range obtained. In the case of altitude, even with the correct speed, maximum range is not achieved unless the correct altitude is used for a given A.U.W. The following additional factor must be considered.

Effect of Air Temperature Variation on Range

22. At a given throttle opening and pressure height, the power output falls if the temperature of the intake gases is increased, since the density and weight of the induction charge fall. To maintain the original power output, the throttle must be opened, or, if it is already fully open, the r.p.m. must be increased. In both cases fuel consumption rises and the range is impaired. The effect of an air temperature increase on range is generally slight, owing to the greater T.A.S. obtained for a given I.A.S. in the less dense air. However, if the intake gases are heated by the use of a carburettor anti-icing device, the effect may be considerable since no alleviation is obtained from a higher T.A.S. The magnitude of this effect depends mainly on the type of carburettor.

Practical Handling for Range

23. **Climbing.** There are three methods of climbing economically to the cruising altitude :—

(*a*) The rich mixture climb, at optimum climb speed.

(*b*) The weak mixture climb, at optimum range speed.

(*c*) The weak mixture climb, at optimum climb speed.

The most economical method depends, amongst other things, on the airframe and engine characteristics, and on the A.U.W. ; the correct method for a given set of conditions may be ascertained from Pilot's Notes. It is generally considered that the weak mixture climbs are the most economical, provided that the rate of climb is not too slow, and that cooling difficulties can be overcome. The graph of Fig. 5 shows the typical climb path and distance covered on the climb for a heavy aircraft, when each method is employed. While the rich mixture climb uses less fuel to reach the desired height, owing to the reduced time spent at high power, the weak mixture climb is more profitable when the same ground distance has been covered.

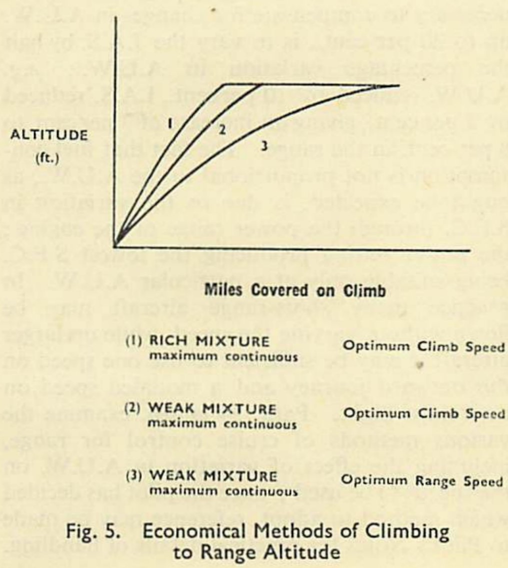

Fig. 5. Economical Methods of Climbing to Range Altitude

Use of Supercharger

24. The use of high supercharger gear results in greater mechanical power losses, and a higher boost and/or r.p.m. are required for the same power output, compared with low gear settings. The extra power is used to drive the supercharger at the higher speed. This reduces fuel economy, and consequently the change to high gear should be delayed until the low gear full-throttle height for climbing power has been reached ; *i.e.* until the boost has fallen by the amount specified in Pilot's Notes. On aircraft fitted with automatic supercharger gear changes, the control is set to change gear at a predetermined height, frequently that which gives maximum performance for a combat climb. For maximum economy when such controls are fitted, the switch should be set to "Manual" and the changeover to "Auto" made only when the altitude, or the fall in boost specified in Pilot's Notes, has been reached.

Descending

25. Best fuel economy in the descent is achieved by using the optimum range speed, with power adjusted to give the required rate of descent. Because S.F.C. tends to rise at the lower end of the cruising power range, the A.N.M.P.G. may fall appreciably if power is reduced too much, and in this case it is preferable to obtain the required rate of descent by increasing the I.A.S. rather than by reducing power to a very low value.

