AP3456
The Central Flying School (CFS) Manual of Flying

Volume 8 – Aircraft Operations

CHAPTER 1 - GENERAL METEOROLOGY

Introduction

1. Weather can be described as the state of the atmosphere at a given time and place, with respect to temperature, moisture, visibility, pressure and wind velocity. It can have a significant effect on aircraft performance and flight safety. This chapter uses the Handbook of Aviation Meteorology (HMSO – IBSN 0 11 400365 3), The Pilot's Handbook of Aeronautical Knowledge (Federal Aviation Administration – FAA-H-8083-25A) and the Australian Defence Force PAARM 02 as reference sources. It is intended to give an overview of meteorology with respect to aviation and users should refer to Volume 10 of AP3456 for more detail.

The Atmosphere

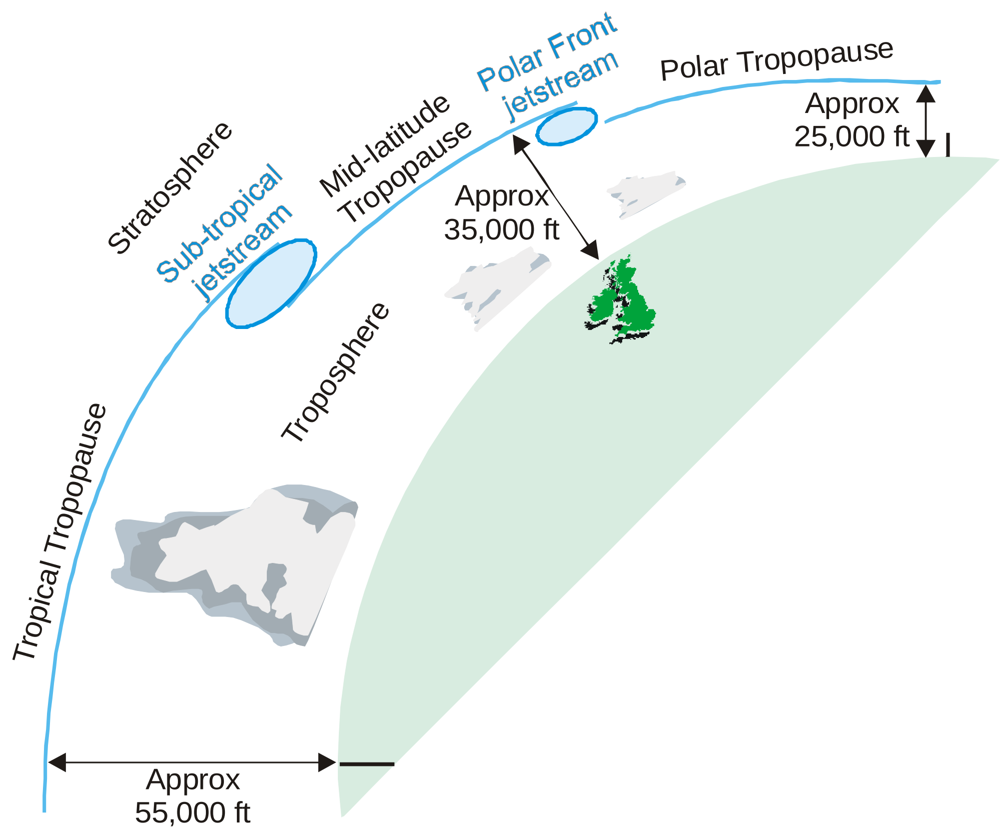
2. The atmosphere is the term given to the layer of air which surrounds the Earth and extends upwards from the surface to about 500 miles. The flight of all objects using fixed or moving wings to sustain them, or air-breathing engines to propel them, is confined to the lower layers of the atmosphere. The properties of the atmosphere are therefore of great importance to all forms of flight. The Earth's atmosphere can be said to consist of four concentric gaseous layers (Fig 1).

8-1 Fig 1 Gaseous Layers of the Atmosphere

SPACE	
THERMOSPHERE	Upper limit not defined. Temperature increases above the Mesopause.
------------------------ Mesopause	**---**
MESOSPHERE	Extends to between 260,000 and 295,000 ft. Temperature falls with height to the Mesopause.
------------------------ Stratopause	**---**
STRATOSPHERE	Extends to about 164,000 ft. Negligible water content. Temperature overall increases. Contains the Ozone layer.
------------------------ Tropopause	**---**
TROPOSPHERE	The Troposphere contains almost all atmospheric water and therefore most of the weather, clouds, storms and temperature variances. Temperature falls with height. The Tropopause varies in height from about 25,000 ft at the poles, 35,000 ft over UK latitudes, to about 55,000 ft over the equator; thus being elliptical in shape. The height varies from day to day and is higher in summer than in winter.
SURFACE	

3. Air masses tend to 'keep' their Tropopause, so in the northern hemisphere, with a moving air mass from the south, the Tropopause will rise with the air mass. The Tropopause is important in aviation as clouds are rare above it, maximum wind speeds are often found just below it, condensation trails occur just below but not above it and severe turbulence may be encountered close to it. A simplified diagram of the troposphere is at Fig 2.

8-1 Fig 2 The Troposphere and Tropopause



Composition of the Atmosphere

4. Air is a mixture of a number of separate gases, the proportions of which are:

Element	By Volume %	By Weight %
Nitrogen	78.08	75.5
Oxygen	20.94	23.1
Argon	0.93	1.3
Carbon dioxide	0.03	0.05

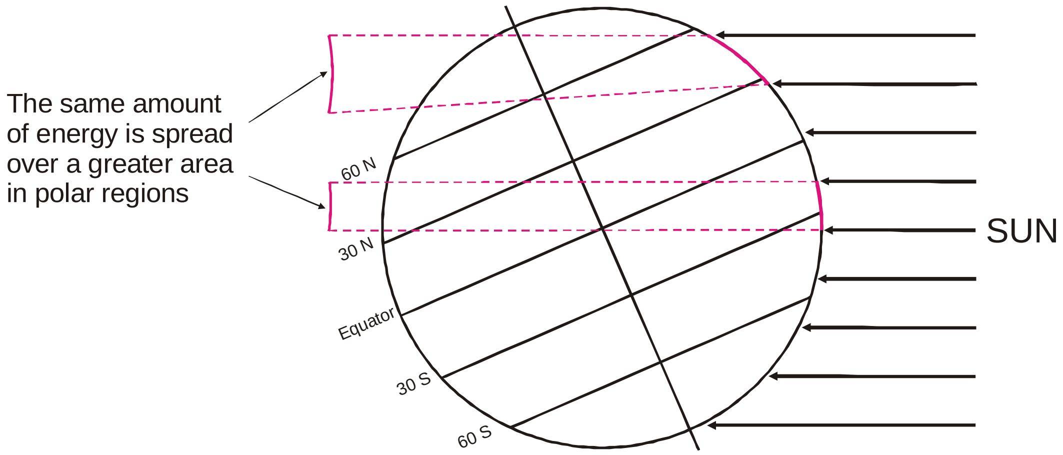
Plus trace quantities of other gases

5. For all practical purposes the atmosphere can be regarded as consisting of 21% oxygen and 78% nitrogen by volume. Up to a height of between 26,000 to 30,000 ft water vapour is found in varying quantities, the amount of water vapour in a given mass of air depends on the temperature and whether the air is, or has recently been, over large areas of water. The higher the temperature the greater the quantity of water vapour that the air can hold.

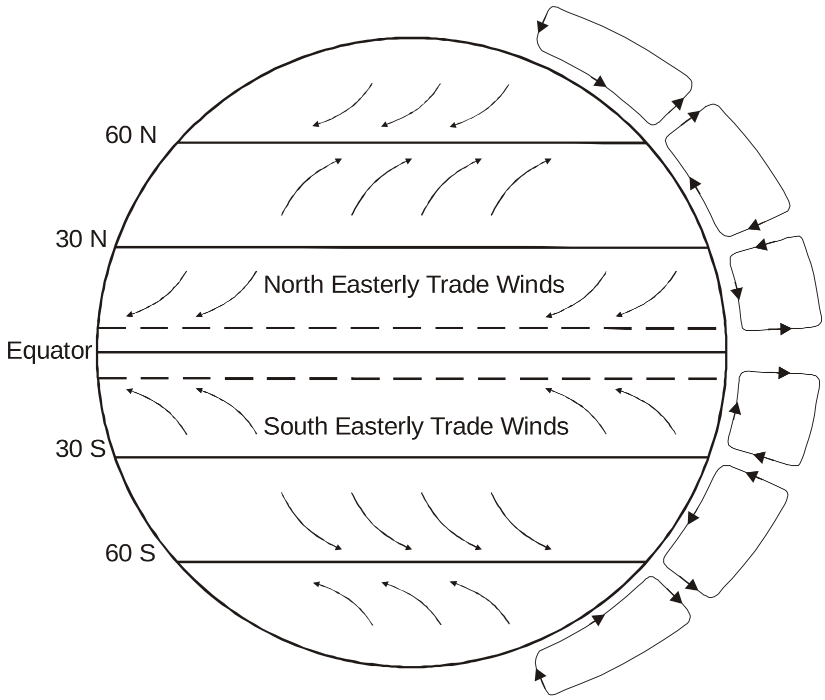
Atmospheric Circulation

6. The combination of the earth's tilt and its curved surface means that the equatorial regions get more direct sunlight, and hence more surface heating from the Sun (Fig 3). This heating causes convection within the atmosphere, resulting in a circular motion of the air (Fig 4) with warm, less dense air rising and being replaced by cooler, denser air. The warm air flows towards the poles where it cools, becoming denser, and sinks back towards the surface.

8-1 Fig 3 Comparing the Sun's Energy Over Polar and Equatorial Regions



8-1 Fig 4 Atmospheric Circulation



Coriolis Force

7. In the general atmospheric circulation theory, warm, less dense air exists in equatorial regions creating areas of low pressure while in polar regions, areas of high pressure exist due to cooler, denser air. In simple terms, high pressure at the poles causes air to flow along the surface towards the equator. This simplified pattern of air circulation is correct in theory, but the circulation of air is modified by several forces, the most important of which is the rotation of the Earth.

8. The force created by the rotation of the Earth is known as the Coriolis force. To a person standing on the Earth the effect of Coriolis is imperceptible because humans move slowly and travel relatively short distances compared to the size of the Earth and its speed of rotation. However, the Coriolis force significantly affects bodies that move over great distances, such as air masses or bodies of water.

9. In the Northern Hemisphere, the Coriolis force deflects air to the right causing it to follow a curved path instead of a straight line (Fig 4). The degree of deflection depends on the latitude. It is greatest at the poles and diminishes to zero at the equator.

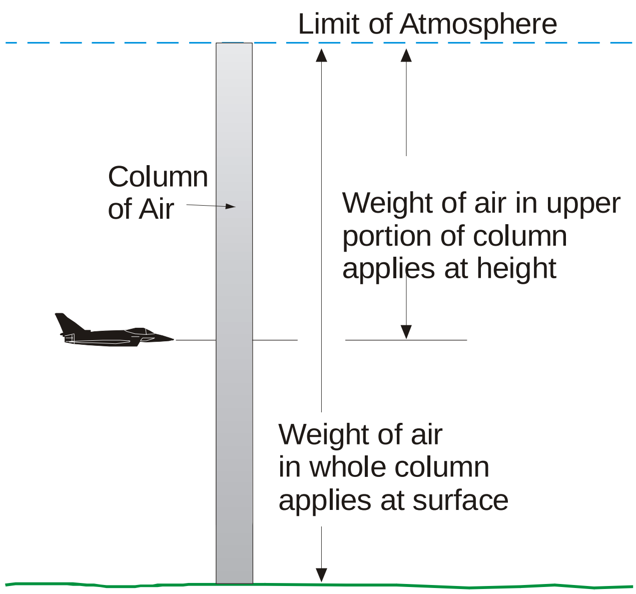
10. The speed of the Earth's rotation causes the general flow to break up into three distinct cells in each hemisphere. In the Northern Hemisphere, the warm air at the equator rises upward from the surface, travels northward, and is deflected eastward by the rotation of the Earth. By the time it has travelled one-third of the distance from the equator to the North Pole, it is no longer moving northward, but eastward. This air cools and sinks in a belt-like area at about 30° latitude, creating an area of high pressure as it sinks toward the surface. Then, it flows southward along the surface back toward the equator. Coriolis force bends the flow to the right, thus creating the north-easterly trade winds that prevail from 30° latitude to the equator. Similar forces create circulation cells that encircle the Earth between 30° and 60° latitude, and between 60° and the poles. This circulation pattern results in the prevailing westerly winds over the United Kingdom.

11. Circulation patterns are further complicated by seasonal changes, differences between the surfaces of continents and oceans, and other factors such as frictional forces caused by the topography of the Earth's surface which modify the movement of the air in the atmosphere. For example, within 2,000 feet of the ground, the friction between the surface and the atmosphere slows the moving air. The wind is diverted from its path because the frictional force reduces the Coriolis force. Thus, the wind direction at the surface varies somewhat from the wind direction just a few thousand feet above the Earth.

Atmospheric Pressure

12. Air molecules are invisible to the naked eye but still have mass and take up space. The circulation of the atmosphere results in there being areas of warm ascending air and cooler descending air. The warm less dense air contains fewer molecules per unit volume than the cooler denser air. The atmospheric pressure at a point on the Earth's surface is equivalent to the weight of the whole column of air standing on the area of that point. As distance increases from the Earth, the weight of the air above will be less, therefore atmospheric pressure decreases (Fig 5).

8-1 Fig 5 Decrease in Atmospheric Pressure with Height



13. Atmospheric pressure is measured in the following ways:

a. **Hectopascal**. The hectopascal (hPa) is the unit of measurement of pressure in common use. At mean sea level (MSL), the atmospheric pressure is of the order of 1,000 hPa (see also the next paragraph); at 50,000 ft it is of the order of 100 hPa.

b. **Inches of Mercury**. Some countries (notably the USA), measure pressure in inches of mercury (Hg). At MSL, atmospheric pressure is 29.92 inches Hg.

c. **Millibar**. Although the hPa is now in common usage, the millibar (mb) is still used in aviation. The hPa and the mb have equivalent values and so can be considered to be identical for all practical purposes. At mean sea level (MSL), the atmospheric pressure is of the order of 1,000 mb (see also the next paragraph); at 50,000 ft it is of the order of 100 hPa.

14. To provide a common reference, the International Standard Atmosphere (ISA) has been established. These standard conditions are the basis for certain flight instruments and most aircraft performance data. The assumed characteristics of ISA are:

a. The air is dry and its chemical composition is the same at all altitudes.

b. The value of g is constant at 980.665 cm/sec^2.

c. At mean sea level the temperature is 15 ºC and the pressure is 1013.25 hPa (29.92 inches Hg).

d. The temperature lapse rate is 1.98 ºC per 1,000 ft up to a height of 36,090 ft above which the temperature is assumed to remain constant at –56.5 ºC.

Table 1 ICAO Standard Atmosphere

Altitude (ft)	Temperature (º C)	Pressure (hPa / mb)	Pressure (psi)	Density (kg/m^3)	Relative Density (%)
0	+15.0	1013.25	14.7	1.225	100.0
5,000	+5.1	843.1	12.22	1.056	86.2
10,000	–4.8	696.8	10.11	0.905	73.8
15,000	–14.7	571.8	8.29	0.771	62.9
20,000	–24.6	465.6	6.75	0.653	53.3
25,000	–34.5	376.0	5.45	0.549	44.8
30,000	–44.4	300.9	4.36	0.458	37.4
35,000	–54.3	238.4	3.46	0.386	31.0
40,000	–56.5	187.6	2.72	0.302	24.6
45,000	–56.5	147.5	2.15	0.237	19.4
50,000	–56.5	116.0	1.68	0.186	15.2

Altitude and Atmospheric Pressure

15. As altitude increases, atmospheric pressure decreases. At sea level, 1 hPa difference in pressure is equivalent to approximately 27 ft of height change; at 20,000 ft, 1 hPa equates to approximately 50 ft. Thus, for calculations close to sea level, it can be assumed that 1 hPa equates to 30 ft.

a. **Pressure Altitude**. Pressure altitude can be defined as the vertical distance from the 1013.25 hPa pressure level. Pressure altitude can be obtained by setting the sub-scale of an ICAO calibrated altimeter to 1013.25 hPa and reading altitude directly from the instrument. Alternatively, the approximate pressure altitude can be calculated as:

$$\text{Pressure altitude} \doteqdot \text{Elevation} + 30p,$$

where p is 1013 minus the sea level pressure at that point.

Example: To determine the pressure altitude of an airfield, elevation 1,700 ft, if sea level pressure is 1003 hPa:

$$p = 1013 - 1003 = 10 \text{ hPa}$$

$$\therefore \text{airfield pressure altitude} \doteqdot 1{,}700 + (30 \times 10) \text{ ft} \doteqdot 2{,}000 \text{ ft}$$

b. **Density Altitude**. For aircraft operations, air density is usually expressed as a density altitude. Density altitude is the pressure altitude adjusted to take into consideration the actual temperature of the air. For ISA conditions of temperature and pressure, density altitude is the same as pressure altitude. Density altitude can be determined by the formula:

$$\text{density altitude} = \text{pressure altitude} + 120t$$

where t is the actual air temperature minus the standard (ISA) temperature for <u>that pressure altitude</u>. Continuing the example calculation above, if the actual air temperature at the airfield elevation is +13 ºC (ISA temp for 2,000 ft is +11 ºC), then the density altitude will be:

$$2{,}000 \text{ ft} + 120\,(13^{\circ}\text{C} - 11\,^{\circ}\text{C})$$

$$2{,}000 \text{ ft} + (120 \times 2) = 2{,}240 \text{ ft}$$

16. The most obvious application of atmospheric pressure is its use in the altimeter. There are four pressure settings that are generally used on the altimeter.

a. **QFE**. QFE is the corrected pressure for a specific datum, usually an airfield. With QFE set, the altimeter will read zero at touchdown and will indicate height above touchdown when in the circuit.

b. **QNH**. QNH is the observed pressure of the airfield elevation, corrected for temperature and reduced to mean sea level (MSL). With QNH set, the altimeter will read altitude above mean sea level (AMSL). At touchdown, with QNH set, the altimeter will read touchdown elevation.

c. **Regional Pressure Setting (RPS)**. The RPS is the lowest forecast value of mean sea level pressure in a geographical region for a specified hour. The UK is divided into Altimeter Setting Regions (ASRs) with an associated RPS for the current hour and forecast RPS for the next hour.

d. **Standard Altimeter Setting**. The standard altimeter setting is used when flying above Transition Altitude (TA). It assumes a MSL pressure of 1013.2 hPa.

