PART 2 : SECTION 4

CHAPTER 4

FLYING AT HIGH SPEED AND HIGH ALTITUDE

Introduction

1. This chapter concerns certain flight characteristics which may be encountered when flying certain high-speed aircraft, particularly at high altitudes. Lack of appreciation of the reasons behind unusual behaviour of an aircraft at high speeds may lead the pilot to take action which, while natural and appropriate at normal speeds, may lead to difficulties at high speeds and high altitude.

2. No reference in this chapter is made to the principles of flight concerning compressibility and the significance of the speed of sound. Information on these subjects is contained in Vol. 1.

3. This chapter should be read in conjunction with Chapter 1.

Aircraft Limitations

4. Speed limitations are imposed for structural reasons alone, and may be expressed either as an I.A.S. or as a mach number. The reasons for imposing these limitations are detailed in Chapter 1.

Effects of High Speed and Altitude on Aircraft Performance

5. **Compressibility.** Compressibility characteristics differ even between aircraft of the same type, and although Pilot's Notes give general guidance on the characteristics to be expected at high mach numbers, it does not necessarily follow that the effects will be reproduced either in part or in whole. One of the major causes of the change in handling characteristics is the condition of the airframe ; paint flaking, badly scratched surfaces, a generally poor finish, and even bird droppings on the wings, can cause totally different behaviour from that expected.

6. **Buffeting.** Buffeting in some degree, apart from the pre-stall buffet, is commonly experienced on many aircraft. Buffeting of tail surfaces may be felt on the control column and/or rudder pedals ; occasionally, on aircraft without power-operated controls, aileron snatching may occur, and also aileron "buzz" in which the ailerons oscillate at a high frequency. Buffeting may be much more pronounced and the compressibility mach number appreciably reduced if external fuel tanks or stores are carried. Aircraft designed specifically for flight under transonic and supersonic conditions are usually free of any marked buffet. Pilot's Notes advise when exceptions occur.

7. **Aircraft Behaviour.** When severe compressibility effects are experienced, the resulting movements of the aircraft may be violent and irregular about all three axes, and when encountered on aircraft without power-operated controls very heavy stick forces may be needed to restrain the movements. The only way to stop the behaviour is to decrease the mach number by throttling back and if necessary opening the air-brakes.

8. **Changes of Trim.** Although changes of speed and power alter the trim, large and occasionally violent changes of trim occur on subsonic aircraft having a definite compressibility mach number.

(*a*) **Longitudinal.** With increase of mach number there may be a nose-up change of trim that changes to a nose-down, or vice versa. The rate of change of trim varies with the rate of change of speed, and the suddenness of the change also varies. A fairly rapid fluctuation, alternating between nose-up to nose-down, is known as "porpoising".

(*b*) **Lateral.** Change of lateral trim in the form of wing dropping is frequently the limiting factor in the control of an aircraft at high mach numbers. Initially the ailerons are effective in checking this symptom and some rudder in the direction of the dropping wing may be helpful —*i.e.* port wing down, port rudder—but if the mach number is further increased the aircraft may become uncontrollable, owing either to lack of aileron effectiveness caused by compressibility or the inability to apply sufficient aileron owing to high stick forces.

9. **Control Effectiveness.** The effectiveness of the controls and trimmers deteriorates at high mach numbers and also at high altitudes.

(*a*) *High Mach Numbers.* At transonic mach numbers, *i.e.* after the first shock waves have formed on the wing, the control surface only affects the airflow up to the shock waves ahead of it. This means that only a portion of the lifting surface is affected by movement of the control surface behind it, and the consequent change of forces is smaller. In addition, the control surface may be operating in a turbulent airflow, in which case the control becomes still less effective.

(*b*) *High Altitudes.* At high altitudes a low I.A.S. corresponds to a high T.A.S. The aerodynamic force exerted by the deflection of a control surface is proportional to the I.A.S., whereas the kinetic energy of the aircraft depends on the T.A.S. The controls are therefore less effective in manœuvring at altitude than at lower levels for the same I.A.S. The kinetic energy of the aircraft must be appreciated and allowed for when manœuvring at high T.A.S. and high altitude, *e.g.* during aerobatics, formation flying, interceptions, and spinning. For this reason the time taken to recover from a spin is greater at high altitudes.

(*c*) *High Indicated Airspeeds.* Control effectiveness may be reduced or lost at high I.A.S. for reasons other than compressibility. The air loads caused by a high I.A.S. may so distort the airframe that the basic incidence settings are changed seriously enough to reduce control effectiveness, or even to cause control reversal. At high I.A.S. any change of trim may be accentuated or reduced by temporary distortions of the airframe and consequent changes in lift, particularly on the tail surfaces. These distortions lead to a change in the magnitude and distribution of the air loads on the surfaces and are independent of compressibility effects. This type of distortion is called "aeroelastic distortion": to some degree this distortion is inevitable and is allowed for in the design of the aircraft. It is more pronounced in denser air at lower levels, where high I.A.S. is reached, and may give rise to a change in the character or degree of the compressibility effects and in the actual compressibility mach number. At an excessively high I.A.S. it is possible to cause distortion greater than the elastic limit of the airframe, resulting in permanent distortion and the risk of structural failure. All maximum speed limitations must therefore *always* be treated with respect.