Cruising

26. Maximum economy under cruising conditions is achieved only if careful consideration is given to the following factors :—

(*a*) Mixture setting.

(*b*) Boost and r.p.m. setting.

(*c*) Supercharger gear.

(*d*) Use of hot air for the carburettor.

(*e*) Use of carburettor air filter.

(*f*) Position of radiator or cowling gills.

27. **Mixture.** If rich mixture is used not all the fuel is completely burnt, and at high powers the excess fuel acts as a coolant to prevent detonation. Since consumption may be increased by as much as 30 per cent., rich mixture is used only for take-off, climb, or when the power required cannot be obtained by the use of maximum weak-mixture boost and r.p.m. Weak mixture should be used at all other times, since complete burning of the fuel ensures maximum economy. If there is no manual mixture control, weak mixture is automatically obtained at boost pressures at or below the weak mixture limit stated in Pilot's Notes. On certain engines (Bristol), the throttle quadrant is marked at the economical cruising boost setting, at or behind which weak mixture is obtained. If the range I.A.S. must be exceeded for some reason, rich mixture must be used with maximum rich-mixture boost, and the r.p.m. reduced to maintain the required speed. A periodic change to weak-mixture continuous setting should be made, and once it is found that as a result of reduction of weight by consumption of fuel, etc., the required speed can be maintained in weak mixture, the flight should be continued as described in para. 28.

28. **Boost and r.p.m.** It was stated in para. 10 that high boost and low r.p.m. usually give best economy. On most aircraft the use of full throttle and minimum r.p.m. at the range altitude and moderate A.U.W. produces less than maximum weak-mixture boost ; in the early stages of a flight, however, higher r.p.m. may be needed to give the required speed, and this may cause the boost to reach, or even exceed, the weak mixture maximum. But as A.U.W. falls, the r.p.m. can be adjusted to give the lower speed required, and the boost falls. The lower limit of the r.p.m. adjustment is usually governed by the generator cut-out r.p.m., or by the onset of marked vibration ; the latter may also occur at other r.p.m., and these settings should be avoided. If, at full throttle with maximum permissible weak-mixture boost and minimum r.p.m., the I.A.S. is still above that required, further reduction of power can be achieved only by a reduction of boost. It may be possible to achieve a balance of power by climbing slightly (see para. 16). On aircraft fitted with inter-connected throttle and propeller controls, the r.p.m. lever should always be set to the AUTO position. After long periods at high boost and low r.p.m., the use of high-octane fuels may result in lead oxide being deposited on the spark plugs, valves, and the interior of the combustion chamber ; this may be prevented by the addition to the fuel of ethyl dibromide and similar compounds. Alternatively, the r.p.m. should be increased to maximum permissible for short periods at intervals of 15 or 30 minutes during flight, and afterwards returned to cruising r.p.m.

29. **Supercharger Gear.** Maximum range is generally produced by using low gear, but at moderate and high altitudes the use of low gear

may necessitate high r.p.m. to maintain the desired I.A.S. Under such conditions it would be profitable to use high gear, but when in doubt Pilot's Notes should be consulted for the correct choice of supercharger gear.

30. **Carburettor Air Intake.** Unless the carburettor is temperature-compensated, the use of hot air must enrich the mixture, impairing range and fuel economy. The effect may be serious owing to the factors outlined in para. 22, but much depends on the type of carburettor. The mixture provided by some carburettors, with the intake in the cold position, is very weak, causing overheating and rough-running at high boost low r.p.m. settings ; consequently the engine runs better with the intake in the hot position. In such cases, owing to the loss of power from the excessively weak mixture in "cold" air, there is little or no loss in range when using "hot" air. No general rule can be laid down, but, unless specified in Pilot's Notes, cold air should be used at all times unless icing conditions are expected.

31. **Air Filter.** Where an air filter is fitted, unfiltered air should be used in flight, since any interference with the airflow into the engine reduces engine efficiency.