Air Masses

17. Air masses are bodies of air, covering a very large area where the temperature, lapse rate and humidity characteristics are almost uniform. They are classified according to the regions where they originate and the track that they follow over the Earth's surface. A source region is typically an area in which the air remains relatively stagnant for a period of days or longer and typically will be either the sub-tropical belts of high pressure, polar anticyclones or areas of high pressure over continental land masses. During this time of stagnation, the air mass takes on the temperature and moisture characteristics of the source region. Air masses are generally identified as polar or tropical based on temperature characteristics and maritime or continental based on moisture content. A combination of these terms is used to describe the source and track of the air mass and will define the weather characteristics resulting from it. As the air mass moves, the terrain/sea that it moves over will slowly modify the weather within it due to surface heating or cooling and evaporation or condensation.

18. Table 2 gives some general conditions that may be applied to air masses affecting the UK. It must be stressed that in practice no two air masses are exactly alike. The character of an air mass undergoes a process of continuous transition due to a combination of many variables which can be surmised from a knowledge of the processes that affect the weather.

Table 2 Air Mass Effects on the UK

Air Mass	Source	Start conditions	Track
Tropical Maritime	Sub-tropical anticyclones	High temperature High relative humidity High Dew Point	Sea
Modified conditions	Cooled from below. With light winds becomes more stable and possible inversion. Stronger winds, inversion is lifted. High relative humidity is maintained or increased to give low stratus, fog, drizzle and orographic cloud. Visibility usually moderate to poor.		
Tropical Continental	North Africa Southern Europe	Warm Air with low humidity	Land
Modified conditions	Lower layers cool, humidity remains low (except where there is some sea track). With a long sea track, process is changed to Maritime. Dryness and cooling of the air prevents cloud formation giving high temperatures. Visibility reduced due to haze.		
Polar Maritime	Arctic	Low temperature, low Dew Point, high relative humidity	Sea
Modified conditions	Heated from below but temperature remains lower than sea surface. Thermal instability gives conditions for convective cloud development and can lead to large Cu and Cb. Showers, thunderstorms, strong gusts or squalls. Can stabilize to give fair-weather Cu or Sc. Visibility good except in showers. On reaching land, air dries and cloud formation more difficult. In winter, air relatively mild but affected by surface cooling, becoming stabilized in lower layers. Shower intensity decreases, clouds tend to be layer types and fog readily forms under a clear sky. A **Returning Polar Maritime** air mass, which moves south and then turns northwards back towards the UK will give similar conditions.		
Polar Continental	Northern continental land mass	Cold air, low Dew Point	Land
Modified conditions	Air absorbs heat and possibly moisture after travelling over warmer surface. In winter, over land, low humidity gives clear skies. If sea track develops, evaporation and heating produce cumuliform cloud and wintry showers and the air mass may transform to Polar Maritime. In the UK, with track over the North Sea, showers develop on east coast but die out further west. In summer, air starts dry and cloudless but moves over warmer land. Air becomes warm and if a track develops over a cooler sea, fog and low stratiform cloud may form.		

Fronts

19. As an air mass moves it will eventually come into contact with another air mass with different characteristics. The boundary between two types of air masses is known as a front. A front of any type will change the weather in a geographical area. Any change will never be absolutely abrupt and the weather will change gradually. While a front is represented on a synoptic chart by a discrete line, it is more realistic to picture it as a 'frontal zone' where one air mass is replaced by another. No two fronts are the same but generalized weather conditions can be associated with specific types of front.

Warm Front

20. **General Conditions of a Warm Front**. A warm front occurs where a warm mass of air advances and replaces a body of colder air. Warm fronts move slowly, typically 10 to 25 mph. The slope of the advancing front moves up and over the top of the cooler air and gradually pushes it out of

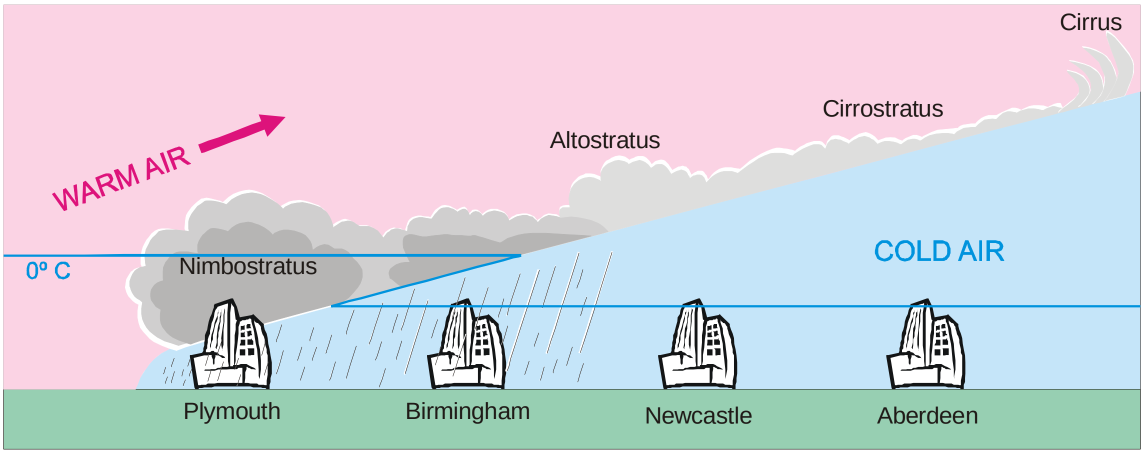
the area. Warm fronts contain warm air that often has very high humidity. As the warm air is lifted, the temperature drops, and condensation occurs.

21. **Conditions of an Approaching Warm Front**. As a warm front approaches, cirriform or stratiform clouds, along with fog, can form along the frontal boundary. In summer, Cbs are likely to develop. Light to moderate precipitation is probable, usually in the form of rain, sleet, snow, or drizzle, with poor visibility. The outside temperature is cool or cold, with an increasing dew point. The barometric pressure falls until the front passes completely.

22. **Conditions in a Passing Warm Front**. During the passage of a warm front, stratiform clouds are visible and drizzle may be falling. The visibility is generally poor but improves with variable winds. The temperature rises steadily. For the most part, the dew point remains steady and the barometric pressure stabilizes. An aircraft flying through a front which is moving in the opposite direction will experience the wind veering. Conversely, if the aircraft is moving in the same direction as the front, the wind will back.

23. **Conditions When the Warm Front has Passed**. After the passage of a warm front, stratocumulus clouds predominate, and rain showers are possible. The visibility eventually improves, but hazy conditions may exist for a short period after passage. The temperature rises, and the dew point rises and then levels off. There is generally a slight rise in barometric pressure, followed by a decrease.

8-1 Fig 6 Structure of a Warm Front



Flight Towards an Approaching Warm Front

24. Fig 6 depicts a warm front moving north east through the UK. Imagine an aircraft flying from Aberdeen to Plymouth.

25. Departing from Aberdeen, the weather is good with a scattered layer of Ci and SC clouds. Progressing towards Newcastle the clouds deepen and become increasingly stratiform in appearance with a lowering ceiling. The visibility decreases in haze with a falling barometric pressure. Approaching Birmingham, the weather deteriorates to low level broken clouds with reducing visibility and rain. With a similar air temperature and dew point fog is likely. At Plymouth, the sky is overcast with low clouds, drizzle and poor visibility.

Cold Front

26. **General Conditions of a Cold Front.** A cold front occurs when a mass of cold, dense, and stable air advances and replaces a body of warmer air. Cold fronts move more rapidly than warm fronts, progressing at a rate of 25 to 30 mph. However, extreme cold fronts have been recorded moving at speeds of up to 60 mph. A typical cold front moves in a manner opposite that of a warm front. The air is denser and so it stays close to the ground and slides under the warmer air forcing it to rise. The rapidly ascending air causes the temperature to decrease suddenly, forcing the creation of clouds. The type of clouds that form depends on the stability of the warmer air mass. A cold front in the Northern Hemisphere is normally oriented in a northeast to southwest manner and can be several hundred miles long.

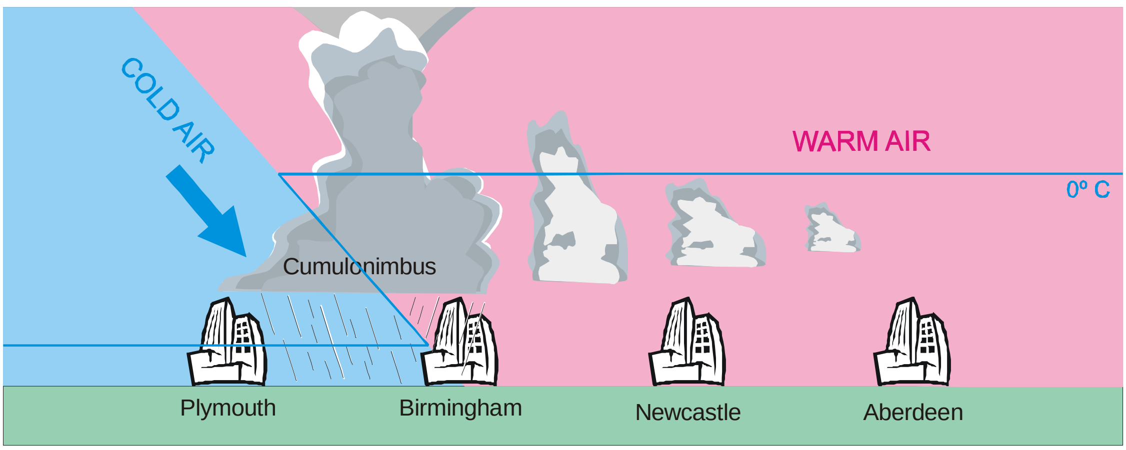
27. **Conditions of an Approaching Cold Front**. Prior to the passage of a typical cold front, cirriform or towering cumulus clouds are present, and cumulonimbus clouds are possible. Rain showers and haze are possible due to the rapid development of clouds. A high dew point and falling barometric pressure are indicative of imminent cold front passage.

28. **Conditions in a Passing Cold Front**. As the cold front passes, towering cumulus or cumulonimbus clouds are present. Depending on the intensity of the cold front, heavy rain showers form and might be accompanied by lightning, thunder, and/or hail. During cold front passage, the visibility is poor, with winds variable and gusty, and the temperature and dew point drop rapidly. A quickly falling barometric pressure steadies during frontal passage and then begins a gradual increase. An aircraft flying through a front which is moving in the opposite direction will experience the wind veering. Conversely, if the aircraft is moving in the same direction as the front, the wind will back.

29. **Conditions When the Cold Front has Passed**. After the frontal passage, the towering cumulus and cumulonimbus clouds begin to dissipate to cumulus clouds with a corresponding decrease in precipitation. Good visibility eventually prevails, temperatures remain cooler and the barometric pressure continues to rise.

30. **Fast-Moving Cold Front**. Fast-moving cold fronts are pushed by intense pressure systems far behind the actual front. Where the front moves over land, the friction between the ground and the cold front retards its movement and creates a steeper frontal surface. This results in a very narrow band of weather, concentrated along the leading edge of the front. If the warm air being overtaken by the cold front is relatively stable, overcast skies and rain may occur for some distance ahead of the front. If the warm air is unstable, scattered thunderstorms and rain showers may form. A continuous line of thunderstorms, or squall line, may form along or ahead of the front. Squall lines present a serious hazard to pilots as squall type thunderstorms are intense and move quickly. Behind a fast-moving cold front, the skies usually clear rapidly and the front leaves behind gusty, turbulent winds and colder temperatures.

8-1 Fig 7 Structure of a Cold Front



Flight Towards an Approaching Cold Front

31. Fig 7 depicts a cold front moving north east through the UK. Imagine an aircraft flying from Aberdeen to Plymouth.

32. Departing from Aberdeen, the weather is good with reasonable visibility with scattered low-level clouds. As the flight progresses towards Newcastle the clouds show signs of vertical development with a broken layer at low level. The visibility has improved, and the barometric pressure is falling. Approaching Birmingham, the weather has deteriorated to overcast clouds with a low ceiling, and poorer visibility in thunderstorms and heavy rain showers. At Plymouth, the weather improves with scattered low-level clouds and a much-improved visibility.

Wind Shifts

33. Wind around a high-pressure system rotates in a clockwise fashion, while low pressure winds rotate in an anticlockwise direction. When two pressure systems are adjacent, the winds are almost in direct opposition to each other at the point of contact. Fronts are the boundaries between two areas of pressure, and therefore, wind shifts are continually occurring within a front. Shifting wind direction is most pronounced in conjunction with cold fronts.

Comparison of Cold and Warm Fronts

34. Warm and cold fronts are very different in nature as are the hazards associated with each. They vary in speed, composition, weather phenomenon, and prediction.

Table 3 A Comparison Between Cold and Warm Fronts

Cold Front	Warm Front
Move at 20 to 35 mph but can be much faster.	Slower than a cold front at 10 to 25 mph
Provide little warning and can move through an area and change the weather in a few hours.	Provides advance warning and can take days to pass through an area.
Steeper frontal slope.	Shallower frontal slope.
Violent weather activity, usually in the frontal zone close to the frontal boundary. In summer, squall lines can advance up to 200 miles ahead of a severe front.	Weather activity much less violent.
Sudden storms, gusty winds, turbulence, hail.	Low ceilings, poor visibility and rain.
Weather clears rapidly after passage with drier air and very good visibility.	Weather improves more slowly.
Aircraft moving in the same direction as the front, wind backs at the frontal boundary.	Aircraft moving in the same direction as the front, wind backs at the frontal boundary.
Aircraft moving in the opposite direction to the front, wind veers at the frontal boundary.	Aircraft moving in the opposite direction to the front, wind veers at the frontal boundary.

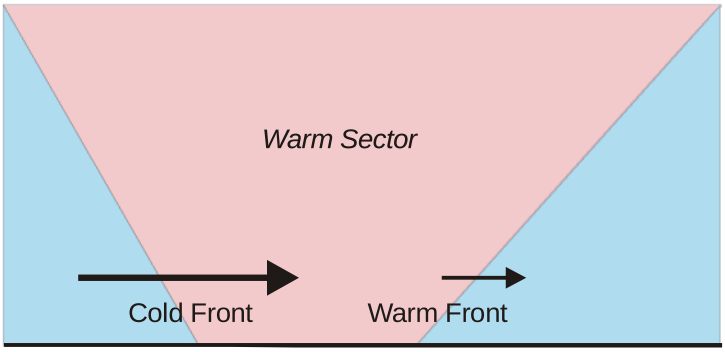
Stationary Front

35. A stationary front occurs when the forces of two air masses are relatively equal. The front that separates them remains stationary and influences the local weather for days. The weather associated with a stationary front is typically a mixture that can be found in both warm and cold fronts.

Occluded Front

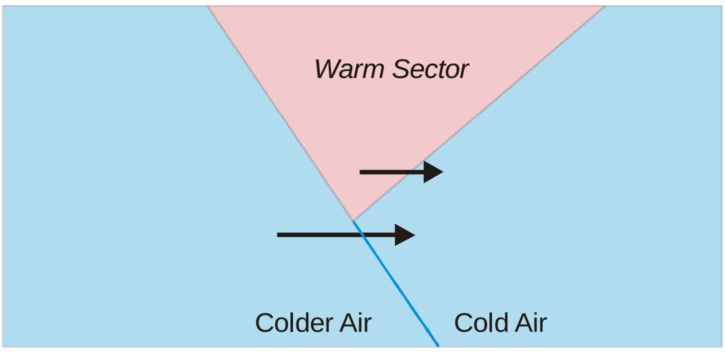
36. An occluded front occurs when a faster moving cold front catches up with a slower moving warm front. As the occluded front approaches, warm front weather prevails, but is immediately followed by cold front weather.

8-1 Fig 8 The Development of an Occlusion



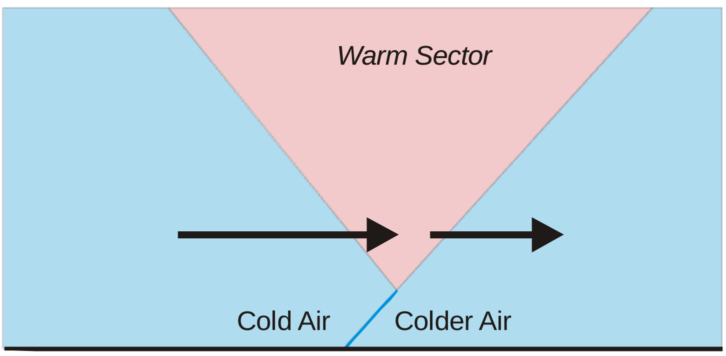
37. Two types of occluded fronts can occur, and the temperatures of the colliding frontal systems play a large part in defining the type of front and the resulting weather. A cold front occlusion occurs when the fast-moving cold front is colder than the air ahead of the slow moving warm front. When this occurs, the cold air replaces the cool air and forces the warm front aloft into the atmosphere. Typically, the cold front occlusion creates a mixture of weather found in both warm and cold fronts, providing the air is relatively stable.

8-1 Fig 9 Cold Occlusion



38. A warm front occlusion occurs when the air ahead of the warm front is colder than the air of the cold front. Here the cold front rides up and over the warm front. If the air forced aloft by the warm front occlusion is unstable, the weather is more severe than the weather found in a cold front occlusion and embedded thunderstorms, rain, and fog are likely to occur.

8-1 Fig 10 Warm Occlusion



39. Prior to the passage of the typical occluded front, cirriform and stratiform clouds prevail, light to heavy precipitation falls with poor visibility. The dew point is steady, and the barometric pressure falls. During the passage of the front, nimbostratus and cumulonimbus clouds predominate, and towering cumulus may also be possible. Light to heavy precipitation falls and visibility is poor, winds are variable, and the barometric pressure levels. After the passage of the front, nimbostratus and altostratus clouds are visible, precipitation reduces, and visibility improves.

Wind Patterns, Air Currents and Stability

40. Air flows from high pressure to low pressure. Air pressure, temperature changes, and the Coriolis force work in combination to create two kinds of motion in the atmosphere. Vertical movement of ascending and descending currents, and horizontal movement in the form of wind. In the Northern Hemisphere, the flow of air is deflected to the right and produces a clockwise circulation around an area of high pressure (anticyclonic circulation). The opposite is true of low-pressure areas; the air flows toward a low and is deflected to create an anticlockwise or cyclonic circulation.

41. High pressure systems are generally associated with good weather as they are areas of dry, stable, descending air. Conversely, air flows into a low pressure area to replace rising air. This air tends to be unstable, and usually brings increasing cloudiness and precipitation.

42. **Unstable Air**. A rising parcel of air that is warmer than its surroundings will continue to rise. Such air is unstable and can produce vertical air currents known as thermals. These conditions often result in turbulence (especially in thermals), the formation of cumuliform (heaped) clouds giving showery rain and good visibility between showers.

43. **Stable Air**. An unstable parcel of air will stabilize when it reaches the same temperature as its surroundings and will stop rising, becoming stable. Stable air results in the formation of stratiform clouds with steady precipitation. Visibility will generally be poor but with smooth flying conditions, i.e. little turbulence. Inversions may form along with fog.

