PART 4: SECTION 2

CHAPTER 1

ENGINE FAILURE DURING TAKE-OFF AND IN FLIGHT

Introduction

1. Flight on asymmetric power is the condition when, owing to engine failure, an aircraft is flown with an unbalance of thrust about the normal axis, this unbalance causing a yawing moment which is counteracted by suitable displacement of the control surfaces.

2. The handling techniques used for flight on asymmetric power are common to both jet and piston-engine aircraft, differing only in engine handling considerations. Pilot's Notes give details of the technique and speeds required when using asymmetric power, the information in this chapter being of a general nature. *It is emphasized that Pilot's Notes, A.M.F.O.'s, and the Flying Order Book should be studied before practising the use of asymmetric power.*

The Basic Problem

3. If one wing-mounted engine of a twin- or multi-engined aircraft fails when under power, two immediate effects occur :—

(*a*) A yawing moment is applied owing to the asymmetry of the thrust line. On propeller-driven aircraft the yaw is aggravated by the possibly high drag of the windmilling propeller. The total moment can be very large, particularly when at full throttle and at low speeds, and is the primary cause of any handling difficulties.

(*b*) With propeller-driven aircraft, a rolling moment is applied owing to the reduction in the slipstream velocity, and hence lift, over the wing behind the failed engine ; this effect is usually small and well within the ability of the ailerons to counter, except possibly at very low speeds or when high lift flaps are used.

4. If corrective action is not taken immediately, the aircraft yaws towards the dead engine causing a skidding motion which, via dihedral, results in a roll towards the dead engine ; at the same time the nose starts to drop. This further effect of the yaw is often very strong.

5. It is important to grasp the fact that the yawing moment is the root of the problem. Therefore the first corrective action by the pilot must be to stop the yaw either by the immediate application of rudder against the yaw or by throttling back the live engine, or a combination of both. The first reaction should not be the instinctive one of using the ailerons to oppose the yaw and roll movement, since the drag of the down-going aileron may accentuate the yaw.

Forces Acting on the Aircraft when on Asymmetric Power

6. An aircraft can fly steadily on a straight course under asymmetric power with an infinite number of combinations of bank and sideslip, *i.e.* of aileron and rudder settings. This apparently complex statement can be shown to be, in fact, a simple one when the matter is considered from the viewpoint of the side forces acting on the aircraft.

7. Since an aircraft is subject to the laws of motion, if it is moving in a straight line there can be no side force acting on it ; if this was not so and an unbalanced side force was acting on the aircraft the flight path would inevitably be curved.

8. The three principal factors contributing to the existence or otherwise of a side force are:—

(*a*) *Side-Slip* (*Yawing Motion*). A side-slipping motion sets up side forces, since the fuselage and fin act as aerofoils.

(*b*) *Rudder*. When rudder is applied, a side force is generated at the rear of the aircraft which tends to yaw the nose in the opposite direction, the aircraft pivoting about the C.G.

(*c*) *Ailerons*. When the aircraft is banked the direction of the total lift vector is tilted, giving one upward component that balances the weight and one sideways component that acts as a side force.

In addition to these major factors are the minor but still possibly appreciable effects of :—

(*d*) *Torque*. Propeller torque tends to roll the aircraft in the opposite direction to that of propeller rotation and increases with power. Torque has a slight effect on the margin of control while using asymmetric power ; if the torque reaction tends to lift the dead engine, *i.e.* oppose the rolling moment due to the side-slip, then its effect is beneficial. On aircraft having contra-rotating propellers there is no torque effect, since the torque of each half of the propeller counteracts the other.