32. **Radiator Shutters and Cooling Gills.** Where thermostatically-controlled shutters are fitted, the AUTO position should be selected, thus ensuring the minimum cooling drag compatible with maintaining temperature limitations. Manually-operated devices should be closed as far as possible while maintaining the correct temperatures.

PROCEDURE TO OBTAIN MAXIMUM FUEL ECONOMY

Summarized Procedure

33. The procedure for setting an aircraft to fly for maximum range may be summarized as follows :—

(*a*) Climb to the recommended altitude, using the method outlined in Pilot's Notes.

(*b*) Set the throttle fully open.

(*c*) Reduce the r.p.m. until the recommended I.A.S. is obtained.

(*d*) If necessary, adjust the speed for prevailing wind conditions.

(*e*) Use weak mixture whenever possible.

(*f*) Use low supercharger gear whenever possible.

(*g*) Use carburettor COLD AIR.

(*h*) Select air filter OUT.

(*j*) Select the best setting of the radiator flaps or cowling gills.

(*k*) Reduce drag to a minimum by trimming the aircraft correctly and checking that all hatches are closed, flaps retracted, etc.

CRUISE CONTROL TECHNIQUES

Introduction

34. In the foregoing paragraphs it has been assumed that the aircraft is to be flown for the greatest range. There are three principal techniques whereby an aircraft can be flown for range. These are :—

(*a*) Adjusting the recommended range I.A.S. to the correct value as the A.U.W. falls.

(*b*) Maintaining a constant I.A.S.

(*c*) Maintaining a constant power.

35. Fig. 6 shows the comparative effects on A.N.M.P.G. of employing these methods and shows I.A.S./A.N.M.P.G. curves for a typical four-engine aircraft, at four different weights, at 10,000 feet, and includes the optimum range speed (PQ), the recommended range speed (OA), a selected constant I.A.S. (OB), and the speed produced at various weights using constant power. The three methods are discussed below.

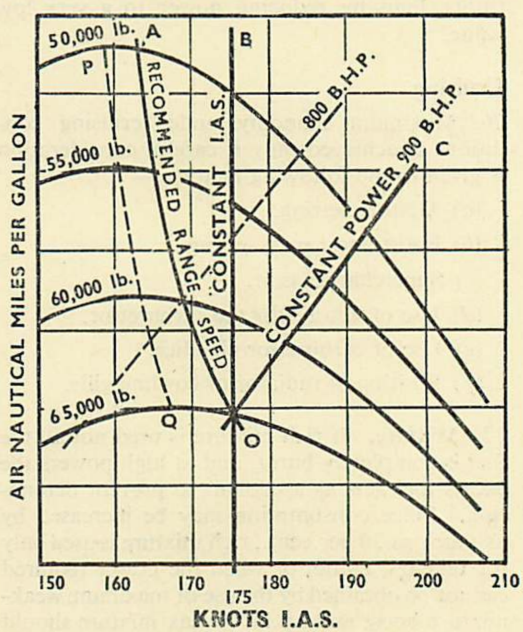

Fig. 6. I.A.S. versus A.N.M.P.G. for a Four-Engined Aircraft

Varying the Range Speed with Decreasing A.U.W.

36. By adjusting the recommended speed during flight for changing conditions of A.U.W., the greatest economy is obtained on long-range flights. The greater the distance to be covered the greater the advantage in using this method. The advantages and disadvantages of this method are :—

(*a*) *Advantages.*

(i) It is suitable for flight distances over which the less efficient methods of operation cannot be used with safety.

(ii) It is best used when maximum payload is more important than saving time.

(iii) It ensures maximum fuel economy.

(*b*) *Disadvantages.*

(i) It gives the longest flight time.

(ii) It is often difficult to compensate for variable winds with any degree of efficiency, and flight planning is complicated.

(iii) Frequent power adjustments may be necessary to maintain an exact I.A.S.

Constant I.A.S.