44. The circulation theory is accurate on a global scale but local conditions, geological features and other factors can affect the weather and wind conditions close to the Earth's surface.

45. **Buys Ballot's Law**. There is a relationship between the direction of the wind and the air pressure (and hence the isobars shown on a synoptic chart) known as Buys Ballot's Law which states:

> **If an observer stands with their back to the wind in the northern hemisphere, then the lower pressure is on the left-hand side. The opposite is true in the southern hemisphere**.

Convective Currents

46. Ploughed land, rocks, sand, and barren land radiate a large amount of heat. Water, trees, and other areas of vegetation tend to absorb and retain heat. This results in uneven heating of the air close to the Earth's surface generating small areas of local circulation called convective currents.

47. Convective currents can cause turbulent air in the lower layers of the atmosphere and updrafts are likely to occur over pavement or barren places with downdrafts over water or expansive areas of vegetation. Convective currents may be noticeable in areas with a land mass directly adjacent to a large body of water. During the day, land heats faster than water, and the air over the land becomes warmer and less dense. This air rises and is replaced by cooler, more dense air from over the water causing an onshore wind (Sea Breeze). Conversely, at night land cools faster than water along with the corresponding air, causing the warmer air over the water to rise and be replaced by the cooler, denser air from the land, creating an offshore wind (Land Breeze).

Effect of Obstructions on Local Wind

48. Structures on the ground may affect the flow of the local wind. Ground topography and large buildings can break up the flow of the wind and create wind gusts that change rapidly in direction and speed. Structures may be manmade, such as hangars and buildings, or large natural obstructions, such as mountains.

49. Local winds in mountainous regions can cause difficult flying conditions. Wind generally flows smoothly up the windward side of the mountain whereas the wind on the leeward side tends to follows the contour of the terrain and is increasingly turbulent.

Low-Level Wind Shear

50. Wind shear is a sudden drastic change in wind speed and/or direction over a very small area and can be present in the vertical and horizontal planes occuring at any altitude. Low-level wind shear is especially hazardous due to the proximity of an aircraft to the ground. Low-level wind shear is commonly associated with passing frontal systems, thunderstorms, and temperature inversions with strong upper level winds (greater than 25 knots).

51. The most severe type of low-level wind shear is associated with convective precipitation or rain from thunderstorms. One critical type of shear is known as a microburst. A typical microburst occurs in a space of less than one mile horizontally and within 1,000 feet vertically. The lifespan of a microburst is about 15 minutes during which it can produce downdrafts of up to 6,000 feet per minute (fpm). It can also produce very rapid wind direction changes of 45 degrees or more.

Atmospheric Stability

52. A stable atmosphere resists vertical movement and small vertical disturbances dampen out, whereas in an unstable atmosphere, small vertical air movements tend to become larger, resulting in turbulent airflow and convective activity. Instability can lead to significant turbulence, extensive vertical clouds, and severe weather.

53. When a gas expands its temperature falls and conversely, when a gas is compressed its temperature rises. Rising air expands and cools due to the decrease in air pressure with altitude. The opposite is true of descending air; as atmospheric pressure increases, the temperature of descending air increases as it is compressed. Adiabatic heating and adiabatic cooling are terms used to describe this temperature change.

54. The adiabatic process takes place in all upward and downward moving air. The rate at which temperature decreases with altitude is referred to as its lapse rate. In the Standard Atmosphere, the temperature lapse rate is 1.98 ºC per 1,000 ft up to a height of 36,090 ft above which the temperature is assumed to remain constant at –56.5 ºC. Moisture in the air will affect its lapse rate. Since water vapour is lighter than air, moisture decreases air density, causing it to rise. Conversely, as moisture decreases, air becomes denser and tends to sink. Since moist air cools at a slower rate, it is generally less stable than dry air since the moist air must rise higher before its temperature cools to that of the surrounding air. The dry adiabatic lapse rate (unsaturated air) is 3 °C per 1,000 feet. The moist adiabatic lapse rate varies from 1.1 °C to 2.8 °C per 1,000 feet.

55. Moisture and temperature determine the stability of the air and hence the resulting weather. Cool, dry air is very stable and resists vertical movement, which leads to good and generally clear weather. The greatest instability occurs when the air is moist and warm, as it is in the tropical regions in the summer, resulting in daily thunderstorms.

Inversion

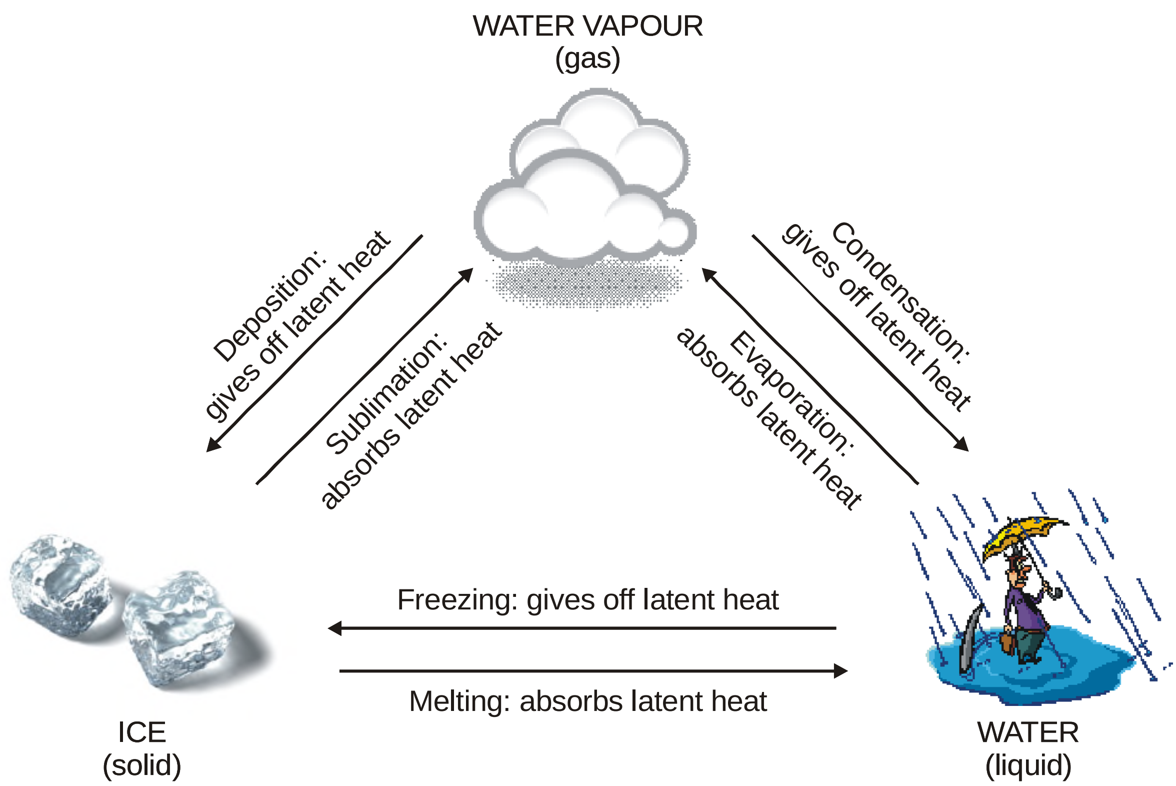
56. Under normal circumstances rising air expands and its temperature decreases. An inversion is an atmospheric anomaly where the air temperature increases with altitude. Inversion layers are shallow layers of smooth stable air close to the ground where the temperature increases to a certain altitude which is the top of the inversion. The air at the top of the inversion traps weather and pollutants below it. Where the relative humidity is high, it can lead to the formation of clouds, fog and haze and in combination with pollutants can significantly affect visibility.

57. Surface based temperature inversions occur on clear, cool nights when the air close to the ground is cooled by the falling temperature of the ground. The air within a few hundred feet of the surface becomes cooler than the air above it. Frontal inversions occur when warm air spreads over a layer of cooler air, or cooler air is forced under a layer of warmer air.

Moisture and Temperature

58. Water can exist in one of three forms in the atmosphere, solid, liquid and vapour. Each form can readily change to another, and during such a transformation latent heat is exchanged (Fig 11). Latent heat is the energy released or absorbed during a constant temperature process. The moisture content of the air is affected by its temperature where warm air can hold more than cold air. As moist air is cooled it reaches its saturation point, where further cooling will result in the moisture condensing. If the air is cooled further, below its saturation point, cloud, mist or fog will form.

8-1 Fig 11 The Three States of Water



59. Definitions:

a. **Sublimation**: The transition of a substance directly from a solid to its gaseous form without passing through a liquid phase.

b. **Deposition**: The reverse process of sublimation.

c. **Evaporation**: The vaporization of a liquid that occurs from its surface into a gaseous state that is not saturated with the evaporating substance.

d. **Condensation**: The change of a vapour into its liquid form commonly caused when a vapour is cooled and/or compressed to its saturation limit. Condensation requires a surface to condense onto. Within the air, the surfaces are provided by microscopic solid particles (condensation nuclei) such as dust, smoke, sea salt, bacteria and pollens.

e. **Freezing**: When the temperature of a liquid is lowered below its freezing point.

f. **Melting**: The reverse of freezing.

Relative Humidity

60. Humidity refers to the amount of water vapour present in the atmosphere at a given time. Relative humidity is the actual amount of moisture in the air compared to the total amount of moisture the air could hold at that temperature expressed as a percentage. For example, if the current relative humidity is 65 percent, the air is holding 65 percent of the total amount of moisture that it is capable of holding at that temperature and pressure.

Temperature and Dew Point

61. The dew point, given in degrees, is the temperature at which a sample of air becomes saturated if cooled at a constant pressure. When the temperature of the air is reduced to the dew point moisture begins to condense in the form of fog, dew, frost, clouds, rain, hail, or snow.

62. There are four methods by which air can reach the saturation point.

a. When warm air moves over a cold surface, the air temperature drops and reaches the saturation point.

b. The saturation point may be reached when cold air and warm air mix.

c. When air cools at night through contact with cooler ground, air reaches its saturation point.

d. When air is lifted or is forced upward in the atmosphere.

Dew and Frost

63. On cool, calm nights, the temperature of the ground and objects can cause the surrounding air temperature to drop below the dew point. When this occurs, the moisture in the air condenses and deposits itself on the ground, buildings, and other objects such as aircraft. This moisture is known as dew. If the temperature is below freezing, the moisture is deposited in the form of frost.

Fog and Mist

64. Fog forms when very small water droplets are suspended in the air, reducing the horizontal visibility at the Earth's surface to less than 1000 m. Where ice crystals are held in suspension, ice fog forms. Mist is defined as for fog but the visibility does not fall below 1000 m. Fog can be taken as a cloud on the surface. Fog typically occurs when air near the ground is cooled to its dew point.

65. **Radiation Fog**. Radiation fog occurs when the ground cools rapidly due to terrestrial radiation, and the surrounding air temperature reaches its dew point. As the Sun rises and the temperature increases, radiation fog usually lifts and burns off.

66. **Advection Fog**. Advection fog is caused by the movement of moist air over a relatively colder surface. Unlike radiation fog, wind is required to form advection fog. Winds of up to 15 knots allow the fog to form and intensify; above a speed of 15 knots, the fog usually lifts and forms low stratus clouds. Advection fog is common in coastal areas where sea breezes can blow the air over cooler landmasses. Advection fog, unlike radiation fog, may not burn off with the morning sun, but instead can persist.

67. **Steam Fog**. Steam fog, or sea smoke, forms when cold, dry air moves over warmer water. As the water evaporates, it rises and resembles smoke. This type of fog is common over bodies of water during the coldest times of the year. Low-level turbulence and icing are commonly associated with steam fog.

Clouds

68. For clouds to form there must be adequate water vapour and condensation nuclei, which are miniscule particles of matter such as dust, salt, and smoke. There must also be a method by which the air can be cooled below its dew point. When air cools and reaches its saturation point invisible water vapour changes into a visible state. Through the processes of sublimation and condensation, moisture condenses or sublimates onto condensation nuclei. The nuclei are important because they provide a means for the moisture to change from one state to another.

69. The cooling of air is usually achieved by lifting and there are four trigger actions that facilitate this lifting process.

a. **Turbulence**. Turbulence formation is caused by mechanical lifting which forms layers of St and Sc clouds.

b. **Convection**. Convection formation is caused by heating from below which forms Cu and Cb clouds.

c. **Orographic**. Orographic formation is caused where air rises over hills and forms St, Cu, Cb and lenticular Ac clouds.

d. **Mass Ascent**. Mass Ascent formation is associated with depressions and fronts forming Cs, Ci, As, Ns and Cb clouds.

70. Cloud type is determined by its height, shape, and behaviour.

a. **High Clouds**. High clouds form above 16,500 feet AGL and usually form only in stable air. Typical high-level clouds are cirrus, cirrostratus, and cirrocumulus. They are made up of ice crystals and pose no real threat of turbulence or aircraft icing.

b. **Middle Clouds**. Middle clouds form around 6,500 feet above ground level (AGL) and extend up to around 23,000 feet AGL. They are composed of water, ice crystals, and super cooled water droplets. Typical middle-level clouds include altostratus and altocumulus. These types of clouds may also be encountered at higher altitudes. Altostratus clouds can produce turbulence and may contain moderate icing. Altocumulus clouds, which usually form when altostratus clouds are breaking apart, also may produce light turbulence and icing.

c. **Low Clouds**. Low clouds are those that form near the Earth's surface and extend up to 6,500 feet AGL. They are made primarily of water droplets but can include super cooled water droplets that cause aircraft icing. Typical low clouds are stratus, stratocumulus, and nimbostratus. Fog may also classified as a type of low cloud formation. Clouds in this family create low ceilings, hamper visibility, and can change rapidly.

d. **Heap Cloud**. Although the high clouds discussed above do not significantly affect aircraft operations, cumulus clouds with extensive vertical development build into towering cumulus or cumulonimbus clouds. The bases of these clouds form in the low to middle cloud base region and their tops can extend into the high-altitude cloud levels. Towering cumulus clouds indicate areas of instability in the atmosphere, and the air around and inside them is turbulent. These types of clouds often develop into cumulonimbus clouds or thunderstorms. Cumulonimbus clouds contain large amounts of moisture and unstable air, and generally produce hazardous weather phenomena, such as lightning, hail, strong gusty winds, and wind shear. These extensive vertical clouds can be obscured by other cloud formations and are not always visible from the ground or while in flight. In this situation these clouds are said to be embedded, hence the term, embedded thunderstorms.

Cloud	Nature of the	Height Band	Moisture Content
Cirrus (Ci) Cirrostratus (Cs) Cirrocumulus (Cc)	High Layer Cloud	45,000 ft to 16,500 ft	Relatively low (Ice crystals)
Altostratus (As) Altocumulus (Ac)	Medium Layer Cloud	23,000 ft To 6,500 ft	Moderate (ice and/or water)
Stratus (St) Stratocumulus (Sc) Nimbostratus (Ns)	Low Layer Cloud	6,500 ft To Surface (possibly to the Tropopause)	Relatively large concentration (Water and/or Ice)
Cumulus (Cu) Cumulonimbus (Cb)	Heap Cloud	Tropopause to Low-level	Often large concentration (Water drops, Ice crystals, hail in Cb)

71. Clouds can be described by type according to the outward appearance and composition.

Cloud Type	Appearance
Cirrus	Ringlets, fibrous clouds, also high-level clouds
Alto	Meaning high, also middle level clouds
Stratus	Formed in layers
Cumulus	Heaped or piled clouds
Nimbus	Rain-bearing clouds
Castellanus	Common base with separate vertical development, castle-like
Lenticularus	Lens shaped, formed over mountains in strong winds
Fracto	Ragged or broken

Cloud Amount and Ceiling

72. Cloud amounts are reported as a fraction in eights, termed Oktas where;

FEW (few)	1 to 2 oktas
SCT (scattered)	3 to 4 oktas
BKN (broken)	5 to 7 oktas
OVC (overcast)	8 oktas

73. For aviation purposes, the ceiling is the lowest layer of clouds reported as being broken or overcast, or the vertical visibility into an obscuration such as fog or haze.

Thunderstorms (Cumulonimbus Cloud)

74 There are three conditions necessary for a thunderstorm to develop.

a. **Instability**. Instability must be present so that once the air begins to rise it will continue to rise (e.g. a steep lapse rate with warm air in lower layers of the atmosphere and cold air in the upper layers).

b. **High Humidity**. There must be abundant humidity over a considerable depth in the atmosphere such that unsaturated air cools through lifting sufficiently to cause condensation. Latent heat is released which increases instability.

c. **Trigger Action**. There must be a trigger action or lifting mechanism to start the air rising. The trigger may be a cold front forcing air aloft, orographic ascent and convective heating from the surface,

75. A cumulonimbus cloud is perhaps the most dangerous cloud type with respect to aircraft. It can appear individually or in groups and is known as either an air mass or orographic thunderstorm. Heating of the air near the Earth's surface creates an air mass thunderstorm; the upslope motion of air in mountainous regions causes orographic thunderstorms. Cumulonimbus clouds that form in a continuous line are non-frontal bands of thunderstorms or squall lines.

76. Since rising air currents cause cumulonimbus clouds, they are extremely turbulent and pose a significant hazard to flight safety. An aircraft entering a thunderstorm can experience updraughts and downdraughts exceeding 3,000 fpm. Thunderstorms can also produce large hailstones, lightning, and significant precipitation, all of which are potentially hazardous to aircraft.

77. A thunderstorm makes its way through three distinct stages.

a. **Cumulus or Building Stage**. A cumulonimbus cloud develops from one or more cumulus clouds which starts to grow larger with a base up to 5 nm (10 km) across and a lifting action of the air begins. Where there is sufficient moisture and instability, the cloud continues to increase in vertical height and continuous, strong updrafts prohibit moisture from falling. Updrafts are generally 16 to 32 ft/sec but can be as high as 100 ft/sec. This stage lasts for 15 to 20 min.

b. **Mature Stage**. Within approximately 15 minutes, the thunderstorm reaches the mature stage, which is the most violent period of the thunderstorm's life cycle. At this point, drops of rain and/or ice, are too heavy for the cloud to support and begin falling creating a downward motion of the air. Warm, rising air; cool precipitation-induced descending air; and violent turbulence all exist within and near the cloud. Below the cloud, evaporation of the rain results in further cooling and an acceleration of the downdraught. The down-rushing air forms a gust front spreading out from the storm increasing surface winds and reducing the temperature.

c. **Dissipating Stage**. This stage begins when the storm has used the local supply of moisture. Once the vertical motion near the top of the cloud slows down, the top of the cloud spreads out and takes on a characteristic anvil-like shape. At this point, the storm enters the dissipating stage where the downdrafts spread out and replace the updrafts needed to sustain the storm.

78. Severe thunderstorms can penetrate the tropopause and extend into the stratosphere reaching heights of 50,000 to 60,000 ft depending on latitude.