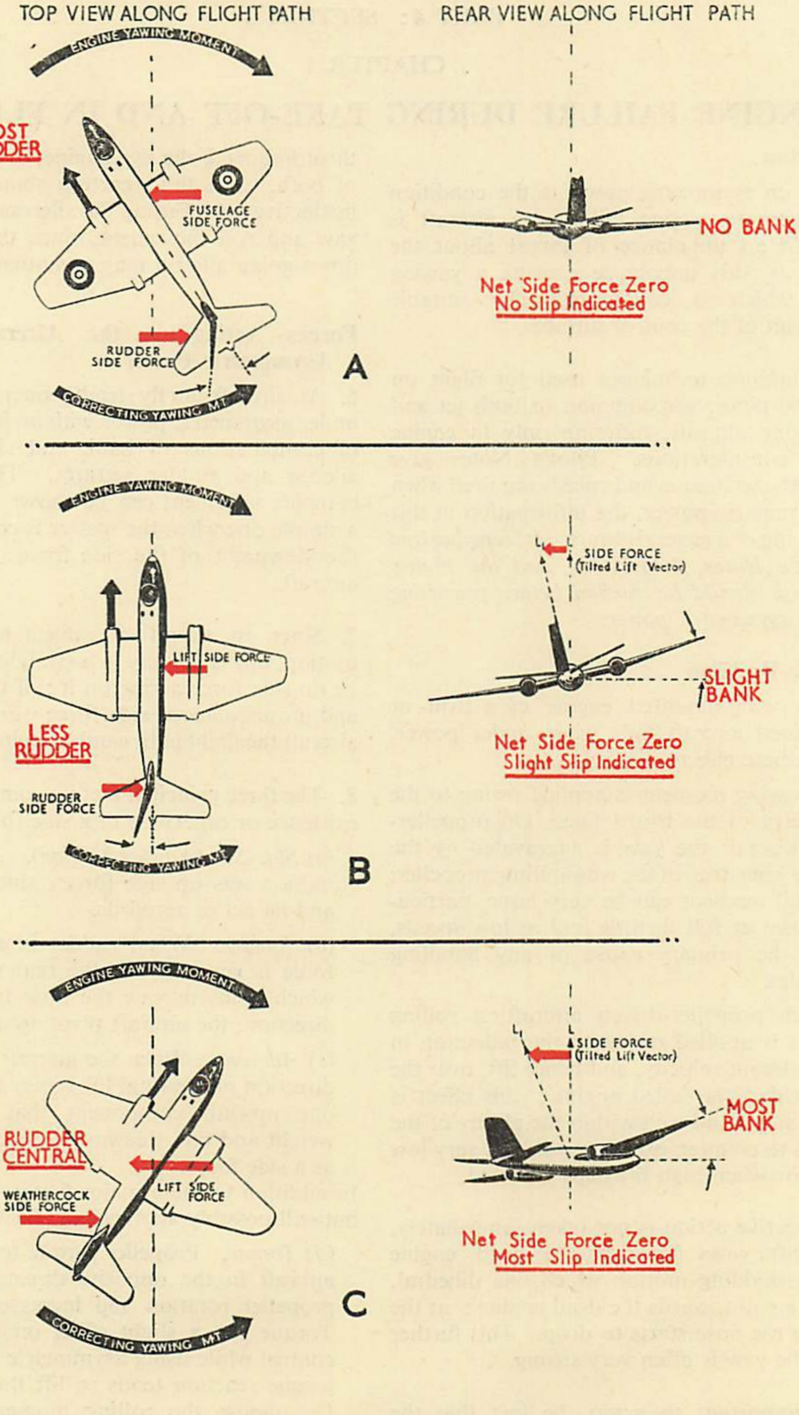

Fig. 1.

Forces Acting on the Aircraft in Asymmetric Flight (*e*) *Yawed Plane of Propeller Rotation.* When the plane of rotation of the propeller is not at right angles to the path of flight, the strength of the yawing moment (propeller thrust (lb.) × distance from the C.G. (ft.)) is changed. For example, if the port propeller rotates clockwise (viewed from the rear) then yawing the nose to starboard (side-slip to port) means that the blades on the right-hand (down-going) side of the propeller disc are operating at a higher angle of attack by virtue of the changed relative airflow and thus give more thrust. This shifts the centre of thrust to the same (right-hand) side of the disc. In this example the yawing moment of the engine would be reduced owing to the effectively shortened distance from the C.G. If the direction of rotation were reversed, the yawing moment would be increased.

