PART 2: SECTION 4

CHAPTER 1

AIRFRAME LIMITATIONS

Introduction

1. Airframe limitations are those operating conditions (*e.g.* indicated speeds, mach numbers, accelerations, weights and C.G. positions) which are fixed for reasons of safety, and depend generally on factors which are not related to the skill of the pilot. They are stated in Pilot's Notes for the type and must not be exceeded intentionally. C.G. and loading information is also contained in Volume 1 of the Aircraft Handbook.

2. Limitations take into account the aircraft role, structure, handling, and controllability, and are imposed only when they are essential. Disregard of limitations leads to damage and weakens the aircraft structure so that it may fail immediately or on some subsequent flight.

Considerations when Imposing I.A.S. Limitations

3. The air loads acting on the airframe depend principally upon dynamic pressure (the $\frac{1}{2}\rho V^2$ effect) and vary roughly as the square of the I.A.S. Fig. 1 shows how the dynamic pressure, which is 35 lb. per square foot at 100 knots, increases to no less than 875 lb. per square foot at 500 knots. Thus at a certain speed the total load on some part of the airframe, usually the wings or tail structure, increases up to the safety limit. The strength of the tail structure is frequently the limiting factor because a considerable down load, produced by the elevators or tailplane, is required to keep the wings at the angle of attack necessary to produce the large amount of lift when manœuvring at high *g*.

4. A further consideration is that at high I.A.S. the loads on the airframe may be great enough to cause aero-elastic distortion which could so alter the stability characteristics of the aircraft as to make its behaviour unpredictable.

5. The maximum permissible I.A.S. given as the service limitation in Pilot's Notes is slightly lower than the design maximum I.A.S., which is the highest figure for which the aircraft is stressed. The difference between the two gives the pilot a small safety margin. If the design maximum I.A.S. were permitted, even the slightest inadvertent exceeding of it would almost certainly cause damage to the aircraft.

Considerations when Imposing Mach Number Limitations

6. A mach number limitation is usually imposed when violent compressibility buffet may lead to structural failure or when loss of control due to compressibility characteristics may cause the aircraft to exceed the structural limitation before control can be regained. Alternatively it may be necessary to impose a mach number limitation in the early stages of an aircraft's service life because trials have not been completed to allow

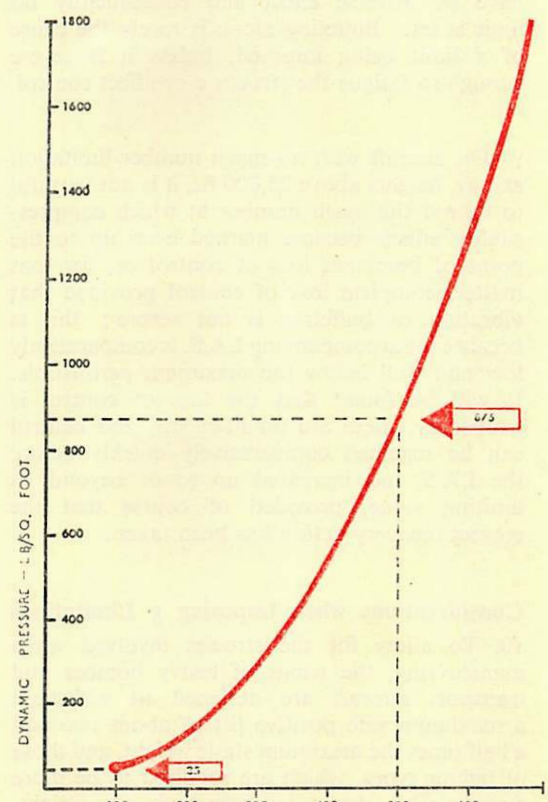

Fig. 1. Effect of I.A.S. on the Dynamic Pressure Experienced by an Aircraft

clearance to a higher mach number. When a mach number limitation is imposed it may be quoted as a definite figure such as 0·88M or as a specific condition of flight, *e.g.* when a nose-up trim change occurs.