79. **Air Mass Thunderstorms**. Air mass thunderstorms are generally the result of surface heating. Some occur at random in unstable air, are short in duration and produce only moderate wind gusts and rainfall.

80. **Steady-state Thunderstorms**. Steady-state thunderstorms are associated with weather systems. Fronts, converging winds, and troughs aloft force air upwards, producing storms which often form into squall lines. In the mature stage, updrafts become stronger and last much longer than in air mass storms, hence the name steady state.

Hazards Associated with Thunderstorms

81. Thunderstorms present several different weather hazards with respect to aviation which occur individually or in combination.

82. **Squall Line**. A squall line is a narrow band of active thunderstorms which often develop on or ahead of a cold front in moist, unstable air, but may develop in unstable air far removed from any front. The line may be extensive making a detour around it difficult and the severe weather may make it too hazardous to penetrate. The squall often contains steady-state thunderstorms and presents the single most intense weather hazard to aircraft. The Squall Line usually forms rapidly, generally reaching maximum intensity during the late afternoon and the first few hours of darkness.

83. **Turbulence**. Potentially hazardous turbulence is present in all thunderstorms and a severe thunderstorm can severely damage an aircraft, even to destruction. The strongest turbulence within the cloud is associated with the shear forces between updraft and downdraft boundaries. Outside the cloud, shear turbulence may be encountered several thousand feet above and 20 miles laterally from a severe storm. A low-level turbulent area is the shear zone associated with the gust front. Often, a "roll cloud" on the leading edge of a storm marks the top of the eddies in this shear and it signifies an extremely turbulent zone. Gust fronts often move far ahead (up to 15 miles) of associated precipitation. The gust front causes a rapid and sometimes drastic change in surface wind ahead of an approaching storm. See also Volume 8, Chapter 17, Flying in Turbulence.

84. **Icing**. Strong updrafts in a thunderstorm are capable of supporting abundant liquid water with relatively large droplet sizes. When carried above the freezing level, the water becomes super cooled and when the temperature in the upward current cools to about –15 °C, much of the remaining water vapour sublimates as ice crystals. Above this level, at lower temperatures, the amount of super cooled water decreases. Super cooled water freezes on impact with an aircraft. Clear icing can occur at any altitude above the freezing level, but at high levels, icing from smaller droplets may be rime or mixed rime and clear ice. The abundance of large, super cooled water droplets within thunderstorms causes the rapid accretion of clear ice between 0 °C and –15 °C.

85. **Hail**. Hail perhaps presents as great a hazard to aircraft as the turbulence associated with a thunderstorm. Super cooled raindrops above the freezing level begin to freeze. Once a raindrop has frozen, forming a hailstone, other drops can freeze to it, significantly increasing its size. Large hailstones can be present within severe thunderstorms which have a large vertical extent coupled with strong updrafts. Eventually, the hailstones fall, possibly some distance from the storm core and may be encountered in clear air several miles from thunderstorm clouds. As hailstones fall through air whose temperature is above 0 °C, they begin to melt, and precipitation may reach the ground as either hail or rain. Rain at the surface does not mean the absence of hail aloft. Hail should be anticipated with any thunderstorm, especially beneath the anvil of a large cumulonimbus.

86 **Ceiling and Visibility**. Generally, visibility is close to zero within a thunderstorm cloud and may be reduced in precipitation and dust between the cloud base and the ground. The hazards to aviation presented by low visibility are multiplied when associated with the other thunderstorm hazards of turbulence, hail, and lightning.

87 **Lightning**. Lightning can damage the structure of an aircraft along with communication, electronic and navigation equipment. Magnetic compasses in particular are vulnerable to lightning discharges which can also disrupt radio communications on low and medium frequencies. Although lightning intensity and frequency have no simple relationship to other storm parameters, severe storms, as a rule, have a high frequency of lightning.

88. **Effect on Altimeters**. Pressure usually falls rapidly with the approach of a thunderstorm, rises sharply with the onset of the first gust and arrival of the cold downdraft and heavy rain showers, and then falls back to normal as the storm moves on. This cycle of pressure change may occur in 15 minutes.

Table 4 Summary of Cloud Types

Type	Definition	Trigger	Composition
Ci	Detached clouds-white, delicate filaments or white (or mostly white) patches or narrow bands. Fibrous (hair-like) appearance or silky sheen or both.	Mass Ascent	Ice crystals
Cs	Transparent, whitish of fibrous or smooth appearance. Totally or partially covering sky generally with a halo phenomenon.	Mass Ascent	Ice crystals
Cc	Thin white layer, sheet or patch of cloud without shading. Small grains or ripples.	Turbulence	Ice crystals
As	Greyish or bluish cloud sheet or layer. Striated fibrous or uniform appearance. Total or partial sky cover with Sun visible as though looking through clouded glass. No halo phenomena.	Mass Ascent	Supercooled Water droplets
Ac	White or grey - patch, sheet or layer cloud. Composed of laminae, rounded masses or rolls-sometimes partially fibrous or diffuse.	Turbulence Convection Orographic	Supercooled Water droplets
Ns	Grey layer, often dark and rendered diffuse by continually falling rain/snow, most of which reaches the ground. Thick enough to obscure the Sun.	Mass Ascent	Water drops/droplets Supercooled Water droplets above freezing level
Sc	Grey or whitish or both. Patch, sheet or layer cloud which almost always has dark parts.	Turbulence Orographic	Water droplets
St	Generally grey layer with uniform base. May give drizzle, ice prisms or snow grains. Outline of Sun clear when visible. Sometimes appears as ragged patches.	Convection with Turbulence Orographic	Water drops/droplets Supercooled Water droplets above freezing level
Cu	Detached clouds, generally dense with sharp outlines. Vertically developed with rising mounds, domes or towers. Sunlit parts brilliant white. Base relatively dark and horizontal. Sometimes ragged.	Convection	Water drops/droplets Supercooled Water drops and droplets above freezing level
Cb	Heavy dense cloud with considerable vertical extent. Part of upper portion usually smooth, fibrous or striated and nearly always flattened. May form classic anvil shape.	Moderate to Strong Convection	Water drops and droplets below freezing level. Supercooled Water drops and droplets above freezing level. Ice crystals and pellets

Visibility

89. Within aviation there are more than one meanings of the word 'visibility'. One is Meteorological Optical Range (MOR) and is usually referred to as 'Met Vis', while another is the Runway Visual Range (RVR).

a. The MOR or Met Vis is the greatest horizontal distance at which suitable objects can be recognised for what they are in daylight, or at which lights of a specified candlepower can be seen at night, by a person of normal sight. Where the visibility varies depending on the direction of view, it is usual to report the lowest visibility.

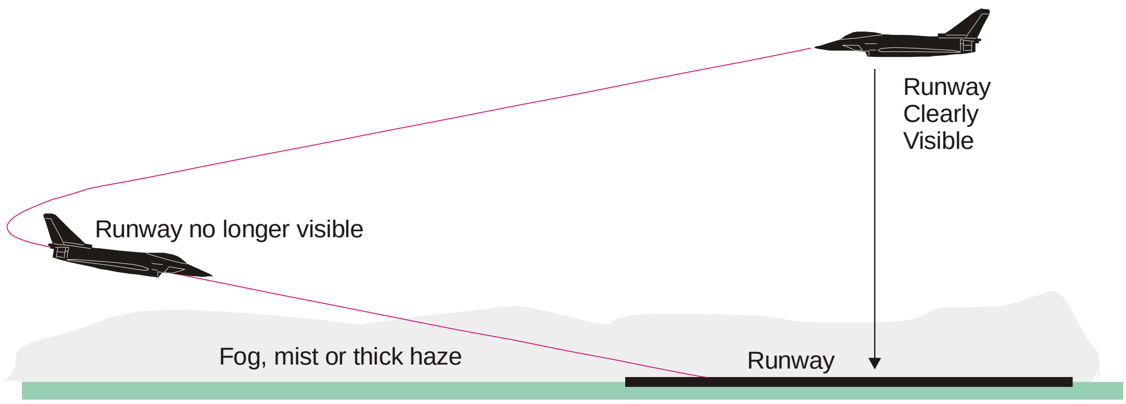
b. The RVR is the maximum distance in the direction of take-off or landing at which the runway or specified lights delineating the runway can be seen from a position on the centreline at a height corresponding to the average eye level of the pilot at touchdown.

c. Because the RVR is determined directionally while the met vis is determined omni-directionally, if there is, for example, fog away from the runway, this may affect the met vis but not the RVR. Also, at night the met vis is measured using lights of a set candlepower whereas RVR may use high intensity lighting to maximize the visual range.

90. The above measures of visibility are made horizontally at ground level and do not cater for the air to ground (slant range) condition. The slant range visibility will depend upon the angle of slant, the thickness of any low cloud or haze layer and the aircraft height. Figs 12 and 13 illustrate this.

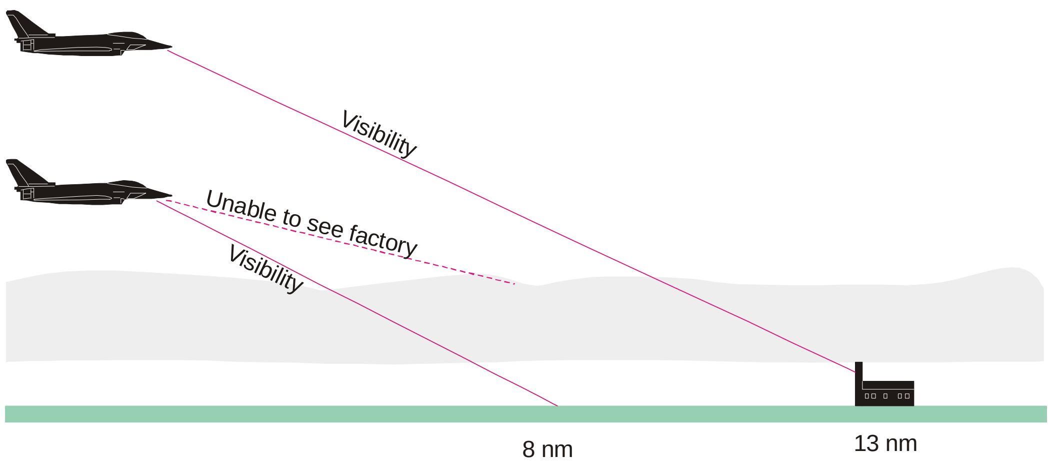
91. Although the airfield may be visible from the overhead, once the aircraft is on the final approach the runway may no longer be visible.

8-1 Fig 12 Reduced Visibility on the Final Approach



92. Fig 13 illustrates the reduced visibility for an aircraft flying over a layer of haze as compared to an aircraft flying at a higher level. The visibility under the haze layer may be unlimited while visibility through the haze will be reduced and will be affected by the aircraft height.

8-1 Fig 13 Slant Range Affected by Aircraft Height



Factors Affecting Visibility

93. Reduced visibility can be caused by several things.

94. **Airborne Water**. Fog, mist and cloud, which are in effect water droplets or ice particles that are suspended in the air, present a serious hazard to aviation.

95. **Precipitation**. Rain Drizzle, hail and snow will affect visibility to varying degrees. Rain will reduce visibility depending upon the size and number of the rain drops. Heavy rain may reduce visibility to between 50 m and 500 m whereas light rain may reduce visibility to 5 or 6 nm. Heavy rain may also collect on the windscreen, further reducing the visibility. Drizzle will normally reduce visibility to about 1.5 nm but heavy drizzle can reduce it to 500 m. Hail has little effect on visibility. Snow may reduce visibility to less than 1000 m but heavy snow, especially if it is blowing in the wind can reduce visibility to less than 100 m.

96. **Sea Spray**. When low flying over the sea or operating from an airfield very close to the sea, visibility may be reduced due to sea spray. Another hazard associated with sea spray is the build-up of salt deposits on windscreens as the spray evaporates rapidly in the airflow.

97. **Smoke, Dust and Sand**. Smoke and industrial pollution can affect visibility to varying degrees and can encourage fog to form as there is likely to be an abundance of condensation nuclei in the air. When combined with an inversion, where the layer of pollution is trapped under the inversion, visibility can be severely reduced. In rural areas visibility may be affected by pollen or dust trapped below an inversion. In desert areas sand can be blown to heights of several thousand feet but is seldom carried far from its source. Close to the source of the sandstorm, and immediately downwind, visibility can be reduced to a few metres.

Precipitation

98. Precipitation refers to any type of water particles, including drizzle, rain, ice pellets, hail, snow, and ice that form in the atmosphere and fall to the ground. Depending on the form of precipitation, it can reduce visibility, create icing situations, and affect the landing and takeoff performance of aircraft. It occurs when water or ice particles in clouds grow in size until the atmosphere can no longer support them. It is accompanied by low ceilings and reduced visibility.

99. Drizzle consists of very small water droplets (0.2 to 1.0 mm in diameter) and usually accompanies fog or low stratus clouds. Water droplets of larger size (2.0 to 5.8 mm in diameter) are referred to as rain. Raindrops that approach their maximum diameter tend to break up into smaller drops. Freezing rain and freezing drizzle occur when the temperature of the surface is below freezing and the rain freezes on contact with the cooler surface.

100. If rain falls through a temperature inversion it may freeze as it passes through the underlying cold air and fall to the ground in the form of ice pellets. Ice pellets are an indication of a temperature inversion and that freezing rain exists at a higher altitude. In the case of hail, freezing water droplets are carried up and down by drafts inside clouds, growing larger in size as they come in contact with more moisture. Once the updrafts can no longer support the freezing water it falls to Earth in the form of hail. Hail can range from pea sized to as much as 12.5 cm (5 inches) in diameter.

101. Snow is precipitation in the form of ice crystals that fall at a steady rate or in snow showers. Falling snow also varies in size, being very small grains or large flakes. Snow grains are the equivalent of drizzle in size.

102. **Virga**. Precipitation that falls from a cloud but evaporates before reaching the ground is known as virga. An important aspect in this process is that the rain absorbs latent heat from the air, causing the air to cool and sink, sometimes rapidly, towards the ground. This can produce a dry microburst which can be hazardous to aircraft. Virga is common in deserts and temperate regions.

Icing

(See also Volume 12, Chapter 15 Helicopter Icing, and Volume 8 Chapter 2 Aircraft Icing)

103. For ice to form on an airframe, three conditions must be present. There must be visible moisture or crystals, the temperature must be in the range +10 ºC to -40 ºC and the airframe temperature must be below 0 ºC.

104. The height at which the temperature is 0 ºC is known as the freezing level and it is generally here that the worst continuous icing conditions are found in heavy stratified cloud or rain. Icing is possible up to 8000 ft above the freezing level and above this, the droplets in the clouds are already frozen. Icing in Cumuliform clouds can occur well above the freezing level as large supercooled water drops can be carried to high altitudes giving the potential for severe icing.

105. The possibility of ice accretion on the airframe of an aircraft should always be considered:

a. Whenever ground temperatures are at or below 0 °C.

b. Whenever flights take place through cloud or rain at temperatures below 0 °C. The most severe icing is usually present in the temperature range 0 °C to about -10 °C.

c. At heights where the temperature is between 0 °C and -20 °C, the rate of icing may be severe over a substantial depth of cloud for a wide range of cloud-base temperatures.

d. At heights where temperatures are between about -20 °C and -40 °C, the chance of moderate or severe icing reduces, except in newly developed convective cloud, but light icing is possible.

e. At temperature below -40 °C the chance of icing is small.

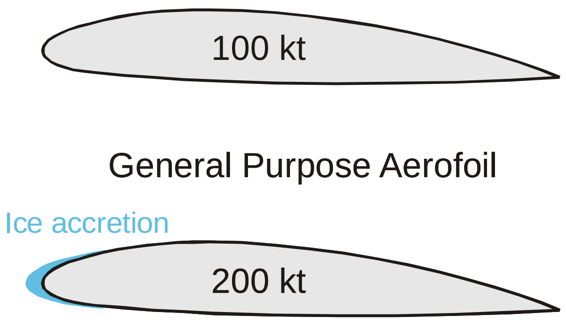
Severity of Ice Accretion.

106. The severity of icing is defined as the rate of accumulation of ice by weight per unit area per unit time. Among the meteorological factors determining this rate are the amount of liquid water present and the size of the droplets. These characteristics are not the same throughout a particular cloud, even at one level. A cloud containing both liquid water and ice crystals may have large patches where one or the other predominate and icing will tend to be severe when the temperature is not far below 0 °C. An analysis of reports on ice accretion shows a preponderance of occasions at temperatures above about minus 10 °C and indicates that the frequency diminishes rapidly when the temperature falls below minus 20 °C, although occasional icing has been reported at temperatures below minus 40 °C. The severity of ice accretion is also dependent on aircraft speed and wing shape (Figs 14 and 15).

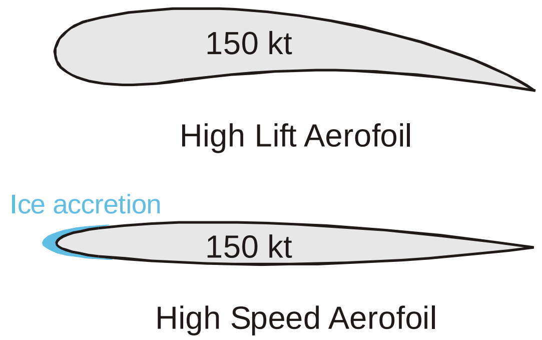
a. **Aircraft Speed**. An aircraft will pick up more icing when travelling faster.

b. **Wing Shape**. A thin wing will pick up icing quicker than a thick, high-lift wing shape.

