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THE EFFECT OF THUNDERSTORMS AND ASSOCIATED TURBULENCE ON AIRCRAFT OPERATIONS.

1 Introduction

1.1 This Circular has been produced to provide an understanding of the hazard that thunderstorms and their associated effects can pose to all aircraft operations and replaces the guidance previously published in AIC P 019/2010. It has been published for the information and safety of all pilots.

1.2 This Circular has been written with two-pilot operation of larger aircraft in mind; however, text that has been highlighted by the use of capital letters is of particular relevance to pilots of all aircraft.

1.3 The overarching advice in this Circular is that flight through thunderstorms should be avoided.

2 Thunderstorm Warnings

2.1 Meteorological Watch Offices (MWO) issue SIGMET (Significant Meteorology) warnings of ‘Thunderstorms’ when significant cumulonimbus clouds likely to produce thunderstorms are forecast and when these thunderstorms are expected to be difficult to detect visually by a pilot. They could be obscured (OBSC TS), embedded in other clouds (EMBD TS) and could possibly be frequent (FRQ TS) or organised along a line (SQL TS). These warnings include information on the location, movement and development of the thunderstorm areas. As it is expected that all pilots will be aware of the additional phenomena associated with thunderstorms, ie hail, severe icing, and severe turbulence (as expanded on in the Annex to this Circular), these forecast details will not be included in the SIGMET text, although heavy hail (HVYGR) could be included. In addition, aircraft commanders are required to send a Special Aircraft Observation when conditions are encountered likely to affect the safety of aircraft. Such a report could then trigger a SIGMET warning. MWOs do not issue SIGMET warnings in relation to isolated or scattered thunderstorms not embedded in cloud layers or concealed by haze (unless prompted by a Special Aircraft Observation). It should therefore be noted that the absence of a SIGMET warning does not necessarily indicate the absence of thunderstorms.

2.2 Aerodrome Warnings are issued by the Meteorological Office for terminal area operations where there is a forecast likelihood of thunderstorms in the immediate vicinity of an aerodrome. Separate windshear warnings may be issued at some aerodromes (notably London Heathrow and Belfast Aldergrove) where a nearby thunderstorm is the criteria for a windshear warning. Elsewhere, the proximity of a thunderstorm will not necessarily result in such a warning, but the probability of windshear is no less. In relation to windshear hazards at low-level your attention is drawn to AIC 84/2008 (Pink 150) - ‘Low Altitude Windshear’.

2.3 Details of the criteria for Special Aircraft Observations and the SIGMET service are given in the UK Aeronautical Information Publication at GEN 3.5 paragraph 6.2 and GEN 3.5 paragraph 8 respectively.

3 Procedures and Flying Techniques

3.1 Notwithstanding the advice that follows, gathered from research and operational experience, the first and most basic advice for all pilots is:

Do not treat thunderstorms lightly and whenever possible AVOID them.

3.2 Thunderstorms should be avoided either visually, by the use of radar, or by other methods. If this cannot be achieved, and in the absence of specific aircraft flight manual or operations manual guidance, the following procedures and techniques are recommended.

a. If it is found necessary to penetrate an area of cloud which may contain cumulonimbus clouds:

i. ENSURE THAT CREW MEMBERS' SAFETY BELTS OR HARNESSES ARE FIRMLY FASTENED AND SECURE ANY LOOSE ARTICLES BEFOREHAND. Switch on the seat belt notices and make sure that all passengers are securely strapped in and that loose equipment (eg cabin trolleys and galley containers) are firmly secured. Pilots should remember that turbulence is normally worse in the rear of an aircraft than on the flight deck.

ii. One pilot should control the aircraft with the other continually monitoring all the flight instruments.

iii. SELECT AN ALTITUDE FOR PENETRATION, BEARING IN MIND THE IMPORTANCE OF ENSURING ADEQUATE TERRAIN CLEARANCE IN LIKELY DOWNDRAUGHTS. Investigations have shown that although in some thunderstorms there is very little turbulence at the lower levels, in others there is a great deal; altitude is not necessarily a guide to the degree of turbulence. Increasing height will decrease the buffet margin and up-currents may force the aircraft into buffet owing to an increased angle of attack.

iv. SET THE POWER TO GIVE THE RECOMMENDED SPEED FOR FLIGHT IN TURBULENCE, ADJUST THE TRIM AND NOTE ITS POSITION SO THAT ANY EXCESSIVE CHANGES DUE TO AUTOPILOT OR MACH TRIM OPERATION CAN BE QUICKLY ASSESSED. Turbulence speeds quoted in flight or operations manuals provide a single speed or a speed bracket.

v. CHECK ALL FLIGHT INSTRUMENTS AND ELECTRICAL SUPPLIES.

vi. ENSURE THAT THE PITOT HEATERS ARE SWITCHED ON.

vii. CHECK THE OPERATION OF ALL ANTI-ICING AND DE-ICING EQUIPMENT AND OPERATE ALL THESE SYSTEMS IN ACCORDANCE WITH MANUFACTURER'S OR OPERATOR'S INSTRUCTIONS. The operation of leading edge, expanding boot type de-icers should be delayed until some ice has formed, otherwise their effectiveness will be greatly reduced. IN THE ABSENCE OF SPECIFIC INSTRUCTIONS, ENSURE THAT ALL ANTI-ICING SYSTEMS, INCLUDING WINDSCREEN HEATERS, ARE ON.