7. On some aircraft, mach number limitations are imposed at low altitudes, because even temporary or partial loss of control at the high accompanying I.A.S. could quickly result in a dangerous situation ; the larger aerodynamic and *g* loads set up by violent behaviour, added to the already large loads imposed by the high I.A.S., might well be more than the airframe could absorb.

8. Mach number limitations are also imposed whenever the addition of external stores has undesirable effects. For example, it is often found that externally carried bombs cause buffeting which is strong enough to damage the airframe. On the other hand, some drop tanks have no adverse effect and consequently no limit is set. Buffeting alone is rarely the cause of a limit being imposed, unless it is severe enough to fatigue the structure or affect control.

9. On aircraft with no mach number limitation at, say, heights above 25,000 ft., it is not harmful to exceed the mach number at which compressibility effects become marked even up to the point of imminent loss of control or, for that matter, complete loss of control provided that vibration or buffeting is not severe ; this is because the accompanying I.A.S. is comparatively low and well below the maximum permissible. It will be found that the loss of control is temporary, there are no ill-effects, and control can be regained comparatively quickly before the I.A.S. has increased up to or beyond its limiting value, provided of course that the correct recovery action has been taken.

Considerations when Imposing *g* Limitations

10. To allow for the stresses involved when manœuvring, the wings of heavy bomber and transport aircraft are designed to withstand a maximum safe positive lift of about two and a half times the maximum static weight, and those of fighter types, which are required to be more manœuvrable, seven or more times the weight. Similar but lower values are usually fixed for the maximum safe negative lift. In fixing the limitations, which are based on strength calculations, there is a margin or factor of safety allowed. This factor is usually 1·5. Taking the case of the fighter this means that a positive lift of seven times the weight, a loading of 7*g*, can safely be applied and the structure should not fail unless a loading of 1·5 times this—about 11*g*—is imposed. There is, however, increasing risk of permanent deformation, usually indicated by skin wrinkling, and failure as the *g* is increased beyond 7.

11. Every type of aircraft is designed to fulfil certain duties and is stressed to carry the loadings that its duty demands. At the same time the controls are designed, as far as possible, to keep the loading that the pilot can impose within the design limits ; this is evident by the comparative heaviness of the controls of large aircraft, which have low *g* limits, and the lightness of those of a well-designed fighter.

12. The longitudinal trimmer (elevator tab or V.I. tailplane) is a powerful control and if it is used without due care it is possible to exceed the *g* limit easily with comparatively light stick forces ; this applies particularly at high I.A.S. when the elevators are often very sensitive and effective (see Chapter 4).

13. Accelerometers are fitted to most aircraft whose duties involve use of high *g*. The accelerometer must be watched when manœuvring, especially at high speeds, as with powerful controls the limits are easily exceeded.

14. The danger of overstressing the aircraft owing to excessive *g* is much greater at lower altitudes, because it is here that the highest loadings are most easily obtained. At higher altitudes the reduced lift due to compressibility effects, combined with the lower I.A.S. obtainable, restricts to a comparatively low figure the maximum *g* that can be reached before the aircraft stalls.

The Use of Anti-*g* Suits

15. When wearing anti-*g* suits, additional care must be taken to check that excessive *g* is not applied unintentionally as the usual physiological warnings are decreased. The anti-*g* suit is designed primarily to enable the pilot to operate more comfortably within the limits of his aircraft and it is not intended to make possible the use of *g* values higher than those permitted.

Aircraft Limitations Expressed as a Manœuvre Zone (Flight) Envelope

16. The diagram of Fig. 2, which is for an imaginary aircraft, plots *g* on the vertical axis against I.A.S. on the horizontal axis. The green line shows the normal stall boundary (the max. lift boundary) at sea level varying with I.A.S. ; the stall in level flight (the 1*g* stall) occurring at 100 knots, the stall at 4*g* at 200 knots, and so on. At sea level and 330 knots it is theoretically possible to reach 11*g*, but it must be remembered that a much lower figure, 7*g* in the example, is the safe limit.