8-1 Fig 14 The Effect of Speed on Airframe Icing

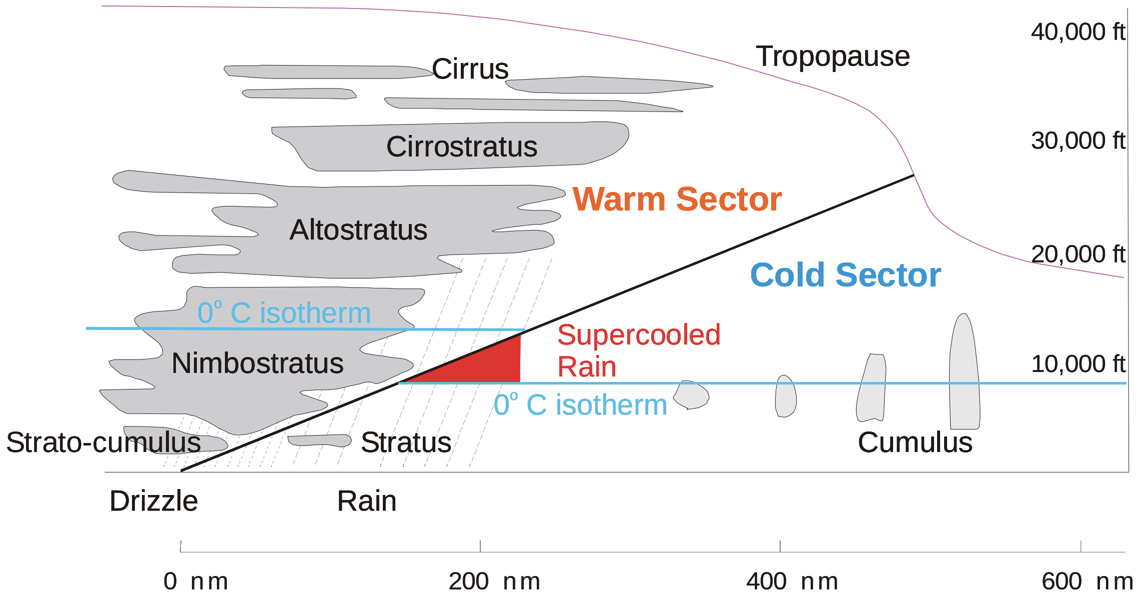


8-1 Fig 15 The Effect of Wing Shape on Airframe Icing



107. **Supercooled Rain**. Supercooled rain occurs beneath warm fronts and occlusions and occasionally beneath cold fronts (Fig 16). When present, there is necessarily a warmer layer above, in which the temperature exceeds 0 °C. When flying beneath this type of meteorological condition the best procedure is to climb into the warmer layer of air. The belt of frontal cloud and rain should if possible be crossed at right angles so as to give the shortest traverse through the icing region. A particularly dangerous procedure is to fly parallel to the front in the freezing rain, since a heavy accumulation of clear ice could form rapidly.

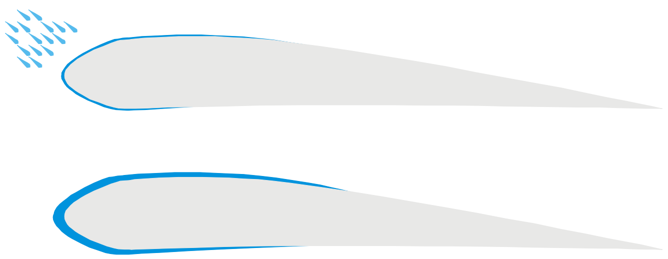
8-1 Fig 16 A Cross-section of a Warm Front, Where Supercooled Rain may Occur



Clear Ice

108. Clear ice is the most hazardous form of airframe icing. It is most likely to be encountered in freezing rain where the raindrops spread and freeze on contact with a cold airframe. Liquid water drops, known as supercooled drops, can exist in the atmosphere below 0 °C. One situation where supercooled drops can form is when rain falls from air whose temperature is above 0 °C into a below freezing layer of air beneath. Supercooled drops are unstable and will freeze on contact with a below 0 °C surface, such as an airframe. When the supercooled drop hits the airframe, it freezes relatively slowly due to the latent heat released in the freezing process. This allows part of the drop to spread backwards before it too freezes. The spread back is greatest when the temperature is just at 0 °C. Clear ice forms a sheet of solid, clear, glazed ice with very little air trapped in it which can dramatically alter the aerodynamic properties of an aerofoil. There may also be a significant increased weight penalty associated with clear ice.

8-1 Fig 17 The Formation of Clear Ice

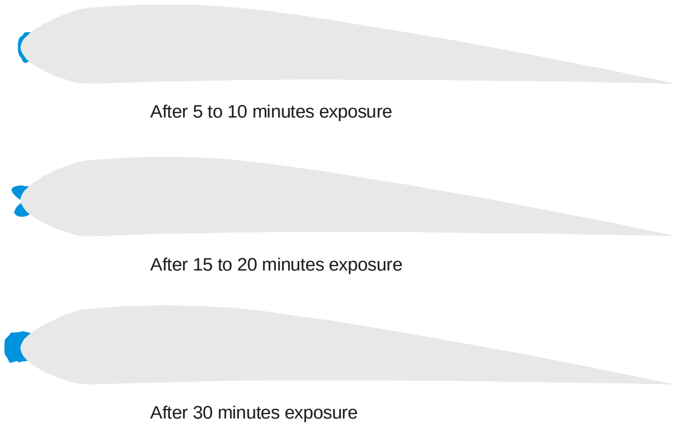


Rime Ice

109. Rime ice occurs when small, supercooled liquid water droplets freeze on contact with a surface that is below freezing. Due to the small size of the water drops, there is little latent heat released to slow the freezing of the water and the airflow also removes some of the latent heat. The small size of the drops also means that there is little water remaining after the initial freezing to coalesce into a sheet of ice, as in the case of clear ice. The result is a mixture of tiny ice particles and

trapped air, giving a rough, opaque deposit that is crystalline and fairly brittle. Rime ice usually forms on leading edges and can affect engine intake airflow. Usually there is little weight penalty and the ice is slow to accumulate. Although rime ice can form in the temperature range 0 °C to -40 °C, it is most commonly found in the range -10 °C to -40 °C.

8-1 Fig 18 The Formation of Rime Ice



Mixed Ice

110. Rain within or falling from clouds can consist of many different sized drops which may result in the formation of a mixture of clear and rime ice, known as Mixed Ice. Most icing encounters are likely to be mixed ice, especially when flying in cloud. Only rarely will just pure rime ice or clear ice form.

Hoar Frost

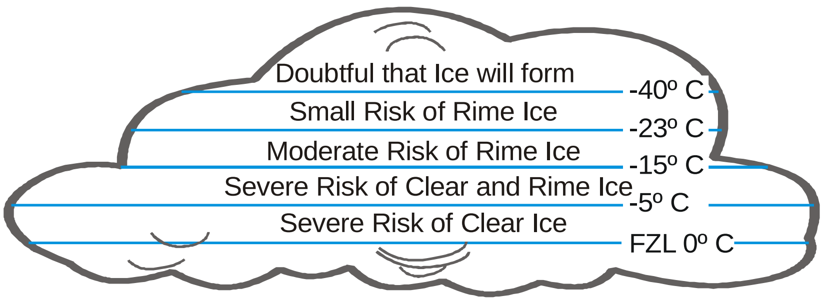
111. When moist humid air comes into contact with a surface below 0 °C frost forms on the surface. The water vapour changes directly into ice and deposits as frost without going through the liquid water stage. Favourable conditions for frost to form are a clear night (making it cool), a calm wind and high humidity. While frost does not alter the basic aerodynamic shape of a wing it can disrupt the smooth airflow over it, causing early separation. As such, frost should be removed from an aircraft before flight. Frost can also form in flight when a cold airframe descends from height into warm moist air. It can also form when climbing through an inversion where warm air overlays cold air.

Airframe Icing and Cloud Type

8-1 Fig 19 Airframe Icing and Associated Cloud Type

Cloud Type	Composition
Cumulus	Predominantly liquid water droplets down to about -23 ºC. Below -23 ºC either liquid drops or ice crystals may predominate. The temperature profile of the cloud will determine the severity and type of icing present in it. (Fig 19). Convective clouds possess considerable vertical motion therefore the risk of icing may be present though out a wide altitude band.

8-1 Fig 20 Potential Icing Temperature Bands in Cumulus Clouds



Stratiform	Predominately liquid water drops down to about -15 ºC with a risk of icing. Stratiform clouds associated with an active front or orographic uplift present a greater risk of icing at lower temperatures than normal.
Precipitation	Rain and drizzle will freeze on an airframe below -0 ºC, with the risk of clear ice increasing with the size of the drops. This may occur when flying in cool air under the warmer air of a warm front from which rain is falling.
Orographic Lifting	The uplift of air enables it to support more moisture. This increases the risk of icing, particularly clear ice, and lowers the freezing layer.
Cloud Base Temperature	Warm air can hold more moisture than cold air. Icing potential in a convective cloud, at a given level, is likely to be greater in tropical latitudes than temperate ones, and greater in summer than winter.
High-level Clouds	High clouds with bases above 20,000 ft are usually composed of ice crystals and so the risk of airframe icing is minimal.

Engine Icing

112. **Piston Engines**. Considerable cooling in the carburettor of piston engines can occur when the OAT is above 0 °C. This cooling is the result of two factors; the evaporation of petrol from surfaces, and the acceleration of air through the carburettor (which causes a local reduction of pressure and results in adiabatic cooling). The combined effect can reduce the temperature of air by as much as 25 °C. To counter carburettor icing, heat is applied to maintain the internal temperature above 0 °C. The direct injection type of carburettor is rarely subject to icing.

113. **Turboprop and Jet Engines**. The intakes of turboprop and jet engines are subject to icing, in the same way as the airframe, when supercooled water droplets are present. The susceptible parts are the rim of the intake where the radius of curvature may be small, any struts across the intake, and the vanes in the early stages of the compressor. Thereafter, temperatures are usually too high for icing to be a problem, although ice breaking away from the inlet may cause damage to the engine. Generally speaking, engine icing will be directly proportional to the rate of airflow through the engine and thus to the engine rpm - it is frequently found that the rate of icing may be reduced by decreasing the rpm. When a jet engine is operating at high rpm during flight at low speeds, as when taking off and landing, or whilst stationary, as in running up, the pressure within the intake is much less than the pressure outside. The consequent adiabatic expansion in the intake causes a drop in temperature by as much as 5 °C. If the clear indrawn air is moist and the temperature is near 0 °C, prolonged operation may result in condensation and ice formation on the intakes when this does not occur on the airframe. This effect may accentuate the icing which would normally be expected when the flight is in icing cloud, or when the aircraft is taking off or landing in freezing fog. Usually jet engines ice up in flight only under conditions which might be expected to produce airframe icing. The intensities of icing

on the airframe and in the engine may be different since the airframe icing rate depends on the airspeed, whilst engine icing depends on engine rpm. At high speeds the engine tends to be supplied with more air than it needs and there is a ram effect, whereas at lower speeds, below about 250 kt, air is sucked in. Because of the ram effect at higher speeds, some of the air is deflected round the intake, and the icing rate increases markedly with increases of airspeed above 250 kt. At speeds where the air is sucked in (below 250 kt) the water concentration of the air entering the intake remains virtually the same as free air so that engine icing rates tend to be constant with decreasing speed, whereas the airframe is likely to show a marked decrease of icing rate with decreasing speed.

114. Aircraft encounter a greater variety of icing conditions in flight than on the ground, resulting in a wider variety of ice deposits. Snow, ice and frost, in all their forms, produce a flight safety risk. Being aware of the physical process and conditions which produce airframe and engine icing will help to avoid the dangers associated with this phenomenon. A more detailed explanation of factors affecting icing of aircraft may be found in the Handbook of Aviation Meteorology (HMSO), Chapter 8. The table overleaf summarizes the various types of aircraft icing.

Table 5 Types of Icing and their Properties

Reference: The Handbook of Aviation Meteorology – HMSO - 1994

Type	Occurs	Appearance	Effect	Action
Hoar-frost	Occurs in clear air on a surface whose temperature is reduced below the frost-point (1) of the air in contact with it. Occurs on clear nights when there is a fall in temperature to a value below 0 °C. May occur in flight when moving rapidly from air well below 0 °C to warmer and more humid air. Should soon disappear as the aircraft warms up. May affect radio reception and may cause frost on the windscreen and instruments.	White crystalline coating, normally of a feathery nature.	Weight of the deposit is unlikely to be serious. It can interfere with the airflow over the wing and thus the attainment of flying speed during take-off. Can also affect vision through the windscreen, the free working of control surfaces and radio reception.	Should be removed before take-off.
Rime Ice	Occurs when small supercooled water drops freeze on contact with a surface at a temperature below 0 °C. At ground level it forms in freezing fog. In flight it may form in clouds of low water content composed of small droplets, comparable with those of freezing fog. Most liable to occur at low temperatures where small, unfrozen cloud droplets freeze almost instantaneously.	Tiny ice particles between which air is entrapped to give a rough crystalline deposit. Forms and accumulates on leading edges with no spreading back. Trapped air gives a white opaque appearance.	Usually breaks away quite easily. Usually little weight. Alters the aerodynamic characteristics of the wings and may block air intakes.	If present, it should be removed before take-off.
Clear Ice (Glaze Ice)	Occurs in dense cloud of convective or orographic type. Forms when large water drops, not far below 0 °C, are encountered in flight. Results from water flowing over a cold airframe before freezing. Drop unite while liquid and little air is trapped. May also occur when an airframe, below 0 °C, descends rapidly through large raindrops. May also occur where there is an inversion where rain falls from a level above 0 °C to a layer where it is below 0 °C. Typically associated with warm fronts where the icing layer occupies a narrow range of altitude below the frontal surface.	Transparent or Translucent coating with a glassy surface. Ice surface is smooth but may have bumps and undulations.	Tough and sticks closely to the surface of the aircraft and cannot be broken away easily. If it breaks away, it sheds in large pieces which may be dangerous. Will affect the aerodynamics and increase weight. May cause unequal loading of the wings, struts and propeller/rotor blades.	Avoid if possible. Use aircraft anti-icing/de-icing systems. Try to avoid the danger area associated with warm fronts. Cross the front at right angles if possible.
Cloudy (Mixed Ice)	Rime and Clear ice are the extreme forms of ice accretion experienced by aircraft in flight through cloud and rain. As a large range of drop sizes may be encountered at any temperature between 0 °C and -40 °C, a wide range of icing exists between the two extremes. These varieties are usually described as Cloudy or Mixed ice.	The smaller the drops and the lower the temperature, the rougher and more clouds will be the build up on the leading edges. A smoother and more glassy ice formation, spreading back over the airframe, occurs with large drops and a temperature closer to 0° C.	Effects as above depending on droplet size and temperature. Where ice crystals are present in a cloud, these may stick to a wet airframe and freeze, along with the cloud drops, to give a formation of rough cloudy ice. If snowflakes are present they are trapped in the ice as it forms, producing an opaque deposit with the appearance of tightly packed snow.	Avoid if possible. Use aircraft anti-icing/de-icing systems.

(1) The frost-point is the temperature to which moist air must be cooled in order to just reach the condition of saturation with respect to a plane ice surface. Further cooling induces deposition of ice in the form of hoar-frost on solid surfaces, including other ice surfaces.

CHAPTER 2 - AIRCRAFT ICING

Introduction

1. It is important that all aircrew are aware of the hazards of aircraft icing. The possibility of ice accretion on the airframe of an aircraft should always be considered:

a. Whenever ground temperatures are at or below 0 °C.

b. Whenever flights take place through cloud or rain at temperatures below 0 °C (often referred to as the Freezing Level).

c. At temperature below -40 °C the chance of icing is small.

d. At heights where temperatures are between about -20 °C and -40 °C, the chance of moderate or severe icing is small, except in newly developed convective cloud, but light icing is possible.

e. At heights where the temperature is between -20 °C and -0 °C, the rate of icing may be severe over a substantial depth of cloud for a wide range of cloud-base temperatures.

Table 1 (at the end of this chapter) summarizes the various types of aircraft icing. Engine icing may occur even in clear air at temperatures above 0 °C.

2. Frost, ice or snow on aircraft will adversely affect performance and even small amounts can have disastrous consequences. Accidents and incidents have been caused by:

a. Ice build-up on engine inlet pressure probes causing erroneous indications of engine power.

b. A thin layer of ice on control surfaces inducing flutter with subsequent structural damage.

c. Severe tailplane icing leading to loss of control when the flaps were selected down.

d. Very small deposits on wing leading edges dangerously eroding performance.

e. Attempting to take-off with wet snow on the wings and tailplane which had accumulated after earlier de-icing with diluted fluid.

The problems of aircraft icing are not limited to in-flight conditions as many icing problems occur on the ground. Two physical processes may cause a deposit of ice on objects exposed to the atmosphere. Ice may form directly from water vapour by sublimation, or ice may form by the freezing of liquid water drops. At ground level, these processes produce two familiar forms of ice deposit known as Hoar Frost and Rime. Glazed ice may also form when raindrops freeze on striking sub-zero surfaces.

Pre-flight Preparation

3. Pre-flight, the whole aircraft should be free from deposits of frost, ice and snow. If a de-icing fluid has been used to remove any frost or ice, it should be remembered that the efficiency of the fluid under varying atmospheric conditions is dependent upon the correct mixture strength. For example, using fluid diluted with water will effectively remove ice; however, its ability to prevent further formation will be significantly reduced. The Flight Information Handbook contains advice on aircraft de-icing and anti-

icing fluids. Under certain circumstances the fact that the aircraft surfaces have been wetted may actually enhance the accumulation of wet snow, particularly if there is any significant delay between de-icing and take-off. The temptation to become airborne because of any time control should be resisted if there is any doubt about the icing condition of the aircraft.

4. Particular attention should be paid to leading edges, control surfaces, flaps, slats and their associated mechanisms, hinges and gaps. All orifices and guards (e.g. generator cooling inlets, fuel vents, APU inlet, pressurization inlet and outlet valves, static plates) and exposed operating mechanisms, such as nosewheel steering and oleos, should be cleared of snow or slush, and de-iced when so recommended. Snow and ice should be cleared from boots before entering an aircraft.

Start-up, Taxiing and Take-off Precautions

5. **Start Up**. On some types of engine, the icing of probes can cause over-reading of power gauges. To prevent this, and also to prevent damage to, or flame-out of the engine, engine anti-icing should be switched on, in accordance with any recommendations within the aircrew manual. If the OAT is less than 10 ºC, and there is either precipitation, standing water, or the RVR is less than 1,000 metres then a possibility of engine icing must be considered. Use of carburettor heat and propeller de-icing may be recommended.

6. **Taxiing**. During taxiing in icing conditions, the use of reverse thrust on podded engines should be avoided, as this can result in ice contamination on the wing leading edges, slats and flaps. For the same reason, a reasonable distance should be maintained from aircraft taxiing ahead. In no circumstances should an attempt be made to de-ice an aircraft by placing it in the wake of the engine exhaust of another aircraft. It should always be remembered that stopping distances on snow and ice are increased. Painted areas are particularly slippery, especially when covered with de-icing fluid or snow.

7. **Take-off**. Just before take-off a final check should be made to ensure that the wings are not contaminated by ice and snow, and that fuel, propeller, airframe and engine icing controls are appropriately set as recommended in the Aircrew Manual. Take-off power should be monitored closely, if possible by cross-reference to all the engine instruments. Take-off direction should be selected by using the driest part of the runway and pilots should be aware of their abort speed. Water and snow will seriously affect stopping distances and if heavy rain has saturated the runway pilots should be aware of the aircraft's aquaplaning speed and the associated hazards.

In-flight Precautions

8. The build up of ice in flight, particularly in cloud and freezing rain, may be very rapid and aircrew should avoid icing conditions for which their aircraft has not been cleared. The various parts of the airframe are affected in different ways by ice formation, both with regard to the types of ice likely to form and to the effect of ice accretion on their performance.