viii. DISREGARD ANY RADIO NAVIGATION INDICATIONS SUBJECT TO INTERFERENCE FROM STATIC, eg ADF.

ix. TURN THE COCKPIT LIGHTING FULLY ON AND LOWER THE CREW SEATS AND SUN VISORS TO MINIMISE THE EFFECT OF ANY LIGHTNING FLASHES.

x. FOLLOW THE MANUFACTURER'S OR OPERATOR'S RECOMMENDATIONS ON THE USE OF THE FLIGHT DIRECTOR, AUTOPILOT AND MANOMETRIC LOCKS. If these are not stated, height, Mach, rate of climb or descent, and airspeed locks should be disengaged but the yaw damper(s), if fitted, should remain operative. On many aircraft the autopilot, when engaged in a suitable mode (turbulence or basic attitude modes), is likely to produce lower structural loads than would result from manual flight. However, if major trim movements occur due to the autopilot's automatic trim the autopilot should be disengaged. Note that Mach trim operation may also occur on some aircraft but the Mach trim should remain engaged.

xi. Continue operating, not just monitoring, the weather radar, or other on-board systems, in order to select the safest track for penetration, and to minimise the time of exposure whilst avoiding areas of intense activity.

xii. Be prepared for turbulence, rail, hail, snow, icing, lightning, static discharge and windshear. In turbine-powered aircraft switch on the continuous ignition system (to reduce the possibility of engine flame-out due to water ingestion) ensuring that limitations on its use, if any, are not exceeded. Also see AIC 29/2004 (Pink 64) - ‘Engine Malfunction caused by Lightning Strikes’.

xiii. AVOID FLYING OVER THE TOP OF A THUNDERSTORM WHENEVER POSSIBLE. Overflying small convective cells close to large storms should also be avoided, particularly if they are on the upwind side of a large storm, because they may grow very quickly. Similarly, do not contemplate flying beneath the cumulonimbus cloud. In addition to the dangers associated with turbulence, rain, hail, snow or lightning, there may well be low cloud base, poor visibility and possibly low-level windshear.

b. Within the Storm Area:

i. CONTROL THE AIRCRAFT REGARDLESS OF ALL ELSE.

ii. CONCENTRATE ON MAINTAINING A CONSTANT PITCH ATTITUDE APPROPRIATE TO CLIMB, CRUISE OR DESCENT, BY REFERENCE TO THE ATTITUDE INDICATORS, CAREFULLY AVOIDING HARSH OR EXCESSIVE CONTROL MOVEMENTS. DO NOT BE MISLED BY CONFLICTING INDICATIONS ON OTHER INSTRUMENTS. DO NOT ALLOW LARGE ATTITUDE EXCURSIONS IN THE ROLLING PLANE TO PERSIST BECAUSE THESE MAY RESULT IN NOSE DOWN PITCH CHANGES.

iii. MAINTAIN THE ORIGINAL HEADING - IT IS USUALLY THE QUICKEST WAY OUT. DO NOT ATTEMPT ANY TURNS.

iv. DO NOT CORRECT FOR ALTITUDE GAINED OR LOST THROUGH UP AND DOWN DRAUGHTS UNLESS ABSOLUTELY NECESSARY.

v. Maintain the trim settings and avoid changing the power setting except when necessary to restore margins from stall warning or high-speed buffet. The target pitch attitude should not be changed unless the mean IAS differs significantly from the recommended penetration speed.

vi. If trim variations due to the autopilot (auto-trim) are large, the autopilot should be disengaged. However, movement of the Mach trim, where it occurs, is necessary and desirable. Check that the yaw-damper remains engaged.

vii. If negative 'G' is experienced, temporary warnings (eg low oil pressure) may occur. These should be ignored.

viii. ON NO ACCOUNT CLIMB IN AN ATTEMPT TO GET OVER THE TOP OF THE STORM.

c. After a Thunderstorm Encounter - In flight:

i. If hail has been encountered, considerable damage to the airframe, not visible from the cockpit or cabin, may have occurred. Consideration should therefore be given to diverting to a suitable and nearby aerodrome where the aircraft can be inspected for damage. If this damage has occurred to aerodynamically significant areas, eg a nose radome, the increased drag will affect fuel burn. Thus the aircraft, if continuing to its destination, may burn considerably more fuel than expected or planned. **Actual** fuel usage should now be monitored very closely, bearing in mind that some FMS calculate ‘expected overhead destination’ fuel, based on data that assumes normal (planned) conditions and normal (ie fully clean) aircraft aerodynamic states.

ii. If the aircraft has been struck by lightning, treat all magnetic information (eg from direct or remote indicating compasses) with extreme caution. The large electric currents associated with a lightning strike can severely and permanently distort the magnetic field of an aircraft rendering all such information highly inaccurate.

d. Air Traffic Control Considerations:

i. Modern ATC radars in general do not display the build up of weather that may constitute a hazard to aircraft and ATC advice on weather avoidance may, therefore, be limited.