37. (*a*) *Advantages.*

(i) Maximum range may be closely approached if a suitable airspeed is selected.

(ii) One airspeed is sufficient for the normal weight and altitude range of most aircraft.

(iii) Flight planning and navigation are simplified.

(*b*) *Disadvantage.* More fuel must be carried to provide the same safety margin when compared to the recommended range speed technique used over the same distance.

Constant Power

38. (*a*) *Advantages.*

(i) This method achieves acceptable fuel economy for short distances, where the weight of the fuel is a small proportion of the A.U.W. The larger and more efficient the aircraft, the greater becomes the absolute distance over which this applies.

(ii) Maintaining constant power is usually the simplest procedure, affording less chance of incorrect operation of the aircraft.

(iii) At any given initial power, and therefore airspeed, for similar conditions, this method gives a shorter flight time than the other two methods.

(*b*) *Disadvantages.*

(i) Its efficiency falls rapidly as the flight distance and fuel used increases. The high initial power necessitated by the initial weight must be maintained, or alternatively a lower power may be selected which at the initial weight may affect controllability.

(ii) The difference in power requirement between this and other methods increases progressively as the flight continues, particularly when the A.U.W. is considerably reduced, *e.g.* when bombs are dropped.

Summary

39. Where fuel economy is less important than flight time, or on short flights involving little fluctuation in A.U.W., the constant I.A.S. or constant power methods are more suitable. In all other cases the constantly-adjusted recommended range speed method is usually the best.

USE OF FLIGHT PLANNING CHARTS

Introduction

40. To assist in preparing the accurate flight plan essential to any flight, Pilot's Notes include flight planning charts comprising three curves plotted against T.A.S. The I.A.S. is not used because in still air the T.A.S. represents the actual ground speed at any height, simplifying the flight planning process.

41. Each chart consists of three interrelated sections, in which the A.N.M.P.G., engine r.p.m., and consumption in gallons per hour are all plotted against T.A.S. for various A.U.W. There may be two or more charts for particular heights, while a means of assessing the reduction in weight due to fuel consumption, and its relation to the speed used, may also be included.

42. The altitudes are chosen taking into account the role of the aircraft and, where appropriate, its performance in both high and low gear. Fig. 7 shows a typical flight planning chart for an aircraft at 5,000 feet in low gear. Charts may also be included which take into account the effect of carrying certain external stores, and of variation in fuel quantity carried.