9. **Aerodynamic Effects**. When ice formation occurs on the leading edges of the aircraft wings and tailplane, the pattern of the airflow becomes modified round the affected part. This leads to an increase in drag, a decrease in lift, an increase in stalling speed (by as much as 30% in some cases), and perhaps to buffeting. Ice accretion on the leading edges of the fin and rudder and other moveable parts may interfere with the airflow to such an extent that control is seriously affected. To appreciate how this accretion forms, consider an object moving through air which contains many water droplets. As it moves, it catches only a fraction of the water which is present in its path; this fraction varies with the

shape of the object and is found to be greater for a thin wing than for a thick wing, other things being equal. It does not follow that a greater total weight of ice is collected by the thin wing, since the path swept out has a smaller cross-section. On the other hand, a small deposit on a thin wing may cause greater aerodynamic disturbance than a similar deposit on a thick wing. This dependence on shape explains why thin objects such as aerials, struts, the leading edges of propellers etc, are more likely to ice up more than the bluff parts of the airframe such as the blunt nose of the fuselage. The extremities of propeller blades have a much higher speed than other parts of aircraft and for this reason one might expect this component to be susceptible to icing, but there is some protection through kinetic heating. The aerodynamic effects of ice accretion are of course not confined to disturbances at the leading edges; ice forming on other parts of the wing or fuselage may lead to a considerable increase of drag. Ice formation under the wing may be particularly dangerous in that it is normally out of sight and its existence may be inferred only from a change in the performance of the aircraft.

10. **Weight and Vibration**. The effect of an accumulated weight of ice will obviously reduce aircraft performance. An unequal distribution of ice may have serious effects, particularly when it occurs on a propeller, for with this component the lack of balance when parts of the ice break away may lead to serious vibration. This type of hazard may also occur in connection with aerial masts, exposed balance weights and control surface links, and may in extreme circumstances lead to fracture. It should be remembered that an uneven increase of weight through ice accumulation might also alter the centre of gravity.

11. **Effect on Instruments**. Any small extension or orifice is liable to gather ice and, if these include the pitot tube or static vents, it could seriously affect the indications of flight or engine instruments.

12. **Effect on Control Surfaces**. Normally there is a gap between the forward edge of a control surface and the fixed surface ahead of it. In some positions of the controls, sufficient ice may form in the gap to jam the control. The risk is greater on small aircraft than on larger ones, since on the former the gap is smaller and the movable part thinner, leading to a greater rate of accumulation. However, it is dependent chiefly on the design of an aircraft rather than on its size.

13. **Miscellaneous Effects**. A well-known effect is the formation of an ice coating on windscreens and canopies so that vision is restricted. This is often due to hoar frost formation in clear air when there is a rapid change of temperature.

14. **Communication**. Ice and frost covering aerials can reduce their effectiveness, and vibration and an increase in weight could damage them.

15. **Undercarriage**. Undercarriage lowering/retraction may be hindered by ice accumulation.

16. **Engines**. Engine air intakes may be blocked or restricted by ice, hindering fuel vapour and air flow.

17. **Descending**. If an aircraft has been operating for a long period at high altitude in cold conditions, a rapid descent into warmer air temperatures, and the higher humidity at lower levels, will cause frosting or misting up of the cockpit windows, and even the faces of instruments. Full use should be made of the defrosting and demisting devices fitted. It may also be necessary to allow time for the aircraft to warm up at lower altitude to disperse this misting before attempting to land. In addition, clear ice may occur on the airframe when a rapid descent is made as the aircraft temperature lags behind the ambient air temperature. If rain is encountered whilst the temperature of the aircraft is below 0 °C, the relatively large water drops form clear ice over a large part of the aircraft, with considerable

spreading over the wings. When the runway is covered with snow and ice or is slippery, a positive landing should be made, without drift, on the centre-line. The aircraft should not be turned off the runway until the speed of the aircraft is suitably low. The friction of a wet runway will be greatly reduced from its dry value depending on the degree of wetness and the type of surface. When the runway is wet, braking distances can be significantly increased. Aquaplaning may occur when there is a layer of water on the landing surface and the tyre is no longer in contact with the surface. Advice on Equivalent Braking Action is given in the Flight Information Handbook.

Airframe Icing Factors

18. **Freezing of Supercooled Water Droplets**. The most important factor for the build-up of ice on aircraft is the freezing of supercooled drops - either cloud particles or raindrops - following impact with a cold aircraft. A certain amount of heat is required to melt a given mass of ice without a change in temperature and the same amount of heat is liberated when freezing takes place. This is known as the latent heat of fusion and its value is approximately 80 calories per gram of water or ice. Only 1/80th of a drop can freeze for every degree Celsius by which the temperature is below 0 ºC. Once the temperature of the partly frozen drop is raised, it begins to lose heat by evaporation and conduction to the object in contact with it, so that the remainder of the drop freezes more gradually while assuming the temperature of its surroundings. The higher the temperature of the supercooled drop, the smaller the fraction which will freeze instantly, and the greater the amount of liquid which will freeze progressively.

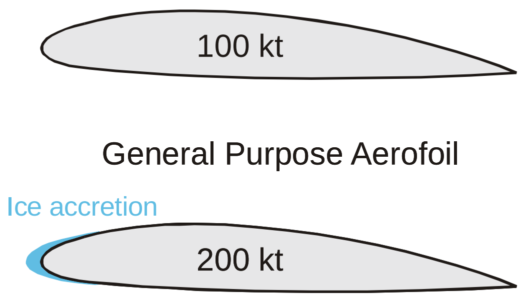
19. **Temperature of the Free Air**. Spontaneous freezing of supercooled drops in the free atmosphere is determined partly by the temperature and size of the drop and partly by other factors. As the temperature falls, the larger drops are likely to freeze first, while at lower temperatures only the smallest drops will remain liquid until a temperature of minus 40 ºC. The higher the temperature of a supercooled drop, the greater the fraction of the drop which remains liquid. The liquid portion then starts to flow over the aircraft thus favouring the formation of clear ice. At lower temperatures, there is a tendency towards the formation of rime ice concentrated near the leading edges.

20. **Size of Supercooled Drops**. The smallest supercooled drops tend to freeze immediately on striking a cold aircraft; the latent heat of fusion is quickly removed by the airflow and there is little or no spreading of the drop before freezing is complete. At the same time, air is enclosed between the particles, so that accretion takes the form of rime concentrated near the leading edge. On the other hand, large drops are accompanied by spreading of water over the airframe while the latent heat is being dissipated, so that freezing takes place more slowly and tends to be in the form of clear ice. Drops of moderate size can produce results intermediate between these two.

21. **Severity of Ice Accretion**. The severity of icing is defined as the rate of accumulation of ice by weight per unit area per unit time. Among the meteorological factors determining this rate are the amount of liquid water present and the size of the droplets. These characteristics are not the same throughout a particular cloud, even at one level. A cloud containing both liquid water and ice crystals may have large patches where one or the other predominate and icing will tend to be severe when the temperature is not far below 0 °C. An analysis of reports on ice accretion shows a preponderance of occasions at temperatures above about minus 10 °C and indicates that the frequency diminishes rapidly when the temperature falls below minus 20 °C, although occasional icing has been reported at temperatures below minus 40 °C. The severity of ice accretion is also dependent on:

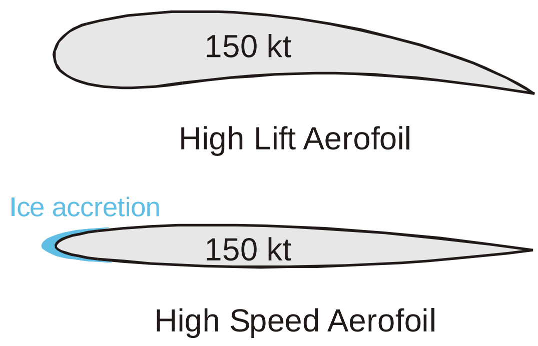
a. **Aircraft speed**. An aircraft will pick up more icing when travelling faster (see Fig 1).

8-2 Fig 1 The Effect of Speed on Airframe Icing



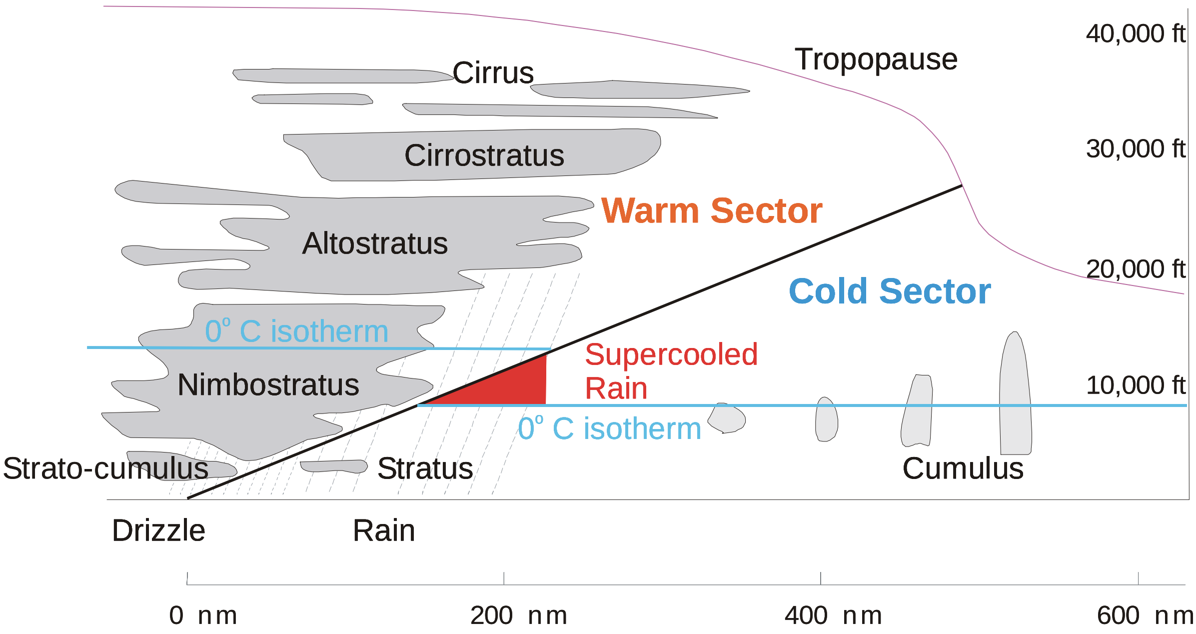
b. **Wing shape**. A thin, fast-jet type wing will pick up icing quicker than a thick, high-lift wing shape (see Fig 2).

8-2 Fig 2 The Effect of Wing Shape on Aircraft Icing



c. **Supercooled Rain**. Supercooled rain occurs beneath warm fronts and occlusions and occasionally beneath cold fronts (see Fig 3). When present, there is necessarily a warmer layer above, in which the temperature exceeds 0 °C. When flying beneath this type of meteorological condition the best procedure is to climb into the warmer layer of air. The belt of frontal cloud and rain should if possible be crossed at right angles so as to give the shortest traverse through the icing region. A particularly dangerous procedure is to fly parallel to the front in the freezing rain, since a heavy accumulation of clear ice could form rapidly.

8-2 Fig 3 A Cross-section of a Warm Front, showing area where Supercooled Rain may Occur



Piston Engine Icing

22. Piston engine induction system icing is commonly referred to as carburettor icing, but this is only one form of engine icing. Such icing can occur at any time, even on warm humid days. It can be so severe that unless the correct action is taken the engine may stop, especially at low power settings during descent, approach or during helicopter autorotation.

23. Considerable cooling of the air in the carburettor of piston engines can occur when the OAT is above 0 ºC. This cooling is the result of two factors:

a. The latent heat of evaporation of the petrol.

b. The pressure decrease passing the throttle butterfly valve.

The combined effect can reduce the temperature of air by as much as 25 ºC. To counter carburettor icing, an alternative hot air supply needs to be selected to maintain the internal temperature above 0 ºC. The direct injection type of carburettor is rarely subject to internal icing; however, the air intakes and filters can be seriously affected by external icing.

24. The aircraft document set such as aircraft manuals and the release to service are the primary source of information for individual aircraft and the advice given in them should be followed.

Types of Icing

25. There are three main types of induction system icing:

a. **Carburettor Icing.** The most common form of icing, the earliest to show and the most serious, is carburettor icing. It is caused by a combination of a sudden temperature drop due to fuel vaporisation and pressure reduction as the mixture passes through the carburettor venturi and past the throttle valve. If the temperature drop brings the air below its dew point condensation forms and if the mixture temperature reduces to below freezing, the condensed water will form ice on the surfaces of the carburettor. The ice gradually blocks the venturi, which upsets the fuel/air ratio causing a progressively smooth and slow loss of power. Conventional float type carburettors are more prone to icing than pressure jet types.

b. **Fuel Icing**. Less common than carburettor icing is fuel icing which is the result of water, held in suspension in the fuel, precipitating and freezing in the induction piping, especially in the elbows formed by bends.

c. **Impact Ice**. Impact ice builds up on air intakes, filters, alternate air valves etc. It forms on the aircraft in snow, sleet, sub-zero cloud and rain if either the rain or the aircraft is below 0 °C. This type of icing can affect fuel injection systems as well as carburettors. In general, impact ice is the main hazard for turbocharged engines.

Engine Factors

26. **Use of MOGAS (MOtor GASolene)**. MOGAS has a greater and seasonally variable volatility and higher water content than aviation fuels and as a result carburettor icing is more likely when MOGAS is used. MOGAS may be used in some aircraft that have been specifically cleared to use it. The CAA Safety Sense Leaflet 4 – 'Use of MOGAS' gives advice and guidance on the use of MOGAS.
(see http://www.caa.co.uk/docs/33/20120117SSL04.pdf (www)).

27. **Reduced Power Settings**. Engines at reduced power settings are more prone to icing because engine induction temperatures are lower. Also, the partially closed butterfly can more easily be restricted by the ice build-up. This is a particular problem if the engine is de-rated as in many piston-engined helicopters and some aeroplanes.

28. **Carburettor Surfaces**. A rough carburettor venturi surface is likely to increase carburettor icing severity.

29. **The Effect of Engine Cooling**. Water-cooled engine bodies tend to cool less quickly when power is reduced, reducing the carburettor icing severity. Coolant directed around the carburettor body may maintain the venturi temperature above freezing.

Atmospheric Conditions

30. Carburettor icing is not restricted to cold weather and will occur on warm days if the humidity is high, especially at low power settings.

31. Serious icing can occur at descent power with the ambient temperature above 25 °C, even with relative humidity as low as 30%. It can also occur at cruise power with an ambient temperature of 20 °C and relative humidity at 60% or more. Cold, clear winter days are less of a hazard than humid summer days because cold air holds less moisture than warm air.

32. Carburettor icing can occur in clear air with the absence of any visual warning.

33. Pilots should be alert to the possibility of carburettor icing when:

a. In cloud and fog where the relative humidity should be assumed to be 100%.

b. In clear air where cloud or fog may have just dispersed, or just below the top of a haze layer.

c. Just below a cloud base or between cloud layers.

d. In precipitation, especially if persistent.

e. The surface and low-level visibility is poor, especially in early morning and late evening, and particularly near a large body of water.

f. The ground is wet (even with dew) and the wind is light.

Recognition of Engine Icing

34. **Fixed Pitch Propeller**. With a fixed pitch propeller, a slight drop in rpm and performance (airspeed and/or altitude) are the most likely indications of the onset of carburettor icing. The loss of rpm can be smooth and gradual, and the usual reaction is to open the throttle slightly to compensate. However, whilst restoring power, this hides the loss. As icing builds up, rough running, vibration, further loss of performance and ultimately engine stoppage may follow.

For a fixed pitch propeller, the primary instrument for detecting engine icing is the rpm gauge in conjunction with ASI and altimeter.

35. **Constant Speed Propeller**. With a constant speed propeller, and in a piston-engine helicopter, the loss of power would have to be large before a reduction in rpm occurs. The onset of icing is more insidious but there will be a drop in manifold pressure and a performance reduction.

For a constant speed propeller, the primary instrument for detecting engine icing is the manifold pressure gauge.

36. In steady level flight, an exhaust gas temperature gauge, if fitted, may show a decrease in temperature before any significant decrease in engine and aircraft performance.

Piston Engine Icing Summary.

37. The main considerations with regard to piston engine icing can be summarised as::

a. Engine icing forms stealthily but can be anticipated.

b. Icing may occur in warm humid conditions at any time of the year in the UK.

c. The use of MOGAS makes carburettor icing more likely.

d. Low power settings, such as in a descent or in the circuit, are more likely to produce carburettor icing.

e. Warming up the engine before take-off improves the effectiveness of any carburettor body heat.

f. Use full carburettor hot air often when flying in conditions where carburettor icing is likely.

g. The RPM gauge is the primary indication of carburettor icing for a fixed pitch propeller.

h. Manifold pressure is the primary indication of carburettor icing for a variable pitch propeller.

i. Treat the carburettor hot air as an ON/OFF control; either full hot or full cold.

j. It takes time for the heat to work and the engine may run roughly while ice is clearing.

k. Timely use of appropriate procedures can prevent carburettor icing.

38. In the event of carburettor heat system failure in flight:

a. Avoid likely carburettor icing conditions.

b. Maintain high throttle settings; full throttle if possible.

c. Weaken the mixture slightly.

d. Land as soon as is reasonably possible.

Turboprop and Jet Engine Icing

39. **Turboprop and Jet Engines***.* The intakes of turboprop and jet engines are subject to icing in the same way as the airframe when flight is taking place in supercooled water droplets. The susceptible parts are the rim of the intake where the radius of curvature may be small, any struts across the intake, and the vanes in the early stages of the compressor. Thereafter, air temperatures are usually too high for icing to be a problem, although ice breaking away from the inlet may cause damage to the engine. Generally speaking, engine icing will be directly proportional to the rate of airflow through the engine and thus to the engine rpm - it is frequently found that the rate of icing may be reduced by decreasing the rpm. When a jet engine is operating at high rpm during flight at low speeds, as when taking off and landing, or whilst stationary, as in running up, the pressure within the intake is much less than the pressure outside. The consequent adiabatic expansion in the intake causes a drop in temperature as much as 5 ºC. If the clear indrawn air is moist and the temperature is near 0 ºC, prolonged operation may result in condensation and ice formation when this would not occur on the airframe. This effect may accentuate the icing which would normally be expected when the flight is in icing cloud, or when the aircraft is taking off or landing in freezing fog. Usually jet engines ice up in flight only under conditions which might be expected to produce airframe icing. The intensities of icing on the airframe and in the engine may be different since the airframe icing rate depends on the airspeed, whilst engine icing depends on the rpm. At high speeds, the engine tends to be supplied with more air than it needs and there is a ram effect, whereas at lower speeds, below about 250 kt, air is sucked in. Because of the ram effect at higher speeds some of the air is deflected round the intake, but the inertia of the water droplets results in a higher water concentration within the intake, and the icing rate increases markedly with increases of airspeed above 250 kt. At speeds where the air is sucked in (below 250 kt) the water concentration of the air entering the intake remains virtually the same as free air so that engine icing rates tend to be constant with decreasing speed, whereas the airframe is likely to show a marked decrease of icing rate with decreasing speed.