(*f*) *Slipstream Effect.* One engine can have a greater effect than the other on the yawing characteristics of the aircraft; depending on the direction of rotation of the propeller, the spiral path of the slipstream meets the fin and rudder at an angle of attack.

Balanced Flight

9. Consider, for simplicity, the three major forces alone. If these can be arranged so that the net side force is zero, then the aircraft will fly on a constant heading and is therefore controllable. Fig. 1 shows three possible modes of flight at a constant heading (zero side force) on asymmetric power under a given set of conditions.

10. In Fig. 1 A the side force caused by the yawed fuselage and fin is balanced by the side force set up by the deflected rudder, so no bank is needed. In this condition the needle or ball of the slip indicator is central—*no side-slip is indicated.*

11. In Fig. 1 B the fuselage and fin are not yawed and hence no side force is derived from the fuselage and fin. The rudder must be used to counter the yawing of the live engine and the rudder side force is then counteracted by banking towards the live engine to obtain a balancing side force. *Some side-slip is indicated by the ball or pointer.*

12. In Fig. 1 C the rudder is central and the aircraft is side-slipped until the yawing moment arising from the side force set up by the directional (weathercock) stability counters the yawing moment of the engine. Since this produces a greater side force than in the example at B, more bank (about 15°) is needed to obtain the greater balancing side force needed. *A large amount of side-slip is shown by the slip indicator.*

13. In practice, at low speeds, most pilots fly somewhere between Fig. 1 B and C with the wings banked slightly (not more than 10°) towards the dead engine; at higher speeds no bank is necessary. With the rudder central, about 15° of bank is required at low speed but, since a higher total drag is set up by the extreme yawed attitude, this method is undesirable since it can lead to fin stall and loss of control and in some marginal cases the drag may be so high that level flight cannot be maintained.

Rudder Effectiveness

14. From the foregoing it can be seen that the effectiveness of the rudder is of prime importance to the prevention of yaw. Rudder effectiveness on a given aircraft depends on the I.A.S. If the I.A.S. is decreased progressively at a constant power setting under asymmetric conditions, a speed will be reached below which the aircraft can no longer be directionally controlled with the rudder at its maximum deflection. Below this speed the aircraft will yaw, and then roll uncontrollably.

Critical and Safety Speeds

15. (*a*) *Critical Speed.* This is defined as the lowest possible speed on a multi-engine aircraft at which, *at a constant power setting* and aircraft configuration, an individual pilot is able to maintain a straight course after failure of one or more engines.

(*b*) *Safety Speed.* This is defined as the lowest speed above the stalling speed at which, on an aircraft in the take-off configuration, and following failure at take-off power of the engine whose failure most affects directional control, a safe margin of control is ensured for the average pilot; the safety speed is therefore always higher than the critical speed as defined in sub-para. (*a*).

Critical Speed

16. The critical speed is affected by :—

(*a*) The power output of the live engine.

(*b*) The angle of bank.

(*c*) Altitude.

(*d*) Weather conditions (turbulence).

(*e*) Loading (C.G. position).

(*f*) Setting of the flaps.

(*g*) On propeller-driven aircraft, which engine has failed. (Slipstream effects.)

(*h*) Asymmetric drag.

(*j*) The strength and skill of the pilot.

If at any time the speed falls below the critical speed and the aircraft cannot be prevented from yawing, *power must be reduced on the live engine.* Any attempt to do otherwise is of no avail. The live engine must be throttled back until the yaw is controllable.