ii. If, as recommended in this Circular, a pilot intends to detour round observed weather when in receipt of an Air Traffic Service that involves ATC responsibility for separation, clearance should first be obtained from ATC so that separation from other aircraft can be maintained. If for any reason the pilot is unable to contact ATC to inform the controller of his/her intended action, any manoeuvre should be limited to the extent necessary to avoid immediate danger and ATC must be informed as soon as possible. In oceanic airspace the weather deviation procedure in PANS-ATM, (ICAO Doc 4444) paragraph 15.2.3 should be followed.

iii. Because of the constraints on airspeed and flight path and the increased workload of the crew when flying in a Terminal Manoeuvring Area, pilots should consider making a diversion from, or delaying entry to, a Terminal Manoeuvring Area if a storm encounter seems probable.

e. Take-off and Landing Problems:

i. The take-off, initial climb, final approach and landing phases of flight present the pilot with additional problems because of the aircraft's proximity to the ground, thus the maintenance of a safe flight path in these phases can be very difficult.

ii. Some operators give advice on the airspeed adjustments to be made to allow for windshear or turbulence (a speed increase of up to 20 knots according to the type of aircraft and the degree of turbulence may be required). The best advice that can be given to the pilot is that, when there are thunderstorms over or near the aerodrome, he/she should delay take-off or, when approaching to land, hold in an unaffected area or divert to a suitable alternate. For further relevant information see AIC 84/2008 (Pink 150) - 'Low Altitude Windshear'.

f. Airworthiness and Maintenance Considerations:

i. Severe weather conditions may cause damage to aircraft and power plant installations, some of which may be invisible to the naked eye. Flight Manuals and Maintenance documents may quantify levels of turbulence which would trigger a maintenance inspection, similar to those that may be applicable to ‘heavy landings’. Hail and lightning damage may often be obvious to crews; however, there will be occasions where damage may be restricted to parts of the airframe not normally visible from the ground, or from the cockpit, immediately following a thunderstorm encounter.

ii. In the event that crews believe that an aircraft has been exposed to hail, lightning, turbulence greater than ‘moderate’, or a heavy landing, they should record the fact(s) in the technical log on arrival to ensure that an appropriate inspection is completed prior to a subsequent release to service. Operators should ensure that procedures in operation manuals for flight crews and maintenance personnel reflect this advice.

g. Light aircraft operators should ensure that their aircraft are adequately secured on the ground when severe thunderstorm activity is forecast.

4 Concluding Remarks

4.1 DO NOT TAKE-OFF IF A THUNDERSTORM IS OVERHEAD OR APPROACHING.

4.2 AT DESTINATION HOLD CLEAR IF A THUNDERSTORM IS OVERHEAD OR APPROACHING. DIVERT IF NECESSARY.

4.3 AVOID SEVERE THUNDERSTORMS EVEN AT THE COST OF DIVERSION OR AN INTERMEDIATE LANDING. IF AVOIDANCE IS IMPOSSIBLE, THE PROCEDURES RECOMMENDED IN THE FLIGHT OR OPERATIONS MANUAL OR IN THIS CIRCULAR SHOULD BE FOLLOWED.

4.4 Pilots of turbo-jet swept-wing transport aircraft are advised to ensure that they are fully conversant with the control problems that may be met in turbulence with the type of aircraft they fly.

4.5 AFTER AN ENCOUNTER WITH A THUNDERSTORM CONSIDER REPORTING THE EVENT IN THE AIRCRAFT TECHNICAL LOG. THIS WILL ENSURE THAT A FULL AND PROPER INVESTIGATION OF THE AIRCRAFT OCCURS.

ANNEX

1 THUNDERSTORMS, FLIGHT HAZARDS AND WEATHER RADAR

1.1 A thunderstorm cloud, whether of the air mass or frontal type, usually consists of several self-contained cells, each in a different state of development. It must be stressed that the storm clouds are only the visible part of a turbulent system that extends over a much greater area. New and growing cells can be recognised by their cumuliform shape with clear-cut outline and 'cauliflower' top, while the tops of more mature cells will appear less clear-cut and will frequently be surrounded by fibrous cloud. It is important, however, to remember that the development of cells, which can be very rapid, will not always be seen, even in daylight, since other clouds may obscure the view. In frontal or orographic conditions, for instance, where forced ascent of air may give the impetus required for producing vigorous convection currents, extensive layer cloud structures may obscure a view of the development of Cumulonimbus thunderstorm cells or Altocumulus Castellanus; the latter is cumuliform cloud with a base above 8000 ft and is an indication of middle level instability which often precedes, or is associated with, the development of thunderstorms. Mammatus clouds, udder shaped features seen beneath cumulonimbus clouds, or the associated medium level altocumulus layer clouds (above 8000 ft), or in association with the high-level cirrus anvil cloud (above 20000 ft), are an indication of strong vertical winds with associated turbulence.