(*d*) *Power-Operated Controls* (*Jack-Stalling*). At high I.A.S. the air loads on the control surfaces are so large that in certain aircraft the servo mechanism may not be powerful enough to move the control surfaces through their full range of movement, *i.e.* the jacks, or servos, stall when the air load on the surface equals the jack output force. When this situation arises the manœuvrability is reduced at high I.A.S. in that the amount of *g* that can be applied is limited ; this calls for special care when diving at high I.A.S. and low altitude as the height lost during recovery is unavoidably increased. The maximum obtainable *g* may be as low as 3 at speeds of about 500 to 550 knots, the precise figures varying with the type of aircraft involved.

Variation of Compressibility Characteristics with Altitude

10. The compressibility characteristics of individual aircraft remain basically the same at all altitudes. However, as a general rule the effects may occur at a lower mach number as the aircraft ages and the finish deteriorates. Changes of trim may be more sudden and severe at the lower levels where the I.A.S. and air loads are higher, thereby giving greater accelerations and possibly causing overstress.

Use of Trimmers

11. **Trim Tabs.** On aircraft using manually operated flying controls and having geared trim tabs, the tab angle required to trim the aircraft at high mach numbers may be large, because of decreasing effectiveness of tabs with increasing mach numbers. Therefore, to avoid very strong changes in trim when speed is reduced and the tab effectiveness is increasing, perhaps rapidly, Pilot's Notes sometimes lays down a mach number beyond which the trimmers should not be used.

12. **V.I. Tailplanes.** On some aircraft, however, the loss of elevator effectiveness may be such that, for trimming, the use of a variable incidence tailplane is a valuable aid in controlling and manœuvring at high mach number. However, even when a variable incidence tailplane is used, a fairly coarse setting may be needed at some high subsonic mach number, and this setting may have to be changed rapidly to cope with strong changes of trim at mach numbers only slightly different from the trimmed speed. When an aircraft has such a feature the trim must be used carefully to avoid the unintentional application of excessive *g*.

For example, consider an aircraft that has a marked nose-up tendency at 0·9M which becomes marked nose-down at 0·94M. When trimmed at 0·94M the tailplane angle will be well into the nose-up range ; if the aircraft is then pulled into a tight turn or out of a dive at high *g* and more trim is applied to do this, then, when the speed falls to 0·9M—and this can happen quickly at high *g*—the combined effect of the nose-up tailplane setting and the inherent nose-up tendency can result in a very rapid increase in *g* that cannot be checked before the *g* limits of the aircraft, and the pilot, are exceeded. *Such an incident can only be guarded against by knowing the behaviour of the aircraft as described in Pilot's Notes.* The type of behaviour described above can be likened to pitch-up, but whereas the latter is due to loss of stability through wing-tip stalling on swept-wing aircraft and/or an excessively aft C.G. position, the behaviour in the example is due to the faulty use of the tail trim and is not instability. Under suitable conditions of altitude, airspeed and *g*, however, the incorrect use of the tail trim could cause an unintentional increase in *g* sufficient to promote the unstable type of pitch-up.

Control at Low Speed

13. The aerodynamic design features required to meet the exacting needs of high-speed flight give less attractive handling characteristics at low speeds. The high wing loadings and swept wings that are a feature of many high-performance aircraft usually entail high take-off and landing speeds. At low I.A.S. the amount of *g* that can be applied without stalling is limited ; near the stall only fractional amounts of *g* are needed to bring on the stall. When the rudder is used to yaw the aircraft, pronounced rolling movements in the same direction occur which are evident under cross-wind landing and take-off conditions. Longitudinal stability often changes to become marginal near the stall. On many aircraft with highly loaded swept wings the ailerons if misused at or near the stall are often more liable to cause a spin than the rudder ; even when full corrective rudder is applied, if the ailerons are not kept central at the stall a spin can result.

Manœuvring at High Altitude

14. Manœuvring cannot be separated from the application of *g*, except in pure rolling. When *g* is applied on aircraft having a definite compressibility mach number, the symptoms of the shock stall will be felt at a lower mach number ; the greater the *g* the lower the mach number. Even though the amount of *g* that can be applied at the highest altitude without stalling is small owing to the low I.A.S., an appreciable reduction in compressibility mach number is often experienced.