17. Fig. 2 shows that as the altitude is increased the *g* at which the aircraft stalls decreases for a given I.A.S. This is due to the falling maximum lift coefficient in the face of increasing compressibility effects.

18. Before the stall boundary is reached, the aircraft will probably pass through two other boundaries (not shown in Fig. 2) of similar shape to the maximum lift boundary. These are the boundaries for the onset of buffet and pitch-up. At a given I.A.S., as the *g* is increased the aircraft reaches a *g* at which buffet is first noticeable. This is called the buffet boundary. As the *g* is further increased the intensity of the buffet increases. Many swept-wing aircraft pitch-up just before the *g* stall occurs and therefore at a *g* value that diminishes with altitude. Any pitch-up that does occur is strongest at the higher values of *g*, *i.e.* at lower altitudes. The tendency to pitch-up occurs at a *g* value between that for the onset of buffet and the *g* stall ; the margins may be small and the three effects may occur in rapid succession if the aircraft is pulled quickly into a tight turn. The margin between the boundary for the onset of buffet and pitch-up is a characteristic of each type of aircraft, and may vary considerably through the mach number range.

19. For this imaginary aircraft, the limiting I.A.S. is 600 knots and this line forms the upper I.A.S. limit to the manœuvre envelope.

20. In the example of Fig. 2, because of the effect of mach number on the maximum lift coefficient it is not possible to apply enough *g* to cause overstress at altitudes above 30,000 feet.

Limitations on High-Altitude Aircraft

21. Aircraft designed to operate at very high altitudes and mach numbers may be severely restricted in terms of both I.A.S. and mach number at low altitudes. For example, an aircraft that cruises at 0·95M at 50,000 feet is flying at 250 knots I.A.S. (540 knots T.A.S.). An aircraft of this type might well be limited to 400 knots I.A.S. at sea level, or about 0·6M. If enough strength were built-in to allow a higher I.A.S. at low altitude the greater weight of structure would drastically curtail the more important high-altitude performance. This type of aircraft, having a large reserve of power at low altitudes, would be capable of easily exceeding the I.A.S. limitation ; it is the pilot's responsibility to see that this does not happen.

Limitations when Flying in Turbulent Conditions

22. Turbulent air imposes *g* loads on the airframe, the effect of which is proportional to the I.A.S. If turbulent air is encountered when flying at high I.A.S., the airspeed should be reduced to that recommended in Pilot's Notes for