1.2 The most severe thunderstorms require an increase in the general wind speed and a change in direction with height to maintain a release of energy. With no vertical wind shear, as the cloud grows and the updraught strengthens, precipitation forms in the upper parts of the cloud. As the precipitation falls towards the ground, it exerts a drag on the updraught, which weakens and the cloud decays. However, for a storm that has the downdraught offset from the updraught, particularly where the updraught is not cut off at the surface by the spreading out of the cold downdraught, it can develop into a self-generating system that can last for hours, independently of any surface heating.

1.3 These up and downdraughts are of comparable intensity, often in close proximity to each other and frequently reach speeds in excess of 3000 ft per minute. Sharp gusts with vertical speeds of 10000 ft per minute have been measured. The horizontal extent of these vertical draughts may, occasionally, be more than a mile. The top of a developing cell has been observed to rise at more than 5000 ft per minute. When thunderstorms are associated with frontal conditions, areas of 'line squall' activity can extend for more than 100 miles. The vertical extent of storms will vary considerably but it is not uncommon for them to penetrate the tropopause with cloud tops exceeding 40000 ft in temperate latitudes and 60000 ft in sub-tropical and tropical regions. Although an individual cell will usually last for less than an hour, a storm system, with new cells developing and old ones decaying, may persist for several hours.

1.4 Areas in which conditions will be favourable for the development of thunderstorms can usually be forecast successfully several hours in advance but it is not possible at present to determine the precise location and distribution of individual storms. Where up-to-date ground weather radar information is available, however, useful information on the expected movement of an individual storm can be forecast for periods of up to an hour or so ahead.

1.5 As a general rule of thumb, in the UK, the movement of a cumulonimbus cloud is in the direction of the 10000 ft (700 millibar) wind, though the tendency for large storms to distort wind fields and the development of new cells will cause variations in this general movement.

1.6 All thunderstorms are potentially dangerous. This considered, there are two facts that should be borne in mind. The first is that a severe storm can occur in practically any geographical area in which thunderstorms are known. The second is that no useful correlation exists between the external visual appearance (or the weather radar appearance) of thunderstorm clouds and the turbulence and hail within them.

2 FLIGHT HAZARDS

2.1 Turbulence Associated with Thunderstorms

2.1.1 The air movement in thunderstorms, generally referred to as turbulence and composed of draughts (sustained vertical or sloping currents) and gusts (irregular and local variations), can become violent, dangerous and even destructive, reaching a maximum intensity in developing and mature cells. High rates of roll and large pitching motions have been experienced in these storms, as have large vertical displacements of as much as 5000 ft. These extreme variations will, of course, only occur in the most severe conditions. Of equal importance is the fact that eddies, which are felt as gusts, can occur some distance outside a thunderstorm cell. The regions around or between adjacent cells are therefore likely to be turbulent - severely so at times - and severe turbulence is often found 15 to 20 miles downwind of a severe storm core. Conditions at or near the surface in the vicinity of thunderstorms are often rough because, during the mature stage of the cells, the outflow from the base is of a turbulent nature and the air is colder than its environment, producing a miniature cold front often accompanied by heavy precipitation and squally conditions. When this is associated with a line of thunderstorms its effects can be felt as much as 40 miles ahead of them. Take-offs and landings in these circumstances are hazardous. Severe turbulence can also be encountered several thousand feet above the tops of active thunderstorm clouds, particularly when the speed of the wind at this level is high (100 kts or more). It is therefore advisable to avoid flying and in particular not to climb, in these areas.

2.1.2 A thunderstorm cell must be well developed before lightning first occurs but it may continue in the decaying cell. Lightning must not, therefore, be regarded as a reliable guide to the degree of turbulence in a cloud.

2.1.3 Accidents involving loss of control of the aircraft have been caused by flying in and around thunderstorms. In some instances there was structural failure that probably occurred during the attempt to regain control.

2.1.4 Stress requirements for modern transport aircraft are set at a level which experience has shown will rarely be reached. Nevertheless, flight research has indicated that, in the extreme conditions that may exist within thunderstorms, abnormal pilot-induced loads are added to already high gust-loads such that stress limits may be exceeded.

2.1.5 In some instances the correct flying technique is difficult to achieve. Indications are that loss of control, which may follow the use of incorrect techniques, is a more serious hazard than the risk of structural failure due directly to an encounter with turbulence. This is because recovery manoeuvres are likely to subject the aircraft to great stresses that may lead to structural failure or serious deformation.

2.2 **Thunderstorm Windshear**

2.2.1 Accidents have occurred during the take-off, initial climb and final approach phases of flight, which were probably due in part, if not entirely, to the effect of a rapid variation in wind velocity known as windshear. For further information see AIC 84/2008 (Pink 150) - 'Low Altitude Windshear'. Unlike the erratic fluctuations caused by gusts, windshear gives rise to airspeed fluctuations of a more sustained nature and is therefore likely to be more dangerous. Gusts are likely to accompany windshear conditions.

2.2.2 Thunderstorms frequently produce windshear and, although it is hazardous at all levels, it is in the lower levels that windshear may have more drastic consequences. Winds caused by the outflow of cold air from the base of a thunderstorm cell have been known to change in shallow layers of a few hundred feet by as much as 80 kts in speed and 90º or more in direction. Due to the effect of inertia, an aircraft in flight will tend to maintain its ground speed and windshear will therefore produce airspeed variations that can be large enough to be extremely dangerous.