15. When *g* is applied, some aircraft exhibit an automatic tendency for the *g* to continue to build up, necessitating a reversal of the initiating force on the control column in order to restrain the increase. This unstable characteristic can arise from either or a combination of :—

(*a*) A flight path which is being maintained by a given control deflection and degree of effectiveness at a high I.M.N. ; any reduction in I.M.N. which occurs as a result of the higher drag resulting from increased *g* would increase the control effectiveness and tend to tighten the turn or pull-out without further movement of the control column. However, this effect is unlikely to be severe and is easily countered.

(*b*) *Pitch-Up.* On swept-wing aircraft, owing to wing-tip stalling and wing flexing at high angles of attack and airspeeds respectively, the C.P. moves forward causing the turn or pull-out to tighten and increase the *g* automatically. This effect occurs at a *g* loading that reduces with gain in altitude, until at the highest altitudes comparatively small amounts of *g* suffice to cause pitch-up ; at low altitude if enough *g* is imposed to cause pitch-up the resulting increase could easily and quickly overshoot the maximum permissible *g* with the consequent risk of breaking the aircraft. The *g* overshoot, at high altitudes, although not sufficient to cause overstress, forms an operational handicap. If, at high altitude, a turn is tightened slowly, pitch-up becomes evident as a reduction in the pull force required to tighten the turn, and the force eventually becomes zero and then changes to a push. The quicker the *g* is applied the quicker does the sequence take place, and if *g* is applied suddenly the pitch-up will be equally sudden and difficult or impossible to prevent. Not all swept-wing aircraft have this characteristic to the same degree, the severity varying between types and with C.G. position, applied *g* and altitude. Pilot's Notes advise on this subject when it is present ; in general, however, pitch-up at low altitudes will only take place if the *g* limit is exceeded.

16. **Effect of Compressibility in Turns.** The higher the I.A.S. that can be maintained while turning as tightly as possible, the smaller is the turning radius. However, this is true only up to those mach numbers at and above which compressibility effects markedly reduce the lift available at all angles of attack. The mach number above which the turning circle becomes larger is given in Pilot's Notes or the Operating Data Handbook. In practice, when manœuvring at the higher altitudes, the speed should not be allowed to drop below the best climbing speed, as height would have to be lost in order to accelerate quickly to this speed ; this applies particularly near the ceiling of the aircraft. In some types of aircraft the I.M.N. giving the best turning circle at altitude is much lower than the best climbing I.M.N. and in these cases the pilot must decide which figure has the most importance for the prevailing circumstances.

17. **Effects of Altitude on Manœuvre.** The ability to manœuvre (*i.e.* the amount of *g* that can be applied without stalling) is reduced as height is gained, and when turning as tightly as possible at increasing altitudes the radius increases and the rate of turn decreases. The primary reason for this is the reduced lift available through the falling I.A.S. and an increase in inertia forces due to the growing T.A.S. The amount of thrust available from all but rocket engines is also reduced. The lift is further reduced because of compressibility effects. The much smaller speed range, *i.e.* the range between the indicated stalling speed and the indicated maximum level speed, available at the higher altitudes also drastically limits the manœuvrability. *For a given altitude and applied g the higher the I.A.S. the larger is the radius of turn and the lower the rate of turn ; conversely, for a given altitude and I.A.S. the higher the g that can be applied without stalling the smaller the radius and the higher the rate of turn.*

Climbing

18. The climbing speeds for jet aircraft are given in the Pilot's Notes as I.A.S. or I.M.N. It can be seen from the following schedule for a basically subsonic aircraft that the I.A.S. is gradually reduced on the climb whereas the optimum mach number at first increases then remains almost constant, increasing slowly. The exact relationship between I.A.S. and I.M.N. during the climb cannot be dealt with in a general way since the technique for climbing depends largely on the role and performance of the aircraft.

Altitude	*I.A.S.* (*knots*)	*I.M.N.*
Sea Level	430	0·65
5,000	415	0·69
10,000	400	0·72
15,000	390	0·77
20,000	365	0·79
25,000	340	0·81
30,000	320	0·84
35,000	290	0·84
40,000	260	0·84
45,000	235	0·85
50,000	210	0·86

19. It is important that the correct climbing speeds are adhered to ; if the speed is allowed to fall too low, especially at the higher altitudes, the rate of climb is seriously reduced and the only method of regaining speed quickly is to dive. At low altitudes there is a large excess of thrust and a wide band of airspeeds at which the aircraft can climb quickly ; the peak rate of climb is achieved at a certain airspeed in this band. As height is increased, the band narrows and the peak rate of climb drops, until near the ceiling the range of speeds over which the aircraft can climb is very small and the speed for best rate of climb realizes only a fraction of the sea-level figure ; at this height a decrease of only 10 knots from the optimum climbing figure can result in the already low rate of climb falling to zero or changing to a descent. The much reduced excess of thrust under these conditions means that the acceleration is very low and the best method of regaining climbing speed quickly is to dive ; because of the smaller excess of thrust a disproportionately large amount of height may be lost in the dive before the climbing speed is regained.