43. A full explanation of the method of using flight planning charts is given in the succeeding paragraphs.

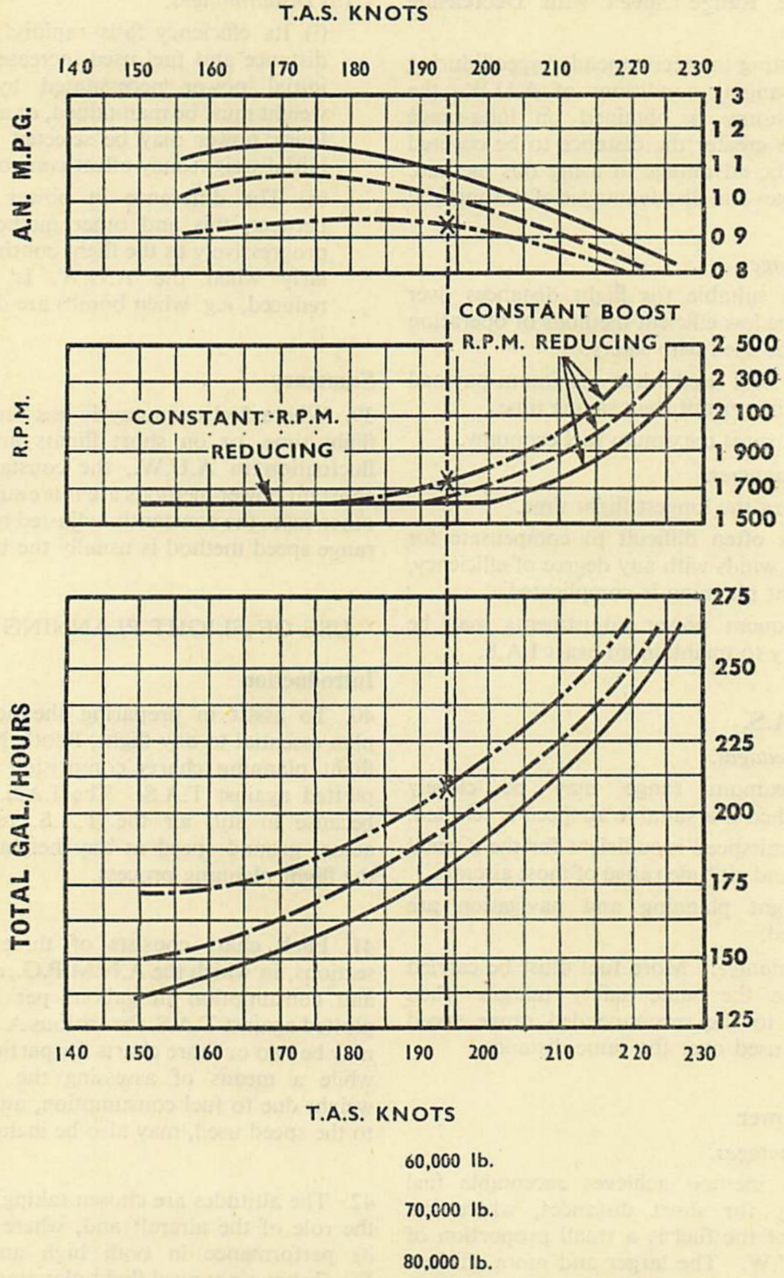

Fig. 7.

Typical Flight Planning Chart for a Piston-Engined Aircraft at 5,000 ft. in Low Gear

Procedure for Use of Flight Planning Charts

44. **Selecting the Cruising Altitude.** After making allowance for adverse winds or other factors, select the altitude at which the peak of the relevant A.N.M.P.G. curve gives the highest A.N.M.P.G. On short flights it may be uneconomical to climb to a high altitude, since the fuel used on the climb may not be recovered during the brief flight at that altitude.

45. **Selecting the Cruising Speed.** When maximum economy is more important than flight time, select an airspeed about 10 knots above that corresponding to the peak of the A.N.M.P.G. curve for the starting A.U.W., in the upper section of the chart. Taking any pressure error into account this should give an I.A.S. within 10 knots of the speed recommended in Pilot's Notes for maximum range. If a given E.T.A. is to be achieved, first divide the distance by the time available. Correct for the expected wind and allow for the distance covered on the climb. The required T.A.S. is the result, and the chart may then be used as before to ascertain the r.p.m. and fuel consumption. If the T.A.S. obtained is high the fuel consumption is greater than when flying for maximum economy, and conversely, no advantage is gained by flying at a lower T.A.S. than that corresponding to the peak of the relevant A.N.M.P.G. curve, in order to achieve the desired E.T.A.

46. **Selecting the Cruising r.p.m.** The edge of a rule, placed vertically on the chart on the airspeed selected, intersects the appropriate r.p.m. curve, in the centre portion of the chart, at the value which gives the selected T.A.S. when using maximum cruising boost. If flying above the full-throttle height for this boost at selected r.p.m. the boost actually obtained should be accepted, unless Pilot's Notes for the type indicate that, for these conditions, it would be advantageous to change to high gear. In flight the predetermined r.p.m. may not give the required I.A.S. and hence T.A.S. ; the resulting I.A.S. should be accepted unless, when flying for range, it is more than 10 knots above or below the recommended I.A.S. In this case power should be adjusted to keep the I.A.S. within these limits. If flying for a required E.T.A. the T.A.S. should be maintained by adjustment of the r.p.m., and, in both cases, a new fuel consumption estimate is required. This can be determined from the chart by finding the fuel consumption corresponding to the new r.p.m. setting.