2.3 **Tornadoes**

2.3.1 Tornadoes present a very serious threat to aircraft. A Fokker F-28 flying in cloud at 3000 ft shortly after take-off from Rotterdam was destroyed by a tornado on 6 October 1981. Tornadoes are generally associated with organised severe local storms. They occur frequently in the United States but can also arise in the UK and Europe although they are less common and seldom as violent. There is evidence that tornado circulation may extend throughout the depth of the storm and constitute a hazard to aircraft at all heights.

2.3.2 The most violent thunderstorms draw air into their cloud bases with great vigour. If the incoming air has any initial rotating motion, it often forms an extremely concentrated vortex from the surface well into the cloud. Meteorologists have estimated that wind velocities in such a vortex can exceed 200 kts. Because pressure inside the vortex is quite low, the strong winds gather dust and debris and the low pressure generates a funnel-shaped cloud extending downward from the cumulonimbus base. If the cloud does not reach the surface, it is a 'funnel cloud'; if it touches the land surface, it is a tornado.

2.3.3 Tornadoes occur with both isolated and squall line thunderstorms. An aircraft entering a tornado vortex is almost certain to suffer structural damage. Since the vortex extends well into the cloud, any pilot flying on instruments in a severe thunderstorm could encounter a hidden vortex.

2.3.4 Families of tornadoes have been observed as appendages of the main cloud extending several miles outward from the area of lightning and precipitation. Thus any cloud connected to a severe thunderstorm carries a threat.

2.4 **Hail**

2.4.1 Notwithstanding all the work that has been done in the field of thunderstorm forecasting, no confirmed or fully reliable method has yet been evolved for recognising a storm that will produce hail. It is safest to assume that hail exists in one part or another of every thunderstorm at some stage in its life. The higher the lapse rate and the greater the moisture content of the air mass, the stronger will be the convective activity which increases the likelihood of the formation of damaging hail. Stability in the upper atmosphere results in the characteristic anvil shape of the spreading-out of the top of the cumulonimbus cloud and strong upper winds will often cause hail to fall from the overhang. Flight beneath the overhang should be avoided.

2.4.2 The maximum size of hailstones which have been found on the ground is around five and a half inches in diameter. It is known that hailstones of four inches in diameter can be encountered at 10000 ft and damaging hail up to 45000 ft.

2.4.3 Although hail encounters are usually of short duration, damage to aircraft can be severe. Hail may damage the leading edges and hence reduce the efficiency of the wing. Windscreens or other transparencies may be shattered. In an encounter in the Middle East, hail severely damaged the airframe of a VC-10 that encountered a thunderstorm shortly after take-off. The radome was torn away, denting and damage to the skin occurred in many areas, but there was no evidence of a lightning strike.

2.4.4 Although no fatal accidents to civil aircraft are known to have been attributable entirely to hail damage, hail can be a serious hazard at all altitudes at which civil aircraft operate. Evidence for this comes from a study of military aircraft accidents in the USA, in which aircraft were damaged or destroyed by the combined effect of hail and turbulence and from experience gained through the United States National Severe Storms Project together with individual reports of encounters with hail in normal operations.

2.5 **Rain**

2.5.1 Water ingestion by turbine engines

2.5.1.1 Turbine engines have a limit on the amount of water they can ingest. Updraughts are present in many thunderstorms, particularly those in the developing stages. If the updraught velocity in the thunderstorm approaches or exceeds the terminal velocity of the falling raindrops, very high concentrations of water may occur. It is possible that these concentrations can be in excess of the quantity of water turbine engines are designed to ingest, which could result in flame out and/or structural failure of one or more engines.

2.5.1.2 At the present time, there is no known operational procedure that can completely eliminate the possibility of engine damage/flame out during massive water ingestion but although the exact mechanism of these water induced engine stalls has not been determined, it is believed that thrust changes may have an adverse effect on engine stall margins.

2.5.1.3 To eliminate the risk of engine damage or flame out by heavy rain, it is essential to avoid severe storms. During an unavoidable encounter with extreme precipitation, the best-known recommendation is to follow the severe turbulence penetration procedure contained in the approved aircraft flight manual, with special emphasis on avoiding thrust changes unless excessive airspeed variations occur. Flight research has revealed that water can exist in large quantities at high altitudes even where the ambient temperature is as low as -30°C. Rain, sometimes heavy, may therefore be encountered and give rise to ice accretion and a possibility of the malfunctioning of pressure instruments. Turbine engine igniters must be switched on.

2.5.2 Heavy precipitation, which occurs in cumulonimbus clouds, may often be seen as shafts of rain below the cloud base. Where this precipitation does not reach the surface, the shafts are known as virga. The evaporation cooling associated with virga may intensify existing downdraughts.

2.6 **Icing**

2.6.1 Flight must not be initiated or continued into areas where the forecast icing conditions will exceed the icing limitations of the aircraft.