20. For maximum range and rate of climb, turbo-jet aircraft are climbed at full throttle and a careful watch must be kept on the j.p.t. to ensure that it does not exceed the limit during the climb. It may be necessary to throttle back to keep the j.p.t. within the limits. Detailed information on engine handling is contained in Pilot's Notes and Vol. 1, Part 1, Sect. 3, Chapter 12 of this manual.

Recovery from Dives at High I.A.S.

21. At low altitudes, turbo-jet aircraft gain speed rapidly, even in a shallow dive, and the height required to regain level flight may be comparatively large. The height required depends on the altitude at which recovery was started, the I.A.S., the angle of dive, the *g* applied, and the A.U.W.

22. The *g* that can be applied when recovering from a dive is limited either by the *g* stall warning or the pilot's *g* threshold. The table below gives an indication of the height needed to recover from various angles of dive with constant *g* loads at various airspeeds for a certain aircraft at low altitude. It can be seen how the height required to recover increases rapidly with increase of I.A.S. and angle of dive. It is emphasized that this table does not apply to all aircraft and is given only as an example.

Applied g	*I.A.S.*	*Angle of Dive*			
		30°	40°	50°	60°
		Height Lost during Recovery (Feet)			
3*g*	400 450	1,700 2,300	3,000 3,800	4,000 5,700	5,600 7,300
4*g*	400 450	1,300 1,700	2,200 2,700	3,000 3,800	4,200 5,500
5*g*	400 450	1,100 1,400	1,800 2,300	2,400 3,100	3,400 4,400

23. When diving at 60° and 450 kts. and then pulling out at 4*g* the height loss is about 5,500 ft. If the loading is increased to 5*g* the height loss is roughly 1,000 ft. less.

24. If a *g* stall occurs during recovery more height is lost because the aircraft mushes, owing to the loss of lift.

25. It is essential therefore to assess the characteristics of an unfamiliar type of aircraft under various conditions at a safe height. Airbrakes help to keep the speed down and should be used wherever a rapid pull-out is necessary because, at a given *g*, least height is lost when the speed is constant or is decreasing during the pull-out; if the speed is still increasing more height is lost. Attention is drawn to the important consideration of para. 9(*d*).

I.A.S. *versus* I.M.N. in a Dive

26. In a dive the mach number may increase rapidly and it is important to realize the changing relationship between the I.A.S. and I.M.N. The main features are discussed below.

27. The highest mach number is reached when diving from the greatest height; from a lower height the peak mach number is less. For example, consider an aircraft making two dives at the same angle and power setting, starting at the same T.A.S. but making one dive from 40,000 feet and the second from 32,000 feet. The following figures are typical :—

Dive from	40,000 feet	32,000 feet
Peak Mach Number	0.89	0.85
Which is reached at...	29,000 feet	20,000 feet
I.A.S. then being ...	330 kts.	380 kts.

28. *In any dive at a constant angle the mach number reaches its peak and begins to fall while the I.A.S. is still rising.* It is therefore possible for an aircraft with poor compressibility characteristics to be in a steep dive with the pilot unable to do more than keep the attitude constant (by pulling back on the control column) and for the I.A.S. to be still increasing; despite this the mach number reaches a maximum and then, as the speed of sound increases in the warmer air at lower altitudes, the mach number begins to fall. When the mach number falls, recovery from the dive becomes possible but may involve a very considerable loss of height which is not normally hazardous unless the aircraft enters cloud during the out-of-control period.

29. Tabled below are the indicated speeds corresponding to 450 knots T.A.S. at various heights, the speed of sound in standard atmosphere conditions at each height, and the mach number. The changing I.A.S./I.M.N. relationship in a dive is clearly shown:—

Height (feet)	*I.A.S. (knots)*	*T.A.S. (knots)*	*T.A.S. of sound in knots*	*I.M.N. at* 450 *knots T.A.S.*
	(*a*)	(*b*)	(*c*)	(*d*) (*equals b/c*)
40,000 ...	225	450	570	0·79
30,000 ...	275	450	590	0·76
20,000 ...	330	450	610	0·74
10,000 ...	385	450	640	0·71
Sea Level	450	450	660	0·68

It can be seen that if the T.A.S. is constant, or even increasing slowly in a dive, the mach number is falling although the I.A.S. is rapidly rising.

Use of Airbrakes

30. The primary purpose of airbrakes is to increase the drag ; in this way better deceleration is obtained or the speed can be restricted during descents. The airbrakes are therefore used whenever it is desired to limit or reduce the speed. In some instances Pilot's Notes remark on the changes of trim and buffeting produced by opening the airbrakes and state any limitations in their use. The main uses of airbrakes are :—

(*a*) To reduce high I.A.S. or I.M.N., in the interests of control.

(*b*) To reduce speed when entering the circuit or when joining a formation.