Summary

40. Aircraft encounter a greater variety of icing conditions in flight than on the ground, resulting in a wider variety of ice deposits. Snow, ice and frost, in all their forms, produce a flight safety risk. Being aware of the physical process and conditions which produce airframe and engine icing will help to avoid the dangers associated with this phenomenon. A more detailed explanation of factors affecting icing of aircraft may be found in the Handbook of Aviation Meteorology (HMSO), Chapter 8. Table 1 summarizes the various types of aircraft icing.

Table 1 Types of Icing and their Properties

Reference: The Handbook of Aviation Meteorology – HMSO - 1994

Type	Occurs	Appearance	Effect	Action
Hoar-frost	Occurs in clear air on a surface whose temperature is reduced below the frost-point (1) of the air in contact with it. Occurs on clear nights when there is a fall in temperature to a value below 0 °C. May occur in flight when moving rapidly from air well below 0 °C to warmer and more humid air. Should soon disappear as the aircraft warms up. May affect radio reception, and may cause frost on the windscreen and instruments.	White crystalline coating, normally of a feathery nature.	Weight of the deposit is unlikely to be serious. It can interfere with the airflow over the wing and thus the attainment of flying speed during take-off. Can also affect vision through the windscreen, the free working of control surfaces and radio reception.	Should be removed before take-off.
Rime Ice	Occurs when small supercooled water drops freeze on contact with a surface at a temperature below 0 °C. At ground level it forms in freezing fog. In flight it may form in clouds of low water content composed of small droplets, comparable with those of freezing fog. Most liable to occur at low temperatures where small, unfrozen cloud droplets freeze almost instantaneously.	Tiny ice particles between which air is entrapped to give a rough crystalline deposit. Forms and accumulates on leading edges with no spreading back. Trapped air gives a white opaque appearance.	Usually breaks away quite easily. Usually little weight. Alters the aerodynamic characteristics of the wings and may block air intakes.	If present, it should be removed before take-off.
Clear Ice (Glaze Ice)	Occurs in dense cloud of convective or orographic type. Forms when large water drops, not far below 0 °C, are encountered in flight. Results from water flowing over a cold airframe before freezing. Drop unite while liquid and little air is trapped. May also occur when an airframe, below 0 °C, descends rapidly through large raindrops. May also occur where there is an inversion where rain falls from a level above 0 °C to a layer where it is below 0 °C. Typically associated with warm fronts where the icing layer occupies a narrow range of altitude below the frontal surface (see Fig 3).	Transparent or Translucent coating with a glassy surface. Ice surface is smooth but may have bumps and undulations.	Tough and sticks closely to the surface of the aircraft and cannot be broken away easily. If it breaks away, it sheds in large pieces which may be dangerous. Will affect the aerodynamics and increase weight. May cause unequal loading of the wings, struts and propeller/rotor blades.	Avoid if possible. Use aircraft anti-icing/de-icing systems. Try to avoid the danger area associated with warm fronts (Fig 3). Cross the front at right angles if possible.
Cloudy (Mixed Ice)	Rime and Clear ice are the extreme forms of ice accretion experienced by aircraft in flight through cloud and rain. As a large range of drop sizes may be encountered at any temperature between 0 °C and -40 °C, a wide range of icing exists between the two extremes. These varieties are usually described as Cloudy or Mixed ice.	The smaller the drops and the lower the temperature, the rougher and more cloud will be the build up on the leading edges. A smoother and more glassy ice formation, spreading back over the airframe will occur with large drops and a temperature closer to 0° C.	Effects as above depending on droplet size and temperature. Where ice crystals are present in a cloud, these may stick to a wet airframe and freeze, along with the cloud drops, to give a formation of rough cloudy ice. If snowflakes are present they are trapped in the ice as it forms, producing an opaque deposit with the appearance of tightly packed snow.	Avoid if possible. Use aircraft anti-icing/de-icing systems.

(1) Frost-point is the temperature to which moist air must be cooled in order to just reach the condition of saturation with respect to a plane ice surface. Further cooling induces deposition of ice in the form of hoar-frost on solid surfaces, including other ice surfaces.

CHAPTER 3 - GROUND HANDLING OF AIRCRAFT

Introduction

1. This chapter provides information on those aspects of aircraft ground handling that are pertinent to all aircrew. Topics are covered in general terms only, as specific details may vary due to local requirements.

GROUND HANDLING

Seeing In and Seeing Off

2. Aircraft arrivals and departures are usually attended by a handling team comprising two tradesmen.

3. On arrival, the handling team will marshal the aircraft into a designated parking area, which has been cleared of foreign objects and non-essential items of ground equipment. When signalled by the pilot, chocks are inserted, and ground power is connected, along with any necessary ground servicing equipment. Fire extinguishers are positioned and manned as required during engine shut-downs, aircraft steps are positioned and, where appropriate, the aircrew are assisted with unstrapping. Finally, the handling team will fit safety devices, covers and blanks.

4. Appropriate actions are carried out in the reverse order for departure.

Marshalling

5. The aim of the marshaller is to assist the pilot in the safe manoeuvring of the aircraft on the ground. The signals used are standard throughout the RAF and are illustrated in AFSP-2, Aircraft Marshalling Signals. Marshallers will normally wear clothing of a distinctive colour as an aid to identification, except where operations dictate otherwise.

6. The need for marshalling assistance will be governed by the pilot’s familiarity with the airfield, the number of obstructions, the size of the aircraft and the field of view from the cockpit. At an unfamiliar airfield, taxiing instructions may be passed by radio and, occasionally, 'follow me' vehicles may be used.

7. **Marshalling Procedure – Day**. The degree of marshalling will vary with circumstances - to park an aircraft in a particular position, when the approaches to it are clear, requires only that the pilot is given an indication of the position where it must finally be stopped. This information should be given to the pilot as soon as possible by the marshaller standing on the required spot with his arms outstretched, facing towards the final position of the aircraft. The pilot is then free to taxi the aircraft, via any suitable route, to the position indicated. If obstructions exist, two extra personnel may be required to complete the marshalling team. They should walk on either side of the aircraft, ahead of the wing tips, and signal to the pilot if there is sufficient clearance for the aircraft to pass. This assistance is most likely to be necessary when marshalling large aircraft with restricted fields of view from the cockpit.

8. **Marshalling Procedure - Night**. While taxiing at night in congested areas, it will be necessary for the marshallers to be more precise in their directions. It cannot be assumed that the pilot will be able to recognize where the aircraft will be finally parked without detailed assistance. If dispersal areas are floodlit, marshalling assistance may be reduced to that given in daylight, but normally the marshaller should hold a lighted wand or torch in each hand. Navigation lights should always be on and taxi lights should be used, although care should be taken not to dazzle the marshaller. Marshallers should be in a position where they can be seen by the pilot at all times and clear signals must be given when

transferring guidance from one marshaller to another. The aircraft must be stopped if the pilot loses sight of the marshaller or if one of the marshaller's wands fails.

9. **Parking Spaces**. Parking spaces are often nominated by letters or numbers and are displayed in the appropriate Aerodrome Charts. Most airfields have yellow-painted guidelines to assist pilots in taxiing and lining up aircraft at a safe distance from each other. However, when visiting an unfamiliar airfield, care should be taken whilst taxiing as there may be insufficient wing tip clearance if the local guidelines are for an aircraft of different wingspan.

10. **Division of Responsibility**. The pilot is always responsible for the safety of the aircraft and is not required to follow marshalling instructions considered unsafe; the safest course of action is always to stop and resolve any problem before continuing.

Chocks, Safety Devices, Blanks and Covers

11. Aircraft should be securely chocked whenever they are shut down and stationary on the ground, and also during ground engine runs. Safety devices, blanks and covers should be fitted throughout the time that the aircraft is shut down, unless removed temporarily for maintenance.

Danger Zones

12. Danger zones are those areas in which there is a high risk of injury to personnel when aircraft components or systems are operated on the ground.

a. **General**. Danger Zones normally comprise areas around engine intakes and exhausts, including auxiliary power units, propellers and helicopter rotors, but also include the areas around the control surfaces and airbrakes. In particular, the propellers of piston-engine aircraft should always be considered 'live' and should only be moved or 'swung' as directed, and then always in accordance with approved procedures. Special care is necessary when in close proximity to a helicopter whose rotors are turning in gusty wind conditions. Blade sailing may bring the rotor blade tips very close to the ground.

b. **Slipstream/Jet Efflux**. Even when the engine is idling, a propeller slipstream or the efflux of a jet engine can be powerful enough to damage loose items of ground equipment or injure groundcrew. Personnel must always be aware of such hazards, particularly during engine start-up and initial taxiing, and take care to prevent an incident.

Wheel and Brake Fires

13. There is a danger of explosion if rapid and uneven cooling of an aircraft wheel or brake assembly should occur. The safest course of first-aid action against an aircraft wheel or brake fire is:

a. To approach the aircraft forward or rearward of the wheels depending on the prevailing wind, but never in line with the axle (since this will be the most probable path of any resultant debris, should the burning brake unit explode).

b. To operate the fire extinguisher at the limit of its range, spraying the extinguishant downwards towards the wheels, ensuring that the flow strikes the ground 0.3 m away from the wheels and flows onto them.

REFUELLING

Fuels

14. The following paragraphs cover the most important aspects of refuelling. Aircrew should be familiar with these topics since they may have to supervise the refuelling of their aircraft.

15. Aviation fuels are described in detail in Volume 3, Chapter 19. The major types of aviation fuel are:

a. **AVGAS** - aviation gasoline used by piston-engine aircraft. The only grade of AVGAS on general distribution is AVGAS 100LL.

b. **AVTUR** - aviation turbine fuel (kerosene). This is the standard fuel for gas-turbine engine operations.

c. **AVTAG** - aviation turbine widecut gasoline. AVTAG is now primarily limited to emergency military use, and use in very cold climatic conditions (freezing point of AVTAG is lower than that of AVTUR).

d. **AVCAT** - aviation turbine fuel with high flashpoint, used largely by the Royal Navy.

The use of approved and alternative fuels is subject to certain precautions and limitations and is described in Volume 3, Chapter 19. Fuels may only be used in accordance with the relevant aircraft type Aircrew Manual and Release to Service documents.

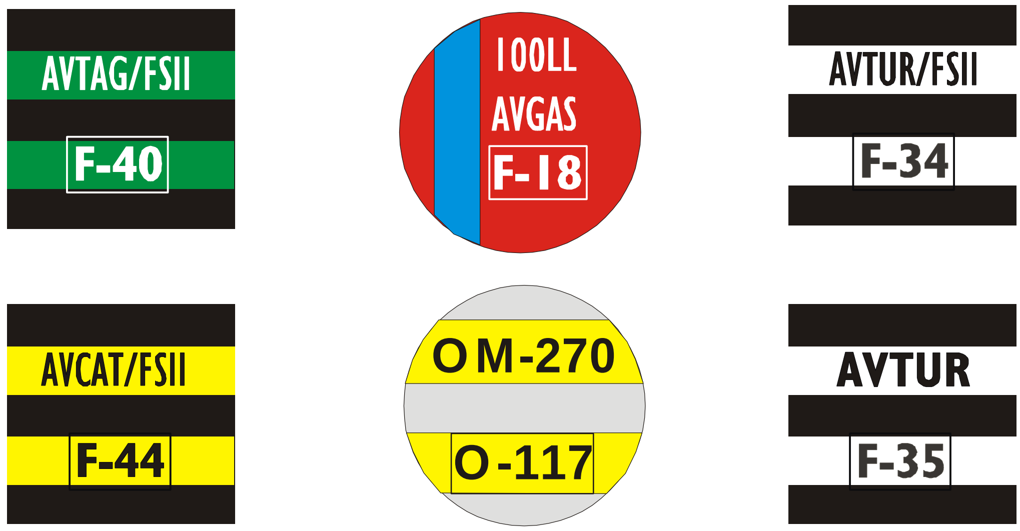
Lubricating Oils

16. Lubricating oils of different types and viscosities are used for reciprocating engines and gas-turbine engines, the latter requiring an oil of very much lower viscosity. The containers for the various grades may be identified by labels with NATO code number or lettering, or by distinctive colour coding (see Fig 1).

Identification

17. With so many fuels and oils in common use, great care is necessary to ensure that aircraft are replenished with the correct grade and type. Aircraft filler caps are normally identified by a red 300 mm diameter circle with AVGAS in white letters, or a black 300 mm square with AVTUR in white, as appropriate. Refuellers are also clearly marked with the grade and colour code of the fuel they contain (see Fig 1). Fuels are often given a full joint-service nomenclature and a recognized abbreviated designation. Lubricants are also allotted symbols by which they are known in all three Services and most fuels and lubricants have a NATO code number for ease of cross-servicing.

8-3 Fig 1 Fuel and Oil Identification Markings



Refuelling Appliances

18. **Hydrants**. Many civil airfields used by military aircraft have a hydrant refuelling system built into the parking area. Fuel is pumped directly from the bulk fuel storage installation to the aircraft using a mobile pump vehicle connected to the hydrant.

19. **Bowsers**. A mobile bowser is the normal military method of conveying fuel from storage tanks to aircraft. There are several types of bowser, but their purpose and layout is basically the same. Fuel is pumped through delivery hoses by the vehicle's main engine or a small auxiliary engine housed at the rear of the bowser. Handling instructions for the auxiliary engine are usually printed on the inside of the housing doors.

20. **Portable Fuel Tanks**. Portable fuel tanks are sometimes used, in conjunction with mechanical or hand pumps, for refuelling aircraft when a bowser is not available. Such a combination might be used to refuel when operating from a temporary base.

Refuelling Precautions

21. Adequate fire fighting equipment must be readily available before aircraft refuelling is commenced. The risk of fire during refuelling is a very real one which can be minimized by the application of the following simple precautions:

a. When refuelling from a vehicle the danger of a spark caused by static electricity should be avoided by first bonding the refuelling vehicle and delivery nozzle to the aircraft and the refuelling vehicle to earth before opening the fuel filler cap/refuelling point. The aircraft should also remain earthed throughout the refuelling process.

b. Spillages of fuel can spread a fire over a large area and should be avoided. Any spillage should be dealt with immediately in accordance with the local Fuel Spillage Plan.

c. Refuelling and defuelling in a hangar or with engines running is not permitted unless specifically authorized.

d. Refuelling crews must not carry cigarette lighters or non-safety matches and they should, whenever possible, wear rubber or crepe soled footwear.

e. Flame-proof torches must be used and no naked lights should be permitted within 30 m of any refuelling or defuelling operation.

f. Work on electrical or radio equipment, including R/T transmissions, must not be conducted whilst refuelling is in progress, or within 15 m of an aircraft which is being refuelled.

g. Refuelling must not be carried out within 40 m of another aircraft with engines running.

h. Refuelling vehicles should be positioned so that they can be quickly moved in the event of a fire. Bowser trailers must not be disconnected from their prime mover during refuelling operations.

Finally, as a general precaution when filling oil tanks, adequate air space should be left for expansion and frothing of oil when heated. All filler caps should be checked for correct fitment following replenishment.

Pressure Refuelling

22. The basic difference between the system for pressure refuelling on the ground and that for use in flight is the position of the filling point. For either system, all tanks or tank groups are fitted with shut-off valves, mechanically or electrically operated. The valves give positive fuel shut-off at the desired level, with pressure relief arrangements to protect the aircraft fuel lines. Essential precautions to be taken when pressure refuelling are to ensure that the refuelling coupling is correctly connected, that bonding is complete, aircraft switches are correctly set and that the maximum refuelling pressure is not exceeded.

Human Factors and Ground Handling of Aircraft

Be aware that what the groundcrew see and therefore perceive may be very different from the perception in the cockpit. Big aircraft taxy slower than small ones…..or is just our perception? Environmental conditions (hot-cold-wet-windy-dark-bright) have a subconscious effect on stress levels and therefore on thinking processes leading to potential human error. Complacency, boredom and familiar routine all have an effect on our performance…….ever driven home after work and not remembered a single bit of it?? Stick to SOPs. If in doubt ask.

CHAPTER 4 - AIRWORTHINESS AND AIRCRAFT DOCUMENTATION

Introduction

1. The purpose of this Chapter is to define and highlight key areas of airworthiness as they affect the operator. A working knowledge of aircraft documentation is essential for the safe and efficient conduct of flight. Reference to relevant Military Aviation Authority (MAA) Regulatory Publications is made where appropriate.

2. Detailed rules for the operation of Service aircraft and for the maintenance of flying discipline are issued by the Ministry of Defence. Such rules will comply with the overall policy laid down by the Ministry of Defence both for aircraft operations generally, and for the individual aircraft, weapons, or other airborne equipment. These rules have taken engineering and operating aspects of airworthiness and flying regulation into account.

AIRWORTHINESS

Military Airworthiness Regulations

3. Airworthiness is defined as the ability of an aircraft, or other airborne equipment or system, to operate without significant hazard to aircrew, ground crew, passengers (where relevant) or to the general public over which such airborne systems are flown. Airworthiness is not only concerned with engineering aspects, but also with the way an aircraft is flown and how its systems are operated. However, airworthiness is a safety consideration, and should not be confused with 'fit for purpose', which is an operational requirement.

4. **The Airworthiness Safety Management System**. The Defence Aviation Safety Board (DASB) requires airworthiness to be achieved by use of a prescribed Safety Management System (SMS). The SMS provides a focus for activities that are particularly concerned with safety performance and legal compliance. Within that SMS, the development and maintenance of a Safety Case provides a clear organizational goal.

5. **The Safety Case**. The Safety Case is the central justification for military aircraft airworthiness and is also a record of safety analysis activities. It is a suite of documents providing a written demonstration that the safety risks have been reduced as low as reasonably practicable. The Safety Case is a 'living' document that will be updated at phases that include inception, procurement, service clearances, in-service operation and eventually, disposal.

6. **Release Documents**. There are two release documents:

   a. **The Military Aircraft Release**. This document was based on a design standard, and not the 'as flown' standard, and was, inter alia, the statement that an acceptable Safety Case had been prepared for the aircraft.

   b. **The Release to Service**. The MOD Release to Service is the release document that authorizes Service flying on behalf of the Service Chief of Staff. It states the definitive limits for the aircraft in Service regulated flying and reflects the 'as flown' configuration.

Generic Aircraft Release Process

7. With effect from 1 November 2004, the management of release for all new aircraft will be in accordance with the Generic Aircraft Release Process (GARP) (MAA MAP 01). Most of the existing aircraft projects retain their traditional aircraft release management procedures (and are now referred to as 'legacy' aircraft). However, legacy projects will, in due course, convert to GARP documentation.