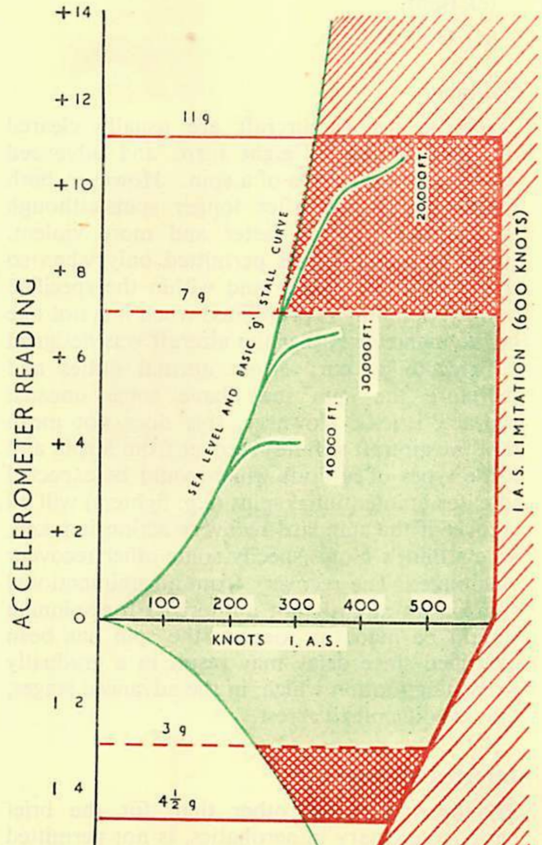

Fig. 2. Typical Flight Envelope

safe flight in these conditions. Speeds higher than the recommended figure may result in damage to the airframe, whereas lower speeds may lead to difficulty in control. Chapter 7 details the technique for flying through severe air turbulence and discusses the best speeds for different types of aircraft.

Prohibited Manœuvres

23. The flying controls on aircraft enable the pilot to manœuvre the aircraft into any attitude ; some of these attitudes may lead to dangerously high loadings and airspeeds which the aircraft has not been designed to withstand. To protect the pilot and aircraft certain manœuvres are prohibited.

24. The following manœuvres are prohibited on all aircraft :—

(*a*) Flick roll.

(*b*) Flick half roll.

(*c*) Bunt.

(*d*) Outside loop.

Spinning

25. Basic trainer aircraft are usually cleared for spins of up to eight turns and advanced trainers for four turns of a spin. However, both types will recover after longer spins although the motion may be faster and more violent. Intentional spinning is permitted only when so stated in Pilot's Notes and within the specified limits. Spinning is prohibited when it is not one of the manœuvres that the aircraft was designed to execute as part of its normal duties and therefore the spin may have some unusual characteristics. However, this does not mean that the aircraft will not recover from a spin and those types of aircraft which could be expected to enter unintentional spins (*e.g.* fighters) will all recover if the standard recovery action is taken, unless Pilot's Notes specify some other recovery technique. The recovery from an unintentional spin on an aircraft not authorized for spinning should be made as soon as the spin has been identified since delay may result in a gradually worsening motion which, in the advanced stages, may be difficult to arrest.

Inverted Flying

26. Inverted flying, other than for the brief periods necessary in aerobatics, is not permitted unless the aircraft is designed or adapted for the purpose. Inverted flying causes prolonged application of negative *g*. Some aircraft can be flown for short periods under negative *g* because they have fuel and oil systems which specifically provide for this, and Pilot's Notes then stipulate the time for which negative *g* may be safely maintained. If this time is exceeded either the engine stops owing to fuel starvation or it is deprived of lubrication.

Aerobatics

27. Pilot's Notes state whether aerobatics are permitted or not. The following are the aerobatics permitted on most aerobatic types of aircraft :—

(*a*) Loop.

(*b*) Stall turn.

(*c*) Inverted flight.

(*d*) Slow roll.

(*e*) Barrel roll.

(*f*) Half roll off the top of a loop.

(*g*) Half roll.

On certain aircraft the list may be reduced ; for example, inverted flight may not be allowed.

Undercarriage and Flap Limiting Speeds

28. The speed limitations for the raising and lowering of the flaps and undercarriage arise from the limited strength of the components to withstand the air loads, or from the power of the operating mechanism. The limiting speed still applies with the service in the extended position unless Pilot's Notes quote a higher speed. Further, should the undercarriage or flaps be lowered at higher speeds the trim and stability of the aircraft may be markedly affected and the airframe overstressed. For these reasons, if the undercarriage or flap indicator shows in flight that either of these components is not in the full up position, speed should be reduced immediately to the maximum permissible for flying with the affected service in the extended position. The defect should be reported after landing, together with details of the speed attained and the duration of the period of overstress. The limiting speed for the flaps is based on the assumption that they are used only during take-off and landing or for straight flight and gentle turns. Unless Pilot's Notes for the type state that the flaps are designed to assist manœuvres, they should not be used under conditions of loading appreciably greater than those of steady level flight. It should be noted that the figures quoted are limitations and are not recommended as the best speeds at which to perform these operations. The limiting speeds

quoted for the operation of other items such as bomb doors, canopies, and landing lamps, are imposed for similar reasons.