(*c*) To prevent an excessive increase of speed when diving or descending.

(*d*) To reduce speed for reasons of manœuvrability.

The Total-Energy Concept

31. Operational and other reasons often require an aircraft to reach a combination of altitude and speed as quickly as possible, starting either from ground level and the appropriate speed or from some other combination of altitude and speed. The usual method is to accelerate or decelerate to the climbing speed, climb to the required altitude, and then adjust the speed. However, this is the slowest method of achieving the new situation and considerable time can be saved in some cases by making use of the kinetic and potential energy of the aircraft. There are practical limitations to the use of this concept and these are discussed below.

32. The total energy possessed by an aircraft in flight is the sum of its kinetic and potential energies given by the formula :

$$\text{Energy Height} = \text{Actual Height} + \frac{V^2}{2g}$$

The energy possessed at any one combination of altitude and T.A.S. can be exchanged for a higher altitude and lower T.A.S. or lower altitude and higher T.A.S. For example, an aircraft at sea level and 650 knots has a certain total energy ; if it were zoomed to 15,000 feet it would arrive at 300 knots and the same total energy. The aircraft is no better off, from the total energy aspect, at 15,000 feet and 300 knots than it was at sea level and 650 knots ; if it were dived back to sea level it would arrive at 650 knots.

33. *The example of para.* 32 *and those following assume that the thrust is adjusted constantly to equal the drag so that the kinetic and potential energy alone carry out the changes of height and speed.*

34. The graph of Fig. 1 shows lines of constant total energy sloping from left to right ; it shows also a mach 1·0 line and superimposed on this framework is the climbing schedule for an imaginary subsonic fighter.

35. Consider an aircraft first at 30,000 ft. and 300 knots I.A.S. and then at 34,500 ft. and 200 knots I.A.S. Both sets of conditions have the same total energy and can be exchanged one for the other. In other words, a zoom climb from 30,000 ft. and 300 knots will take the aircraft to 34,500 ft. and 200 knots, *i.e.* along a line on Fig. 1 parallel to the slope of the constant-energy lines. This of course assumes the proviso of para. 33. If full throttle was used, the aircraft would arrive at 34,500 ft. at a higher speed and if the thrust was less than the drag it would arrive at a lower speed.

36. The principle of total energy is based on the fact that at any particular altitude there is only one speed at which energy can be increased economically and rapidly—this speed is the best climbing speed for that height (maximum excess power is available). Using this speed and climbing power, total energy can be increased (stored) most effectively. The best energy-increasing technique is the I.A.S. and altitude combination given by the climbing schedule in Pilot's Notes.

37. Using Fig. 1, the following two examples are given of the efficient use of the energy height concept. The examples are designed to show the theoretical gains only ; in practice certain limitations discussed in para. 40 govern the final flight paths.

38. Starting from point A on Fig. 1 (20,000 ft./200 knots I.A.S.) the aircraft is to be climbed to B (40,000 ft./250 knots I.A.S.). The standard "energy" technique is :—

(*a*) Put the aircraft onto the best climbing basis *as quickly as possible.*

(*b*) Keep the aircraft on this basis for as long as possible.

Therefore, dive from 20,000 ft. until a speed/altitude combination is reached which lies on the climbing line ; moving parallel to the constant energy curves, this is reached at about 13,000 ft. on Fig. 1. Then climb, following the climbing line, until the total energy curve for 40,000 ft. and 250 knots is intercepted at about 41,000 ft. From this point, dive to 40,000 ft. where 250 knots will be obtained.

39. A final example is given by the case of having to accelerate quickly from 250 knots I.A.S. to 300 knots I.A.S. at 40,000 ft. The best technique is to zoom until sufficient speed is lost to put the aircraft onto its correct I.A.S./altitude climbing combination ; this involves moving up parallel to the constant energy line and intercepting the climbing line at about 41,000 ft. Then climb, following the climbing line to intercept the total energy curve which passes through 40,000 ft. and 300 knots. This occurs at 45,000 ft. Dive back to 40,000 ft. and, automatically, to 300 knots.

Practical Limitations and Considerations when Using Total-Energy Principles

40. In practice, the accelerating dives would be done under power and not with thrust equal to drag, and this would mean that the aircraft would not be moving along a constant-energy line but diverging upwards. However, as long as the correct climbing schedule is reached quickly, little is lost. At this stage a further complication arises because the flight path must be changed gently, keeping the *g* low to avoid drag effects, from a dive to a climb at a precise I.A.S. appropriate to a specific altitude. Therefore the pull-out must be made gradually, commencing at some lower I.A.S. than that desired until the aircraft arrives on the climbing line of Fig. 1. The greater the rate of gain of speed in the dive and the higher the commencing climbing I.A.S. the sooner should the pull-out be started if 3–4*g* is not to be exceeded. The sharp "corners" of the dotted flight path from A to B are not possible practically and a smoother, more gradual change of path results.