2.6.2 Formation of ice on the airframe must always be considered likely when flight takes place through cloud or rain at a temperature below 0°C. The temperature range favourable for ice accretion in thunderstorms is from 0°C down to -45°C, ie where water droplets can exist in a supercooled state. Below about -30°C, however, a large part of the free water content of the atmosphere normally consists of ice particles or crystals and snowflakes and chances of severe icing at these low temperatures are, therefore, greatly reduced. Conversely, because of downdraughts, the freezing level inside thunderstorm clouds must be assumed to drop to the base of the cloud. Airframe icing can therefore be expected everywhere in a thunderstorm cloud.

2.6.3 In piston engines, loss of power can occur over a wide range of temperatures as a result of the formation of ice in the induction system. Proper use of carburettor heat or other induction anti-icing equipment is therefore essential to prevent or minimise the loss of power. Furthermore, in clear air of high humidity (ie of the order of 60% or more), which might exist in areas of thunderstorm activity, carburettor ice can easily form.

2.6.4 Where turbine engines are concerned, the danger of flame out must be recognised whenever icing conditions are met. Igniters must therefore be switched on and remain on provided they are cleared for continuous operation. In all circumstances operators' or manufacturers' instructions must be strictly followed to achieve maximum protection.

2.6.5 It must be emphasised that, when flying in thunderstorms, anything more than very light ice accretion adds to the problems related to turbulence because of the increased weight of the aircraft, the disturbance of the normal airflow and the reduced effectiveness of the control surfaces.

2.6.6 Experience has shown that, provided the normal precautions are taken (ie using the anti-icing or de-icing equipment correctly), icing conditions need not be a grave hazard if penetration of a thunderstorm area cannot be avoided. However, failure to recognise or anticipate icing conditions, failure to use the equipment properly, equipment unserviceability or extended flight through a storm area will all considerably increase the risks involved.

2.7 **Lightning**

2.7.1 Lightning can occur both within and away from cumulonimbus clouds, with discharges taking place either within the cloud, between neighbouring clouds, or commonly between a cloud and the ground and less commonly from the top of a cloud upwards. Most recorded lightning strikes have occurred at levels where the temperature is between +10°C and -10°C, ie within about 5000 ft above or below the freezing level. Some risk also exists outside this band, particularly in the higher levels. Strikes are either electrically positive or negative, although the polarity of the strike is not evident at the time. Positive polarity strikes are likely to be the more severe (ie cause more damage to the aircraft), and recent investigations have shown that the North Sea is an area prone to a higher than normal frequency of positive strikes, although the overall frequency of strikes per flying hour is similar to that in the rest of Europe. The presence of soft hail has been associated with some positive strikes and may thus be indicative of the conditions conducive to a positive strike. For further information regarding lightning and aircraft engines see AIC 29/2004 (Pink 64) - 'Engine Malfunction Caused by Lightning Strikes'.

2.7.2 The brilliant flash, the smell of burning and the accompanying explosive noise may be alarming and distracting to the pilots of an aircraft struck by lightning. The report on a serious accident, in which a large transport aircraft was destroyed, stated that it was due to a lightning strike causing ignition of vapour in the region of fuel tank vents but fatal accidents due to lightning strikes have fortunately been very few and most aircraft receive only superficial damage when struck.

2.7.3 The effect of lightning strikes upon both direct reading magnetic compasses and magnetically slaved compasses can be severe with deviations of many tens of degrees having been recorded. Magnetic compasses should not be relied upon after an aircraft has been struck and should be checked as soon as possible.

2.8 **Static Electricity**

2.8.1 This phenomenon will generally first be noticed as noise on the High and Medium frequency radio bands and also, to a lesser extent, on VHF receivers. As the static electricity increases in severity, the noise will increase and in extreme cases a visible discharge, known as St Elmo's fire, will be seen on some parts of the aircraft, particularly around the edges of windscreens. Static electricity is not associated only with thunderstorms but such conditions are particularly favourable to its creation. Although it is not normally dangerous, there have been rare incidents when a static discharge has occurred across a windscreen or plastic panel causing it to break.

2.8.2 An understanding of the effect of static electricity on radio equipment is important. It is detrimental to the performance of MF (eg ADF) and HF equipment but has little or no effect upon VHF and UHF. On HF, static may cause the signal-to-noise ratio to be such that communications are impossible. In these conditions navigational aids such as ADF must be used with extreme caution due to the fluctuating or erroneous indications that may occur.

2.9 **Instrumental Errors and Limitations**

2.9.1 Altimeters and Vertical Speed Indicators

2.9.1.1 Local pressure variations can occur in or very close to a thunderstorm at all heights and this, together with local gusts, may give rise to errors in the indications of altimeters and vertical speed indicators. There is some doubt as to the magnitude of altitude errors but there is evidence that they can be as much as ± 1000 ft. It is essential, for ground clearance purposes, that due allowance is made for such errors when flying in or near thunderstorm areas. Near the surface, periods of heavy rain are an indication of the likelihood of pressure variations and gusts.

2.9.2 Airspeed Indicators

2.9.2.1 Despite the precautions taken in the design of pitot heads, there is still a possibility that very heavy rain may cause an airspeed indicator to give a false indication even when the pitot head heaters are used. If the power which gives the safest speed for penetration has been selected before a storm is entered, no action should be taken to correct for violent or short period airspeed indicator oscillations, provided a reasonably level attitude is maintained.