17. **Power Output of the Live Engine.** As the force initiating the yaw is proportional to the thrust on the live engine, then for a given I.A.S. more rudder will be required to maintain directional control as the thrust is increased. Therefore the higher the thrust from the live engine the higher the I.A.S. at which the pilot reaches full rudder deflection and directional control is lost.

18. **Angle of Bank.** Bank should not be used unless it is necessary in the interests of control. The maximum amount used should not exceed 10°, and it is easy to over-estimate this small amount and thus worsen the situation. Ideally the wings should be kept level whenever possible, since the slip indicator can then be kept centred thus giving a positive *instrument* indication that balanced flight is being maintained ; as long as the slip indicator is central with the wings level, the aircraft must be steering a straight course and the speed must therefore be above the critical speed.

19. **Altitude.** The thrust from the live engine for a given throttle setting decreases with the height, and therefore the critical speed for full power at altitude is less than at sea level.

20. **Weather Conditions.** On a day with rough and gusty conditions the margin of control is reduced. If the rudder is almost fully over in one direction, a very limited amount of movement is available for corrections necessitated by air turbulence.

21. **Loading (C.G. Position).** Since all yawing movements take place about the C.G., if the aircraft is at an aft C.G. at the time of engine failure the effective moment arm of the rudder is reduced. The greater the permissible limits in the travel of the C.G. the larger will be the difference between the effects of engine failure at the two C.G. limits.

22. **Setting of the Flaps.** The position of the flaps may have a marked effect on the airflow over the tail surfaces. As this effect varies from type to type no general rule can be laid down. The effect on a particular type can be found by experiment and if it is significant it is mentioned in Pilot's Notes.

23. **Propeller-Driven Aircraft.** Whenever propellers are used the considerations of para. 8(*d*) to (*f*) apply. In addition, any drag that can be reduced on the same side as the dead engine reduces the total force tending to yaw the aircraft in that direction. On most propeller-driven aircraft this is best achieved by feathering the propeller of the failed engine and placing such items as gills and oil coolers to the minimum drag position ; it should be noted that the minimum drag position is not necessarily the fully closed position but usually slightly open, so that the surface of the adjustable shutter lies parallel to the local airflow.

24. **Strength and Skill of the Pilot.** On many aircraft, when high thrust is being used at low speed, the foot loads are considerable and the physical strength and length of leg of the pilot have an important bearing on the amount of rudder he can apply. A skilful pilot can concentrate his entire attention on controlling the aircraft directionally while completing his other actions almost instinctively. The position and availability of the trim tabs also have a bearing on the amount of rudder that can be applied.

Safety Speed

25. The safety speed, which should be attained as soon as possible after take-off, gives the average pilot a margin of control so that if an engine fails while still at take-off power and with the aircraft in the take-off configuration, the aircraft will not immediately become directionally uncontrollable. The pilot has time, therefore, to take corrective action in spite of any temporary delay caused by the unexpectedness of the failure and the lag in his own reaction time. Engine failure at safety speed means that control can be maintained and a straight course steered by means of instant and coarse use of the rudder and the use of the ailerons as required ; no other immediate action need be taken.

26. Some aircraft, when taking off at or near their maximum weight, cannot maintain height if an engine fails ; in this case the power of the live engine should be used to make a controlled

landing, the undercarriage being raised, or at least unlocked, if the landing area is unsuitable for a wheels-down landing. When the power available from the remaining engine is just sufficient to maintain height, delicate handling is necessary, and care must be taken to avoid all but the shallowest turns while positioning the aircraft for a landing.

Identification of the Failed Engine

27. On all types of twin-engine aircraft there is no problem in identifying the failed engine; the aircraft will always yaw towards the failed engine. However, on an aircraft with four piston engines the yaw only indicates on which side the failure has occurred and does not identify the failed engine. In the absence of fire or other obvious damage, the engine instruments should be checked and if there is still no obvious indication of failure the inboard engine should be throttled slowly back. If the yaw does not increase it can be assumed that this is the failed engine. If the yaw increases then the other engine has failed. As soon as positive identification has been made the propeller of the failed engine should be feathered. On turbo-jet aircraft the falling j.p.t. and r.p.m. will always show the failed engine.