41. Two points are important whenever energy techniques are used ; the *g* must be kept low, if possible not exceeding 4*g*, so that the drag is kept substantially constant during entry into dives and pull-outs. Also, the dives and climbs must be made in as short a time as possible so that the energy is not markedly affected by thrust or drag.

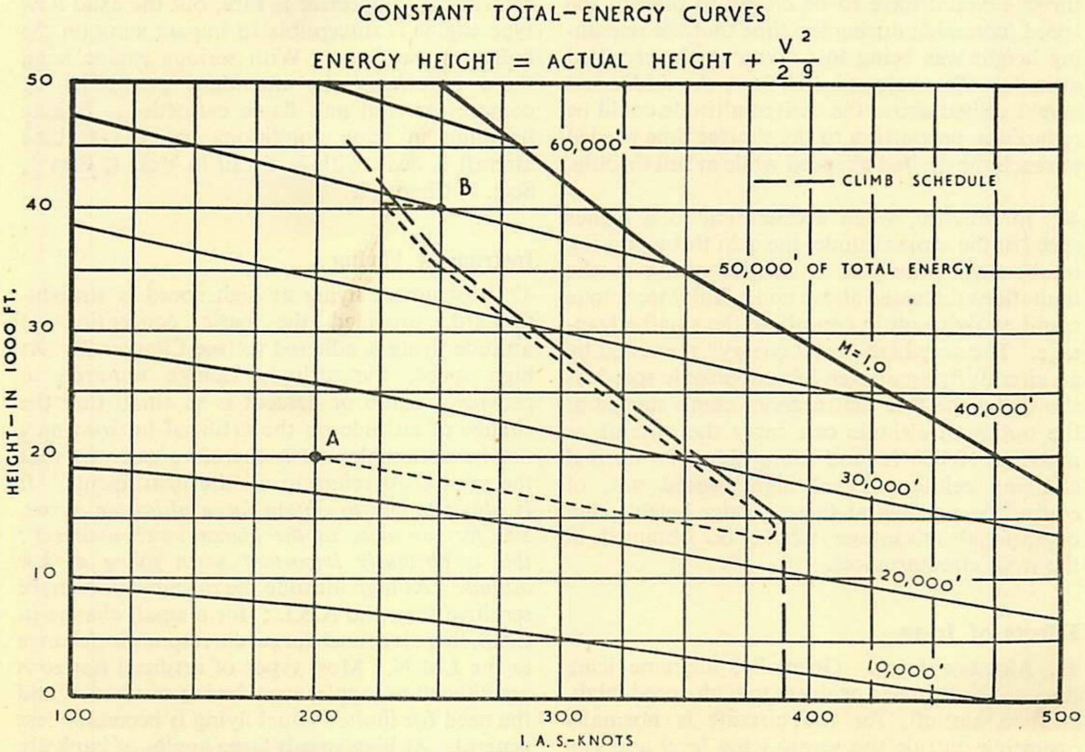

Fig. 1 Constant Total-Energy Curve

42. When accelerating up to the climbing speed after take-off in an aircraft capable of sustained, or nearly so, supersonic speed, the best technique for entering the climb is governed by "energy" principles. For example, if an aircraft has an initial climbing speed of 500 kts., the best technique may well be to start pulling into the climb some 30 to 50 kts. before 500 kts. and holding a constant *g* during the time that the speed continues to build up (more slowly, because of the *g*) until at some higher altitude, say 10,000 ft., the correct I.A.S. for that altitude is reached.

43. If the speed required at a given altitude is higher than the climbing speed, the climb should be continued to the correct amount above the desired altitude and the aircraft dived back to accelerate to the required I.A.S. If the rate and angle of climb are still high, the quickest method of entering the dive would be to invert the aircraft and then pull through to the required dive angle, otherwise uncomfortable amounts of negative *g* would be encountered. Again, this dive should theoretically be made with thrust equal to drag, but in practice climbing or full power is used ; this means that the required I.A.S. would be reached before the required altitude and that the throttle would have to be closed to prevent the speed increasing during the time that the remaining height was being lost down to the required altitude. To overcome this loss, the additional height gained above the desired altitude could be reduced in proportion to the shorter time needed to reach the desired airspeed while at full throttle.

44. In practice, when accelerating to a higher speed at the same altitude, the gain through using total-energy principles is smaller owing to the limitations discussed above and a faulty technique could easily result in cancelling the small advantage. The very high "total energy" possessed by an aircraft flying at even low supersonic speeds is shown by the fact that a zoom climb started at the optimum altitude can carry the aircraft as much as 10,000 ft. and more above its normal climbing ceiling. Level flight would not, of course, be possible at these greater heights, but operational advantage would be obtained in the right circumstances.