2.9.3 Attitude Indicators

2.9.3.1 Attitude is indicated by instruments presenting pitch and roll information alone or by other more complex flight directors containing attitude indication amongst other elements.

2.9.3.2 The simple artificial horizons fitted to most aircraft, either as the main attitude indicator or as a standby instrument when remote reading indicators are installed, provide indications of pitch angle up to 85° nose up and down and may have complete freedom in the rolling plane. Except in rare circumstances these instruments give an adequate range of indication but may lack referencing, which would enable the pilot to assess attitude accurately at large angles of pitch or be given maximum assistance in recovery from any unusual attitudes.

2.9.3.3 Pitch referencing is also lacking on the attitude indicators of some flight director presentations. Moreover, their range of indication is much less than 85° up and down, in some cases less than 30°. The presentation of information on these earlier instruments does not give an indication to the pilot of the point at which the aircraft's pitch attitude exceeds the limit of indication of the instrument. These instruments therefore give no guidance as to the progress of recovery from attitudes outside their normal range of indication.

2.9.3.4 The wide variety of instruments which may be encountered makes it essential that pilots are fully aware of the limitations of the particular attitude indicator(s) fitted in the aircraft they fly.

2.9.4 Magnetic Compasses

2.9.4.1 Magnetic compasses are likely to be seriously affected by a lightning strike. They should not be relied upon after an aircraft has been struck and should be checked as soon as possible.

2.10 **Use of Weather Radar**

2.10.1 Pilots should be in no doubt about the function of airborne weather radar. It is provided principally to enable them to AVOID thunderstorms although they can be of assistance in penetrating areas of storm activity, where avoidance has not been possible. **However, pilots should also be aware of the potential for displayed data to be unreliable when used for calculating the safe vertical clearance for the overflight of active storm cells.**

2.10.2 Pilots should be familiar with the characteristics and operation of the radar in their aircraft and its limitations. Operators should ensure that their crews are given adequate instructions in relation to the radar equipment fitted to its aircraft, including the operation of the antenna and radar controls and on the adjustment and interpretations of the display.

2.10.3 It should be noted that the subject of airborne weather radar is quite complex and whilst the following notes give a generalised overview, they are no substitute for manufacturers' instructions in relation to specific products.

a. Most modern airborne weather radars operate in the frequency band of 8-12 GHz (ie wavelengths between 2.5 and 4 cm). This band, sometimes known as the ‘X’ band, was chosen for weather radars as it is highly sensitive to wet precipitation which is a feature of most weather systems that might need to be avoided by pilots. Airborne weather radars do not detect turbulence, although turbulent air, particularly within a thunderstorm, often contains water. In some radars, a change in frequency (a Doppler shift) in the reflected (returned) radar signal caused by moving precipitation is measured and is used to give an indication of likely turbulence.

b. Although wet precipitation is the most reflective of radar signals, other water products will reflect lesser amounts of incident radar energy. In descending order (ie from most to least reflective) these are: wet hail, rain, hail, ice crystals, wet snow, dry hail and dry snow.

c. The intensity of the returned radar signal will also be affected by the range of the aircraft from the precipitation, the amplification of signal (gain) being used by the receiver and the aerial tilt setting.

d. It should be noted that, with weather radars, the significance of radar returns of given intensity usually increases with altitude, but the strength of the echo is not an indication of the strength of any associated turbulence.

e. Radar return intensities may also be misleading because of attenuation resulting from intervening heavy rain. This may lead to serious underestimation of the severity of the rainfall in a large storm and an incorrect assumption of where the heaviest rainfall is likely to be encountered. The echo from that part of an area of rain furthest from the radar will be relatively weaker, and the actual position of the maximum rainfall at the far edge of the storm area will be further away than indicated on the radar display, sometimes by distances up to several miles. Additionally, a storm cell beyond may be completely masked.

f. It should also be noted that, notwithstanding recent research and operational experience, it still seems impossible to use radar to detect with certainty areas where large hailstones exist, because clouds containing rain or hail can produce identical radar pictures. Some operators have claimed success in avoiding hail by keeping well clear of cloud echoes that have scalloped edges or pointed or hooked ‘fingers’ attached. The best advice is to give radar echoes a wide berth, when detouring storms visually.

g. The high rate of growth of thunderstorms and the danger of flying over or near to the tops of both the main storm and the small convective cells close to it must also be remembered when using weather radar for storm avoidance.

h. Some guidance on the distances by which thunderstorms should be avoided is given in the table below. It is strongly recommended that the decision to avoid a thunderstorm be taken early.

i. Where weather information is available from ATC radar, it should be used to supplement the aircraft's weather radar (but see paragraph 3.2(c) of this Annex).

3 THUNDERSTORM AVOIDANCE GUIDANCE - WEATHER RADAR

Flight Altitude (ft)	Echo Characteristics			
	Shape	Intensity	Gradient of Intensity*	Rate of Change
0 - 20000	Avoid by 10 miles echoes with ‘hooks’, ‘fingers’, scalloped edges or other protrusions from the main storm return.	Avoid by 10 miles echoes with sharp edges or strong intensities.	Avoid by 10 miles echoes with strong gradients of intensity.	Avoid by 10 miles echoes showing rapid change of shape, height or intensity.
20 - 25000	Avoid all echoes by 20 miles			
25 - 30000	Avoid all echoes by 20 miles.			
Above 30000	Avoid all echoes by 20 miles			
* Applicable to sets with Iso-Echo or a colour display. Iso-Echo produces a hole in a strong echo when the returned signal is above a pre-set value. Where the return around a hole is narrow, there is a strong gradient of intensity.				