Acceleration on Asymmetric Power

28. The ability to accelerate on asymmetric power depends on the amount of power that can be used while control is retained and the reduction that can be made in the drag.

29. Engine failure in the most adverse configuration and at the highest weight (*i.e.* wheels down, partial flap), makes it essential that the drag be reduced to a minimum, so that the aircraft can accelerate to a safe speed on the power available. Therefore the undercarriage and flaps should be raised and jettisonable stores dropped as soon as possible.

30. When the aircraft is at the critical speed, two methods of attaining a safer condition, or a combination of them, can be used. The necessity to increase the speed is paramount. The aircraft can be dived until control has been regained or the live engine may be partially throttled back. In practice a combination of these methods is the normal procedure.

31. Although it is important to know the critical speed for a given set of conditions, it is also of value to know the speed at or above which, under the worst conditions, directional control can be maintained.

ENGINE FAILURE DURING TAKE-OFF

Considerations

32. Engine failure during take-off on a twin- or multi-engine aircraft can be considered under three main headings:—

(*a*) Engine failure below the refusal speed (refusal speed is defined in para. 33).

(*b*) Engine failure above refusal speed but below safety speed:—

(i) On the ground.

(ii) In the air.

(*c*) Engine failure above safety speed.

On some later types of aircraft, full control can be maintained after engine failure at any stage, and the take-off completed in all but the most adverse conditions of runway length and A.U.W. The considerations of this chapter are centred around aircraft on which control can be lost after engine failure.

Refusal Speed

33. The refusal speed is the maximum speed, for a given length of runway, from which a particular aircraft could be brought to rest in the remaining length of a dry runway, using maximum (anti-skid) braking applied not more than five seconds after one engine has failed.

Engine Failure Below Refusal Speed

34. If the failure occurs below refusal speed, abandon the take-off. If for some reason it becomes apparent that the aircraft cannot be stopped or obstacles avoided, the undercarriage must be raised. The decision to deliberately swing the aircraft with the wheels down is seldom justified in view of the more extensive damage incurred when the undercarriage structure collapses under a side load.

Engine Failure Above Refusal Speed but Below Safety Speed

35. **On the Ground.** Abandon the take-off and proceed as in para. 34. It is almost certain that the wheels will have to be raised.

36. **In the Air.** On the majority of heavily laden, high-performance aircraft this usually means a forced landing straight ahead. The live engine should be used within the limits imposed by the critical speed, to select the best landing area. However, if the critical speed has been attained, and particularly if the overall conditions allow power to be reduced on the live engine, then the

immediate corrective use of rudder assisted if necessary by a slight amount of bank may enable the aircraft to be kept on a straight course. The undercarriage should be raised and all jettisonable external stores should be dropped, and, on propeller-driven aircraft, feathering action should be taken. If any bank has been applied to assist directional control, it should be taken off as soon as directional control is assured, as any but the smallest amount detracts from the performance and complicates the procedure if the emergency has occurred under instrument conditions, since the slip indicator is displaced from the central position.

Engine Failure Above Safety Speed

37. Whether the aircraft will climb or not, the following actions must be taken immediately an engine fails. If the aircraft is very low and will not climb, it may not be possible to complete this procedure before forced landing. Nevertheless, as much of the following drill as time permits should be completed :—

(*a*) Keep straight by instant and coarse use of the rudder, and if necessary lower the nose to maintain speed.

(*b*) If airborne, raise the undercarriage.

(*c*) If applicable, feather the propeller.

(*d*) Trim the rudder if the foot load is very heavy.

(*e*) If necessary, jettison all external stores that may safely be jettisoned.

(*f*) If the flaps have been used for take-off, they usually impair the ability to climb and should therefore be raised as soon as a safe height is reached.