Effects of Icing

45. **Airframe Icing.** Generally, airframe icing does not constitute a problem to high-speed, high-altitude aircraft, for the aircraft is normally operating outside the severe icing level and can quickly climb through an icing region. When flying through severe icing conditions at high I.A.S. the rate of ice accretion may be as high as two inches per minute. Apart from the normal problems associated with icing (such as an increase in stalling speed), external radio aerials subjected to severe icing vibrate excessively and subsequently fracture. One major problem associated with high-altitude aircraft is the formation of mist or hoar frost on the canopy. Full use should be made of the demisting equipment from ground level, and sufficient fuel should be held in reserve to be able to fly around at low levels and allow time for the canopy to warm up and de-mist before landing. The more rapid the rate of descent, the heavier will be the misting and the rate of spread.

46. **Engine Icing.** On piston-engine aircraft the only significant difference between engine icing at low speed and at high speed is that impact icing in and around intakes builds up more quickly at higher speeds. With some jet engines, there is a possibility of the fuel control linkages exposed to the airflow becoming ice-bound and jamming. If ice forms on a guard ahead of the compressor, the reduced and uneven airflow causes a reduction in thrust and a rise in j.p.t. Malfunction due to icing in jet engines using a centrifugal compressor is rare, but the axial flow type engine is susceptible to impact icing on the bullet at the front. With serious engine icing there is always the attendant possibility of compressor stall and flame extinction. Engine handling in icing conditions for gas-turbine aircraft is dealt with in detail in Vol. 1, Part 1, Sect. 3, Chap. 12.

Instrument Flying

47. Instrument flying at high speed is straightforward, provided the basic conception of attitude flying is adhered to (see Chapter 2). At high speed, the attitude change required to provide a climb or descent is so small that the change of attitude on the artificial horizon may not be noticeable. It is therefore essential that the pilot cross refers to all the instruments. *It is also possible to obtain large altimeter errors, 500 feet or more at the higher mach numbers ; this is obviously important when flying at low altitude.* At high altitude the machmeter is more sensitive than the A.S.I. ; for a small change in I.A.S. there is a much larger corresponding change in the I.M.N. Most types of artificial horizons are difficult to topple, even during aerobatics, and the need for limited panel flying is becoming less general. At high speeds large angles of bank are required for even a low rate of turn. The rate of climb and descent indicator gives the quickest

indication of changes of attitude in the pitching plane, in terms of thousands of feet per minute whereas the A.S.I. initially shows a difference of only a few knots for a large change of attitude. At the highest altitudes, owing to the absence of light-reflecting particles in the air, there is a strong contrast between sunlit and shaded parts of the cockpit; this effect may require the use of some lighting to facilitate reading the instruments.

Lookout

48. At high speeds a good lookout is always necessary, whatever the altitude. Even though accurate high-altitude flight requires the use of instruments, the habit of systematically searching the sky must be developed. In the empty visual field at high altitudes the pilot has no objects on which to focus his eyes so that they can be properly accommodated to see objects at a range of a few miles. The human eye is so built that, when left to itself, it tends to focus at very short ranges. The result of this weakness is that sighting ranges decrease considerably at these altitudes thus emphasizing the need for a more careful lookout.

Physiological Considerations

49. In sustained high-altitude flight it is common on certain aircraft for parts of the cockpit interior to be covered in hoar frost, and if bare skin comes into contact with such metal parts there is danger of it sticking to the cold surface. A further consideration is that owing to the lack of filtration of the sunlight normally provided by the dust-laden atmosphere in the lower levels, exposed skin may suffer severe burning.

Safety Equipment

50. **Oxygen.** Before flying at high altitude all oxygen equipment should be thoroughly checked and the working of the system understood.

51. **Dinghy Expansion.** The reduced cockpit pressure at high altitude causes any air trapped in the dinghy or life-jacket to expand, with the possibility of jamming some control or constricting breathing. When dinghies are carried, crews are recommended to carry a knife or other pointed instrument with which to puncture the dinghy if it starts expanding.

52. **Checking of Safety Equipment.** All personal equipment and safety equipment must be checked for serviceability. In an emergency the severe effects of exposure to high-altitude conditions of very low temperature and air pressure can be countered only by the use of the proper equipment, adequately cared for and maintained. The chapters dealing with the various items of safety equipment contain details of the necessary checks.