3.1 The above avoidance criteria can be simply summarised as: if above 20000 ft avoid by a minimum of 20 nm; if below avoid by a minimum of 10 nm.

3.2 If storm clouds have to be overflown, always maintain at least 5000 ft vertical separation from cloud tops. It is possible to estimate this separation (using the principle outlined below), but ATC or Met information on the altitude of the tops may also be available for further guidance:

a. To ensure that the optimum radar beam is used for this purpose, it will be necessary to adjust the ‘gain’ control. One particular weather radar manufacturer recommends that with an aircraft in straight and level flight and the aerial tilt set to zero (ie with the centre of the weather radar beam (ie along the bore-sight) aligned to the horizontal) the gain should be reduced until the ‘radar paint’ from the clouds just disappears. The gain should then be increased until a ‘solid paint’ is produced and the gain left at this setting for the required measurement. The range of the nearest part of this ‘paint’ should then be recorded.

b. The beam should now be raised (by adjusting the aerial tilt upwards) until the return 'disappears'. The tilt angle associated with this disappearance should be recorded. Return the tilt to zero in order to continue to monitor the storm and its development and the separation of the aircraft from it. Then either using data provided by the radar manufacturer (as in a 'look-up' table) or by mental arithmetic the approximate height of the cloud top may be obtained. One method of approximation is as follows:

   One half of the notional beam-width as quoted by the radar manufacturer (usually in the region of 3° to 4°) should be subtracted from the recorded angle of tilt. Then using the 1:60 rule, this remainder should be applied to the recorded range of the edge of the return to calculate the height (in nautical miles) that the cloud top is above the aircraft.

   Example: In an aircraft at 20000 ft, with a radar whose notional beam width is 4°, a cloud return at 40 nm is made to 'disappear' at an aerial tilt angle of + 3.5°. 3.5 minus 2 (ie ½ the notional beam-width) = 1.5, which, when applied to 40 miles using the 1:60 rule, indicates that the cloud tops are 1 nm (or 6000 ft) above the aircraft. Thus if the cloud is to be overflown with the minimum recommended clearance of 5000 ft, a climb to at least 31000 ft is indicated. If this course of action is followed, do remember that in the finite time it will take the aircraft to climb and to close this distance, the top of the storm cloud itself, if very active, might easily have ascended to a higher altitude.

c. If the aircraft is not equipped with radar or it is inoperative, avoid by at least 10 miles any storm that by visual inspection is tall, growing rapidly or has an anvil top.

d. Intermittently monitor long ranges on radar to avoid getting into situations where no alternative remains but to penetrate possibly hazardous areas. Unless otherwise instructed by the radar manufacturer, it is usually necessary to adjust both 'gain' and 'tilt' during this monitoring process to ensure that new weather 'targets' are not missed and that active clouds are continually tracked.

e. Avoid flying under a cumulonimbus overhang. If such flight cannot be avoided, tilt antenna full up occasionally to determine, if possible, whether precipitation (which may be hail) exists in or is falling from the overhang.

f. Notwithstanding the principle outlined above, or other guidance provided by radar manufacturers, or by instructors in radar systems, it should always be borne in mind that the result is only an estimate of the height of the storm cloud tops and that the accuracy of the estimate is critically dependent on certain assumptions. These assumptions include radar handling (eg that the beam width in actual use is similar to the quoted notional beam width; and that the tilt control knob has not slipped on the spindle). It should be remembered that weather radars are provided **primarily for storm avoidance** not penetration or overflight.

4 USE OF INFORMATION FROM A LIGHTNING DISCHARGE MONITOR

4.1 Instruments are available which indicate and record lightning discharges. However, in a similar manner to that of airborne weather radar they should be used for storm avoidance and not penetration. They work on the principle that in mature thunderstorms, air turbulence has changed the normal distribution of charged particles such that large build-ups of electrical charge occur. Lightning dissipates these build-ups. These lightning discharges are detected by the equipment and normally shown on a screen with its centre that of the aircraft. The displayed distance of the discharge from the screen centre is an indication of the strength of the lightning discharge; it is not the actual range of the discharge from the aircraft. The distance calculated uses an algorithm based around the average strength of lightning discharges. Thus, a high power discharge at long range will be displayed at the same distance as a low power discharge at short range.

4.2 Because lightning is more likely to be associated with the most severe turbulence, an area of frequent discharges in a particular direction should be avoided. However, it has been found that the first lightning discharges from recently formed cells (where no discharges have been evident beforehand) may be particularly strong (ie violent). Thus, the lack of an indication of discharge is no guarantee that lightning will not strike. One particular manufacturer recommends that pilots using his equipment should manoeuvre their aircraft such that all discharge clusters are kept at least 25 nm away.

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