38. As indicated below, subsequent actions depend on the ability to climb on asymmetric power :—

(*a*) *Doubtful Climb.* If, after carrying out the immediate actions detailed above, the ability to climb is in doubt, continue to use full power and raise the nose gently in an attempt to gain height ; but the airspeed must not be allowed to fall below the critical speed.

(*b*) *No Climb.* If the aircraft loses height, the choice of landing area is restricted ; but full use should be made of the live engine to reach the best available landing space, keeping the I.A.S. above the critical speed for the amount of power being used.

(*c*) *Satisfactory Climb.* If the aircraft will climb, a turn in either direction may be started at a safe height and the aircraft flown to a suitable position for landing.

(*d*) *Power Used.* The use of take-off power may be continued as long as it is necessary, but power should be reduced to the maximum continuous figures as soon as this may be done safely. While at full power and low I.A.S. the temperature of the live engine should be watched closely.

TWIN-ENGINE AIRCRAFT—
ENGINE FAILURE IN FLIGHT

Autopilots

39. ▶When an auto-pilot is in use the pilot on watch must be strapped in, in case of auto-pilot failure which may cause large control deflections.◀ If the auto-pilot is in use when engine failure occurs it should be disengaged at once. Unless Pilot's Notes state otherwise, it may however be re-engaged subsequently provided the forces can be trimmed out. After alterations in power and speed the auto-pilot should be disengaged again and the aircraft retrimmed.

Immediate Actions

40. The following immediate actions should be taken:—

(*a*) *Rudder.* Keep straight by instant and coarse use of the rudder, putting the nose down if necessary to keep the speed above the critical speed.

(*b*) *Trim.* Trim out any foot load, aiming to keep the slip indicator central.

(*c*) *Throttles.* With piston engines, close the throttle of the failed engine, then reopen it slowly to see if any power is available (see Note after sub-para.(*f*)). If there is no power, close the throttle again and set the r.p.m. control lever to the minimum r.p.m. position. With gas-turbine engines, close the throttle and H.P. cock as soon as possible after engine failure has been identified.

(*d*) Increase power as necessary on the live engine and then retrim the aircraft.

(*e*) On piston-engine aircraft if the cause of failure cannot be found and remedied, feather the propeller of the failed engine.

(*f*) When flying on instruments and/or if any difficulty is experienced in checking the swing, it may be advisable to throttle back all engines and put the nose down to maintain directional control more easily; power on the live engine may then be increased.

Note : On all propeller-driven aircraft, if a definite mechanical failure and/or fire occurs, stop the engine and feather the propeller immediately. If the cause of the failure is unknown, then on *piston-engine* aircraft the propeller should not be feathered until a systematic check has been made around the cockpit in an attempt to locate the fault.

Subsequent Actions

41. Check the possibilities of reducing drag. See that the flaps and undercarriage are fully up and that the bomb doors are properly closed. As far as possible, close all apertures.

42. If difficulty is experienced in maintaining height, disposable load and then fuel should be jettisoned as required. The power on the live engine should only be increased above maximum continuous to prevent a dangerous loss of height.

Piston-Engine Performance at Altitude on Asymmetric Power

43. The ability to climb on asymmetric power depends on both height and speed. Since the variation of power with height of the piston engine is determined by several variables, the handling technique to obtain the optimum performance is not straightforward; this is especially so when two-speed superchargers are fitted. The ceiling in both high and low gear is very much reduced. In the example illustrated in Fig. 2 the power at the high gear full-throttle height is less than the power required to maintain height at that altitude. The ceiling on asymmetric power is, therefore, the low gear ceiling of about 11,000 feet. Fig. 3 shows the effect of speed on the same aircraft ; it is just possible to maintain the full-throttle height of 10,000 feet at 145 knots. At a lower speed the ceiling is higher ; but, even at the best climbing speed of 120 knots, at heights above about 11,000 feet it will be necessary to descend until height can be maintained, unless load can be jettisoned. If, for economy, power is reduced to the weak mixture maximum, the ceiling will be still further reduced. It follows that :—

(*a*) A fairly rapid loss of height is to be expected initially if the failure occurs very much above rated altitude. This height is given in the engine manuals and sometimes in Pilot's Notes.