47. **Determining the Fuel Consumption.** The intersection of the edge of the rule with the appropriate gallons per hour curve in the lower section of the chart will show the fuel consumption. Knowing the fuel consumption it is now possible to calculate the time taken to reduce the weight by an arbitrary figure, say 5,000 lb. At this stage of the flight the I.A.S. can be adjusted (according to the rules stated in para. 18) to give the new recommended speed to correspond with the reduced weight. At the same time the new power setting can be determined from the flight planning charts ; if the rule now intersects the flat portion of the A.N.M.P.G. curve, the available power at maximum cruising boost and lowest practicable r.p.m. is greater than the power required. The boost should be reduced accordingly.

48. **Planning a "Constant-Power" Flight.** After selecting the altitude to be used, a T.A.S. is selected which will, in effect, be too slow for the initial half of the flight and too fast for the latter half. For maximum range on a constant-power flight, the T.A.S. is slightly above that corresponding to the peak of the A.N.M.P.G. curve for the mean A.U.W. of the flight. The required r.p.m. and the fuel consumption, which do not vary significantly during the flight except for the climb, can then be ascertained from the chart.

49. **Determining the Endurance Speed.** The aircraft should be flown at the speed corresponding to the minimum value of the gallons per hour curve at the foot of the chart, unless this speed (after conversion from T.A.S.) is less than the minimum practicable level flight I.A.S. Owing to considerations of control and manœuvre, the recommended endurance speed given in Pilot's Notes may be greater than the speed thus obtained.

Range on Asymmetric Power

50. The aim should be to maintain as closely as possible the recommended I.A.S. using weak mixture. If altitude cannot be maintained at this power and I.A.S. two courses of action can be considered :—

(*a*) Accept the rate of descent, if practicable, in order to maintain the range speed using weak mixture. When maximum range is essential this method is best ; the altitude eventually settles at a constant figure since the power required at a given I.A.S. decreases with altitude.

(*b*) If altitude must be maintained then there is no alternative but to use a rich mixture power.

There is an infinite number of variables between (*a*) and (*b*) and the exact power used depends on the prevailing conditions of altitude, distance to go, and A.U.W. Each case must therefore be judged on its merits, bearing in mind that the recommended range speed is the most efficient, and that the greater the departure from this speed the greater is the loss in range.

SUMMARY OF RANGE AND ENDURANCE FLYING PISTON-ENGINE AIRCRAFT

	RANGE		ENDURANCE	
EFFECT OF	ON RANGE SPEED	ON RANGE OBTAINED	ENDURANCE SPEED	ENDURANCE OBTAINED
VARIATION IN A.U.W.	Speed varied by half percentage variation in A.U.W. (up to 20%)	Varied by three-quarters of the percentage variation in A.U.W. Weight down, range up	As for range speed	As for range
ALTITUDE	Unaffected by altitude	Maximum at range height, reduced above and below	Unaffected by altitude	Maximum at sea level
WIND	Increased 4 to 5 % in headwinds over 50 kt. and vice versa	Reduced economy on round flight into and downwind, compared with round flight in still air	No effect	No effect
ADDITIONAL DRAG	May be reduced in cases of large drag increment	Reduced in proportion to drag increase	Must be maintained, even if extra power necessary	Reduced in proportion to additional drag
VARIATION IN TEMPERATURE	No effect	Range reduced in increased outside temperatures, but offset by increased T.A.S. owing to falling density	No effect	Reduced, but to greater extent than range for similar conditions
USE OF ASYMMETRIC POWER	Reduced, or only possible with very high power	Varies from considerable reduction to small reduction ; never an increase	Normally obtainable, but rich mixture may be necessary	Reduced, but to much less extent than range for similar conditions