Weight Limitations

29. Weight limitations are imposed on all aircraft, the determining factors being the strength of the undercarriage, particularly for the landing case, and the loads that can be absorbed by the wings when manœuvring at the maximum permissible *g*. On twin and multi-engined aircraft the performance on asymmetric power is sometimes critical, and exceeding the weight limitations may result in a serious drop in performance.

30. Pilot's Notes often give more than one weight limitation, for example :—

" Maximum weight for take-off and gentle manœuvres only " and a lower limit :—

" Maximum weight for all other permitted forms of flying " and a still lower limit :—

" Maximum weight for landing ".

This means that at the highest weight the aircraft must be handled gently, moderate turns should be made and only small amounts of *g* imposed. Also, the I.A.S. and mach number should be kept well within the limitations until the weight falls to the limit at which all forms of flying are permitted. Similarly, no attempt should be made to stall the aircraft at these high weights, or to carry out any type of manœuvre which, although not essentially involving high *g* loads, may lead to temporary loss of control, and to the unavoidable use of high *g* during recovery. The limits imposed for landing should be exceeded only when an emergency landing must be made and excess load cannot be jettisoned.

31. To avoid large shock loads, emergency landings at weights above the maximum permissible should be made so that the aircraft is lowered gently on to the runway. The speed during the approach and when crossing the runway threshold should be a little higher than the normal speed for a maximum weight landing. The landing run will be longer owing to the increased inertia and the higher speed.

C.G. Limitations

32. Flying limitations include the most forward and most aft permissible positions of the C.G. This information is contained in Volume 1, Part 1 of the Aircraft Handbook under " Loading and C.G. Data " and is also given in Pilot's Notes in most cases. The aircraft should be flown at standard loadings at which the C.G. is within safe limits. Allowance should always be made for any shift of the C.G. as fuel is used or stores dropped.

33. On aircraft which carry a large fuel load distributed at various positions in the fuselage and wings, the fuel should be used in the sequence given in Pilot's Notes in the paragraphs dealing with management of the fuel system. If this is not done the position of the C.G. may move beyond its safe limits and control will be affected. For the same reason Pilot's Notes sometimes specify the disposition of the crew and passengers or the amount and position of ballast needed.

34. Aircraft may sometimes have occasion to carry non-standard loads and pilots must ensure that the disposition of these loads will keep the C.G. within its limits. If an aircraft has to carry a heavy, concentrated load which can only be secured well aft or well forward of the C.G., the balance must be preserved by placing an equal weight on the other side of the C.G. position at an equal distance, or a lesser weight at a greater distance. In other words, the moment of the load must be balanced by an equal moment in the opposite direction. (See Part 2, Sect. 1, Chap. 3.)

35. Non-observance of C.G. limits may lead to uncontrollable nose or tail heaviness at low speeds and instability at all speeds. In addition the effective useful range of the tail trimmer may be reduced. (See also Vol. 1, Part 1, Sect. 1, Chap. 13.)

Exceeding Limitations

36. Exceeding flying limitations, in particular the maximum I.A.S. limitations, the mach number limitation (if any), and the maximum *g* limitation, involves risk of structural failure, and must be avoided unless operational necessity or an emergency make it essential for the pilot deliberately to take risks with his aircraft, balancing one risk against another. In all cases, if these limitations are unavoidably exceeded, the facts must be reported after landing, giving details and the duration of the overstressing period. This is necessary so that the airframe can be checked for damage which, as stated earlier, might prove fatal in a later flight if not

attended to, even though on this occasion the pilot had "got away with it". On every occasion that overstress occurs some of the ability of the airframe to absorb high stresses is lost, and the strength of the structure and so the breaking load are reduced, perhaps to a very low figure. The early signs of an overstressed airframe are loose rivets and wrinkles in the skin, particularly at the wing roots and along the rear fuselage.


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