(*b*) The rate of descent becomes less as the aircraft approaches the ceiling on asymmetric power ; this is usually near the rated altitude. Thus if conditions permit, descent should be made at least to the rated altitude.

(*c*) If height is still lost slowly at the rated altitude, level flight may yet become possible as fuel is used and so reduces the weight. Although the engines develop less power below full-throttle height, the aircraft requires less power to fly at a given I.A.S.

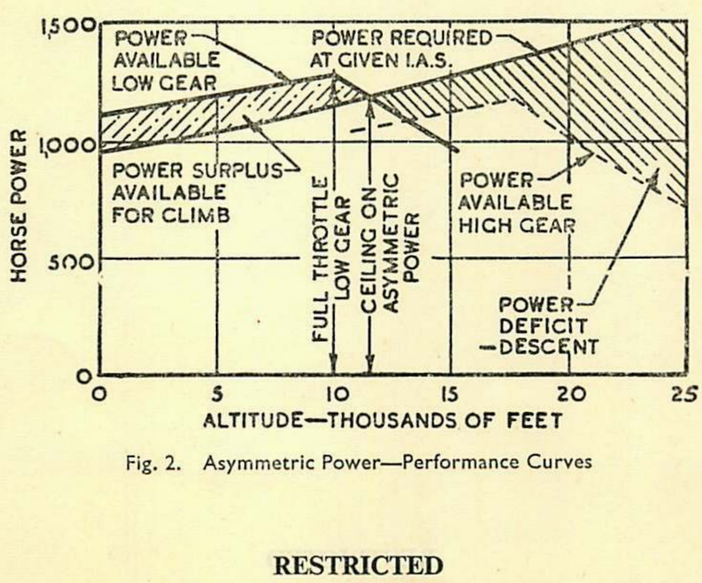

Fig. 2. Asymmetric Power—Performance Curves

44. In general the aim should be to maintain the recommended range speed, but if height cannot be maintained in weak mixture at this speed, conditions will govern which of the following actions should be taken :—

(*a*) Accept a small rate of descent, if practicable, to maintain the range speed in weak mixture, when maximum range is of paramount importance.

(*b*) Use rich mixture, if required, when it is of primary importance to maintain height.

An infinite number of variables exist between sub-paras. (*a*) and (*b*), each being governed by the particular conditions. Every case should always be judged on its merits, remembering that the range speed is the most efficient speed.

Range Flying on Asymmetric Power

45. This aspect of range flying for both piston- and jet-engined aircraft is dealt with in the appropriate chapters of Part 3, "Range and Endurance".

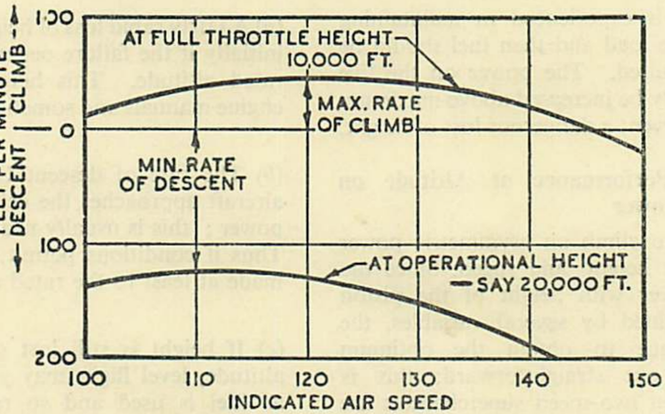

Fig. 3. Asymmetric Power—Effect of I.A.S. on Level Flight


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