▶Effect of Shock Waves on Nearby Aircraft

53. The theory that the pressure rise in a shock wave is a function of free stream static pressure has been substantiated by flight tests. The data in Figs. 2 and 3 was obtained from a suitably

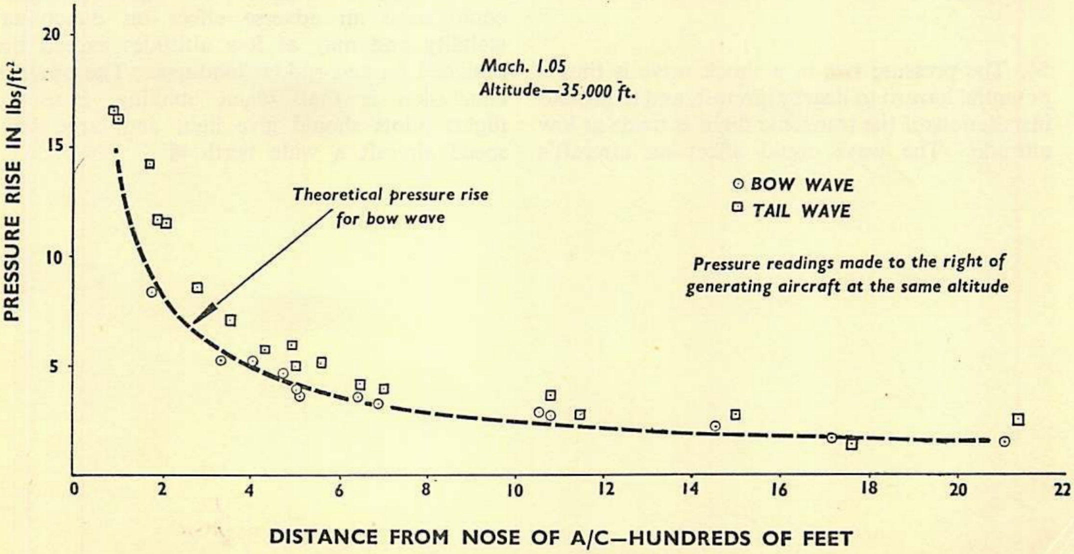

Fig. 2. Pressure Rise in a Shock Wave

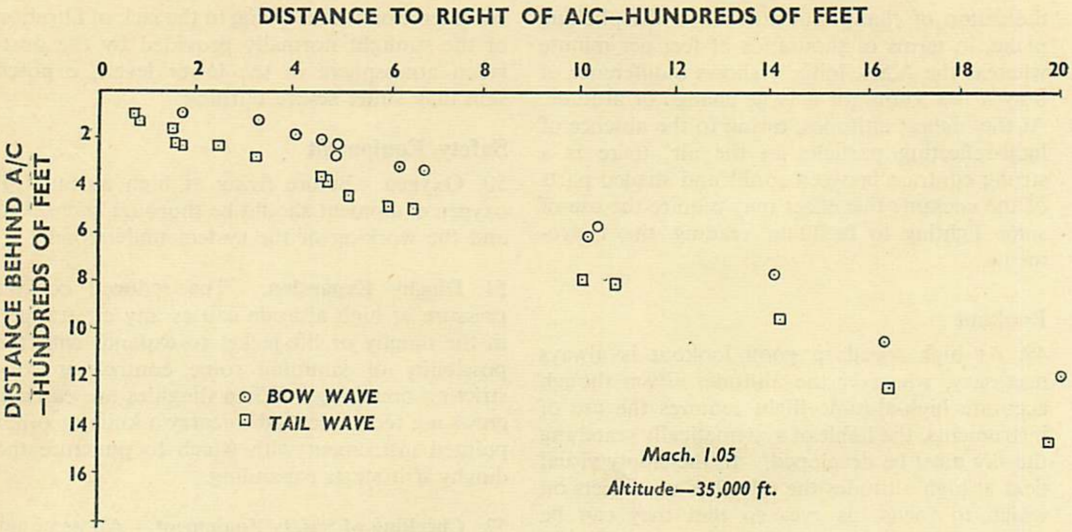

Fig. 3. Shock Wave Pattern to Right of Generating Aircraft

instrumented aircraft overtaking another flying level at M 1·05. Fig. 2 shows that the pressure rise decreased as distance from the generating aircraft increased, and it is interesting to note that the tail wave (a recompression shock wave) produced a greater rise than the bow wave. Other flights indicated that there is little difference, if any, between the pressure rises to the side of, or below, the generating aircraft. If the data is extrapolated to give the sea level figures the pressure rise at 100 ft. from an aircraft at M 1·05 can be expected to be approximately 60 lb./sq.ft.

54. The pressure rise in a shock wave is thus a potential hazard to nearby aircraft, and to ground installations if the transonic flight is made at low altitude. The wave could affect an aircraft's structure and/or stability. When an aircraft is subjected to a shock wave it tends to yaw towards the generating aircraft in the same way that an aircraft weathercocks when taxying. However, aircraft designed to fly at high mach number would not be affected structurally because they are stressed to withstand greater loads than could be expected from the strongest shock; nor would their stability be materially affected because sufficient control is available to counteract any yawing tendency. With light, and large slow-speed aircraft however, the phenomenon is more significant because the highest pressures could have an adverse effect on directional stability and may at low altitudes exceed the designed fin and rudder loadings. The obvious conclusion is that when making transonic flights pilots should give light and large slow-speed aircraft a wide berth. ◀