8. The main changes introduced by GARP include the following:

a. There is no MA Release document.

b. The Safety Case and Aircraft Document Set reflect the 'as flown' aircraft configuration.

c. When the aircraft is in service, the Safety Case will be 'owned' by the Release to Service Authority (RTSA).

d. Amendments to the Release to Service document are agreed jointly between the Integrated Project Team (IPT) and the RTSA.

e. Service Deviations will not apply under this process. RTS information which has not been derived from a fully substantiated Safety Case is termed a "Clearance with Limited Evidence" (CLE) and is recorded in Part F of the RTS.

Changes to Release Documents

9. Whenever a Service initiated change is being planned, it is the responsibility of the RTSA, in consultation with the IPTL, to consider the possible impact on the Safety Case. Where acceptable, the IPTL should authorize the work and trials to assess the change proposal, and ultimately, the Safety Case and Release to Service document should be amended. However, where this is not possible, for various reasons, the RTSA may initiate a CLE or, for legacy aircraft, raise a Service Deviation to cover the change, referring to the revised Safety Case.

AIRCRAFT DOCUMENTATION

Aircraft Document Set

10. An Aircraft Document Set (ADS) (MAA RA 1310) is produced and maintained for each aircraft type. The ADS will include the Release to Service, Aircrew Manual, Flight Reference Cards, Pilots' Notes (when required), Minimum Equipment List (when required), Operating Data Manual, Flight Test Schedules, Aircrew Land away and Turnaround Schedule, Technical Publications and the Support Policy Statement. The ADS forms an integral part of the Safety Case.

Military Aircraft Release

11. For legacy aircraft, the Military Aircraft Release (MA Release) is the statement of the operating envelope, conditions, limitations, design standard and associated operating procedures within which the airworthiness of the design has been established. Usually, it is the product of considerable effort from industry, test pilots, and supporting engineering staffs; it recommends to the Aircraft Operating Authority, the use and the limits to which the aircraft may be safely flown in Service. It also includes the approved Operational Emergency Clearances (OEC) and advice on their application. Responsibility for the content of a MA Release lies with the Integrated Project Team Leader (IPTL).

Release to Service

12. The MOD Release to Service (RTS) is the authority to conduct service flying. It states the operating limitations for a specific aircraft and its airborne systems and equipment, in Service-regulated flying (MAA RA 1300). RTS are configured and managed to either GARP or 'legacy' procedures:

a. **GARP Procedures**. The RTS is a stand-alone document (ie there is no MA Release) and reflects the 'as-flown' aircraft standard.

b. **'Legacy' Procedures**. The RTS is founded upon the current standards of MA Release supplemented with Service Deviations and explanatory notes.

Service Deviations

13. For legacy aircraft, a Service Deviation (SD), issued and controlled by the Aircraft Operating Authority, is a permitted deviation from the conditions of the MA Release for the purpose of Service-regulated flying. There are two categories of SD, depending on whether the SD is inside or outside the MA Release:

a. Category 1 SDs give clearance to operate outside the established RTS limitations, or in a configuration not recognized in the MA Release.

b. Category 2 SDs, which pertain to operations carried out within the limitations of the RTS, may be used, for instance, to prolong fleet life by reducing fatigue or for reducing the flight envelope for normal operation in peacetime.

Special Flying Instructions

14. Special Flying Instructions (SFIs) are issued by the RTSA to notify aircrew urgently of important changes to the way in which aircraft or their equipments are to be operated.

Aircrew Manuals

15. Aircrew Manuals (AMs) are published by Handling Squadron, Boscombe Down, to explain and describe aircraft systems, operating drills and limitations. The Manuals, and their associated Flight Reference Cards (FRCs), are live documents, constantly under review and amendment as modifications are embodied and experience of type grows. Liaison between Handling Squadron authors, aircraft manufacturers, support authorities, trials units and front-line crews enables the best available technical and operating advice to be provided. In terms of flight safety and the legal obligations of operational airworthiness, the AM is a part of the Aircraft Document Set for the aircraft. FRCs are complementary to the AM for the aircraft concerned. The AM is complementary to the RTS and associated Operating Data Manual (ODM).

16. The limitations quoted in the AM (unless over-ridden by the RTS) are mandatory and are not to be exceeded except in recovering from emergency situations as covered at para 22. Any violation of limitations is to be formally reported in accordance with para 24. Other information within the AM is advisory but instructions containing the words "is to" and "are to" are also mandatory.

WARNING: The RTS is the overarching document for limitations and takes precedence over the AM, as the changes to the RTS may take some time to be reflected in the AM.

17. The AMs, and their associated FRCs, aim to provide the best operating instructions and advice currently available. Although they provide guidance for most eventualities, they are not substitutes for sound judgement and good airmanship; moreover, they assume an adequate knowledge of the pertinent volumes of AP 3456. Furthermore, circumstances might require aircrew to depart from or modify the prescribed procedures and drills. Consequently, the AM and FRCs should not be regarded as immutable, and operators are encouraged to pass observations or suggestions to Handling Squadron through respective Standards squadrons.

Flight Reference Cards

18. FRCs (or electronic presentations thereof) are designed to be used by aircrew in flight, and are an aide-mémoire containing definitive checks and drills for normal and emergency operation of the aircraft and its systems. In terms of flight safety and operational airworthiness the FRCs are a part of the Aircraft Document Set for the aircraft.

Operating Data Manual

19. The ODM provides definitive performance definitions and data on the aircraft concerned for aspects such as take-off, climb, manoeuvre, descent and landing. This information is normally presented in the form of performance graphs which are used by aircrew in planning the flight concerned. The performance presented in the ODM is only achieved when the aircraft is flown using the relevant techniques described in the AM. The ODM is a part of the Aircraft Document Set for the aircraft.

Advance Information Leaflets

20. Advance Information Leaflets (AILs) are issued to promulgate new information to AMs quickly when a modification changes operating procedure, introduces a new piece of equipment, or when operating procedures are to be changed and need to be explained urgently. Action can be initiated as a result of activities at Design, Special Trial Instructions, Service Modifications and the like, but AILs are not normally used if the new information can be included in a routine amendment in sufficient time. AILs are not used for FRCs.

Advance Notification of Amendments Procedure

21. An Advance Notification of Amendment (ANA) procedure is used to disseminate urgent amendments to FRCs, AMs and ODMs. ANAs are normally issued by signal and generally will take the form of a manuscript amendment, which will be incorporated in the next formal amendment.

Aircraft Limitations

22. Flying must be planned so that the engine, airframe or handling limitations quoted in the RTS will not be infringed in Service-regulated flying. RTS limitations are reflected in the AM, FRCs and ODM, and are not to be exceeded except under specifically controlled and permitted conditions, or as circumstances dictate during combat, emergency or humanitarian missions.

23. Aircraft limitations may be of two types:

a. **Normal Operating (NO) Limits**. Normal Operating (NO) Limits are limits that may be reached on a day-to-day basis in normal operation of the aircraft or equipment without significant penalty in flight safety, airworthiness or fatigue. The design and airworthiness criteria impose a number of conditions that have to be satisfied in order to protect the aircraft in aspects such as overall strength, gusts and turbulence, and also in the case of failure and runaway conditions. The criteria are derived by a combination of calculation and flight test.

b. **Never Exceed (NE) Limits**. Never Exceed (NE) Limits are close to the limit of the tested or design flight envelope, beyond which there is no guarantee of airworthiness; in particular controllability, resistance to flutter and structural integrity.

24. If aircraft limitations are exceeded at any time, or if the aircraft has been subjected to abnormal stress or strain in the air or on the ground, the pilot is to report the fact on the Form 700 or Tech Log for the aircraft concerned, and to the authorizing officer, as soon as possible.

Omissions or Inaccuracies in Aircrew Publications

25. Any individual, observing a deficiency, omission or inaccuracy in any military aircrew publication should raise the issue on the appropriate form; for AMs, FRCs and ODMs. For the MAA Regulatory Publications, use the appropriate form from the MAA03 – MAA Regulatory Processes.

CHAPTER 5 - AIRCRAFT FIRES

Introduction

1. Precautions against fire are now design requirements for all aircraft. This design philosophy, together with the improvement of safety devices and extinguisher systems, has reduced the fire risk for all aircraft operations.

2. Aircrew should have a thorough knowledge of:

a. Fire warning and extinguisher systems.

b. The vital actions involved in dealing with aircraft fires.

c. The location and operation of any aircraft cabin fire-fighting equipment.

d. Electrical, hydraulic, bleed air, fuel and other associated aircraft systems.

e. The structural details of their aircraft, in relation to emergency escape.

Fire Warning

3. **Engine Bay Fires**. Aircrew may not get an immediate visual indication of an engine fire, because of the location of the engine. Fire detectors, situated in the engine bays, actuate fire warning systems usually consisting of red warning lights accompanied by an audio warning. Fire warning lights are usually located on a central warning panel, though in some multi-engine aircraft, there may be an additional fire warning indication in each engine emergency shut-down handle. Crash and inertia switches, if fitted, will automatically operate the engine fire extinguisher systems in the event of a crash landing.

4. **Fuselage Fires**. Normally, the crew will be alerted to a fuselage fire by the presence of smoke or fumes, a little of which can quickly fill a cockpit, flight deck or cabin. However, smoke or fumes emanating from a fire in an under-floor compartment are rarely detected visually; the problem is normally detected by the appropriate fire/smoke/overheat sensors, which then generate a visual and/or audio warning to the crew.

5. **Electrical Fires**. Electrical fires are usually caused by arcing or short circuits and may affect almost any part of the aircraft electrical wiring system. Warning of an electrical fire is normally obtained from the presence of pungent smoke or fumes in the cockpit.

FIRE IN THE AIR

General Considerations

6. On receipt of a fire warning, or on visual observation of a fire, the captain should warn the crew and initiate the appropriate FRC drill. As well as carrying out the FRC drill for extinguishing the fire, the crew should also action the FRC drill for smoke or toxic fumes in the cockpit, if appropriate. On some aircraft, it may be possible to open cockpit or flight deck windows. However, opening windows may cause an induced forward draught which could draw smoke and fumes into the area. Cockpit or flight deck windows should, therefore, be kept closed until the fire is extinguished, when they may be opened to assist in removing toxic fumes (see Volume 6, Chapter 8).

7. There is a high risk that an uncontrolled fire will increase in intensity and spread to the fuel tanks and the airframe. This may subsequently cause an in-flight structural failure. Therefore, if the fire shows no signs of abating after completion of the FRC drill, the captain should:

a. If parachutes are available and height permits, order ejection or 'abandon aircraft', rather than attempt a forced landing.

b. If abandoning the aircraft is not an option, perform a forced landing as soon as possible.

Engine Fires

8. The detailed instructions and drills for dealing with an engine fire for a particular aircraft type are found in the Aircrew Manual (AM) and associated FRCs. The specific drills will vary considerably depending on the number of engines fitted to the aircraft, and the fire fighting equipment and extinguishers carried. The AM and FRC drills are formulated by the aircraft manufacturer and it is vital that they are adhered to rigidly. Any unauthorised variation to the drills may pose an extra unforeseen hazard to the crew.

9. **Piston Engines**. Fires in piston engines are commonly caused by leaking fuel or oil. Although a fire may be stopped by the immediate operation of a fire extinguisher, if fitted, it is liable to restart if the engine continues to run. The supply of fuel and, if possible, engine oil, should be shut off. To remove the unburnt gases in the cylinders, the ignition should not be turned off until the engine rpm starts to slow down, when the propeller should be feathered to stop the engine. Once the propeller is stationary, or at minimum rotation, the fire extinguisher should be operated. For a single-engine aircraft not fitted with an engine fire extinguisher, the throttle should be closed, the rpm lever moved to minimum and the fuel and, if possible, the oil supply, switched off. When the rpm has slowed to a minimum, the ignition should be switched off and the electrical system isolated.

10. **Turboprop Engines**. The source of fire in a turboprop engine may be a leak of fuel, engine oil or hydraulic systems, or a fracture in one of the pipes in the engine hot bleed air system. The affected engine should be stopped by pulling the appropriate fire emergency shut-down handle, where fitted. The fire extinguisher should then be operated, once the propeller has stopped or reached minimum rpm. If no dedicated shut-down handle is fitted, the fuel, engine oil, hydraulic, electrical and bleed air systems should be isolated, the propeller feathered, and then the fire extinguisher operated as above. Some aircraft are fitted with more than one fire extinguisher for each engine or engine zone. Others may have a central supply of fire extinguishant that needs to be routed by the fire emergency shut-down handle to the affected engine.

11. **Turbojet Engines**. The basic principles that are applied to turboprop engines are also applicable to turbojet engines. The throttle should be closed and the fuel turned off. Speed should be reduced as quickly as possible (to reduce the airflow through the engine nacelle) and then the fire extinguisher should be operated. All engine systems should then be isolated.

12. **Actions After an Engine Fire**. After an emergency engine shut-down and operation of the fire extinguisher system, it is important to prevent any smoke, fumes, or extinguishant contaminating the cockpit. The smoke and fumes elimination drill should be actioned and, if possible, 100% or emergency oxygen selected as appropriate, and used by all crew members.

13. **Restarting Engines**. No attempt must be made to restart an engine after an engine bay fire has been successfully extinguished. The fire is liable to recur if the engine is restarted and there may be no fire extinguisher available to fight the subsequent fire.

Fuselage Fires

14. Prompt detection and action by the crew, using hand-held fire extinguishers, will normally be successful in combating fires in the fuselage. Fires detected automatically in the under-floor compartments are normally extinguished by collocated, remotely-controlled fire extinguishers. Hand-held fire extinguishers fitted to most aircraft contain an inert gas which is non-toxic, but inhaling high concentrations of the gas should be avoided. The most common extinguishing agent in use is bromochlorodiflouromethane (BCF). Aircraft equipped with a large amount of electrical equipment within the fuselage, (eg maritime/AWACS) are normally equipped with CO_2 extinguishers specifically to fight fires within electrical equipment. All high voltage radio and radar equipment should be switched off, if possible, before any type of extinguisher is used. Further details of fire extinguishing agents are given in Volume 6, Chapter 8.

Accidental Operation of Fire Extinguisher System

15. If an engine bay fire extinguisher is accidentally discharged, the engine should be operated according to the advice given in the Aircrew Manual. If an extinguisher using methyl bromide, or any other chemical of a toxic nature, is discharged inside the aircraft, the smoke and fumes elimination drill should be actioned immediately.

16. It is important that the operation of fire extinguishers, accidental or deliberate, must be reported after landing so that the necessary action can be taken to minimize corrosion and fouling, and to replenish the extinguisher system.

FIRE ON THE GROUND

General

17. A fire on the ground may start during refuelling, on engine start-up, or during routine testing and servicing. In addition, wheel brakes may become excessively hot during the landing run or when taxiing, and cause a fire.

Refuelling/Defuelling

18. Generally, during refuelling and defuelling, only those electrical services necessary for the operation (e.g. electrical fuel contents gauges) should be in operation - no other electrical service (especially radio and radar) should be operated. Fuel contents gauges should not be switched off until the operation is completed and the aircraft is free of fumes. All mechanical refuelling appliances should be earthed to the airframe and ground earthing points throughout the refuelling operation. (However, some types may be cleared for operational turnarounds with power applied to the airframe, and helicopters may be cleared to refuel with rotors running).

Engine Fires

19. Prior to an engine start, fire extinguishers should be positioned close to the aircraft and within easy reach of the ground crew. If practicable, at least one of the aircraft's radios should be on and tuned to a suitable local or ground frequency.

20. If a fire occurs, the following actions should be taken:

a. **Ground Crew**. The ground crew should immediately warn the pilot by intercom, if an external socket is used, or by hand signal as specified in AFSP-2 – Aircraft Marshalling Signals.

(Make rapid horizontal figure-of-eight motion at waist level with either arm, pointing at the source of fire with the other.) They should then use the ground fire extinguishers to fight the fire.

b. **Aircrew**. The FRC drill for fire on the ground should be actioned immediately. The aircrew will also use the radio to inform ATC of the aircraft tail number and parking slot/area, so that the airfield fire service can be alerted to the correct aircraft with the minimum of delay. When this has been done, all electrical services should be switched off and the aircraft vacated as quickly as possible.

21. Where light aircraft are parked close to others on a line, releasing the brakes before exiting the aircraft should enable it to be pushed clear of the line by the wingtips.

22. An engine that has been on fire should never be restarted until it has been examined by qualified servicing personnel.

Overheating Wheels and Brakes

23. If wheelbrakes have been severely overheated, they should be allowed to cool naturally if fire is not apparent. It should be noted that peak temperature in overheated brake and wheel assemblies is not reached until 30 minutes have elapsed after the application that caused the overheating. If a wheel catches fire, it should be approached from a fore or aft direction, not in line with the axle, thereby obtaining some protection from the tyre. Only dry chemical powder should be used to fight wheel fires; the dry powder prevents the rapid cooling and contraction of the metal, thus reducing the risk of a wheel explosion.

24. Carbon dioxide, water or foam extinguishers should not be used on wheel and brake assembly fires because they cause the metal to cool too rapidly. The resultant contraction of the heated metals can result in explosive fractures. Wheel and brake disc fragments from such fractures have caused damage at distances of up to 150 metres.

Human Factors and Aircraft Fires

Aircraft fires tend to focus the mind somewhat and cause high levels of Stress. Stress plays a large part in how we process information and therefore our ability to make good decisions. Focussed attention is a primary cause of losing Situation Awarenes and can be potentially fatal. Use the Simulator to good effect and be prepared. Don’t turn a “red card drill” into an accident. Aviate, Navigate and Communicate.

CHAPTER 6 - FORCED LANDING

Introduction

1. A forced landing is a landing which was not planned as part of the flight. This can, therefore, vary from a normal landing at a diversion airfield to an unpremeditated landing without power on to any selected area. The factors affecting the course of action to be followed for a forced landing will vary considerably with each aircraft type. Therefore, this chapter will deal only in broad terms with the general considerations of forced landings for all types.

2. Also included in this chapter are notes on other landing emergencies. Again, these will be dealt with in general terms and reference must be made to the Aircrew Manual for the type for detailed procedures for any specific emergency.

General Considerations

3. When an engine failure occurs in flight, two courses of action are generally available to the captain:

a. To abandon the aircraft where parachutes or ejection seats are fitted.

b. To land at the nearest airfield or on the best available terrain.

4. Landing on an unprepared surface would probably entail severe damage to the aircraft. It may, therefore, be wiser to abandon the aircraft to ensure the safety of the crew. In some aircraft types, the Aircrew Manuals advise against an attempted landing unless the selected terrain area is known to be suitable and recommend abandonment. However, the types of emergency which can be encountered are many and varied and it is possible that on some occasions there may be no other option but to land. In such cases, the procedure to be adopted depends on the circumstances prevailing at the time, but the main considerations are:

a. Whether or not engine power is available.

b. The height above ground.

c. The aircraft handling characteristics.

d. Weather.

e. Nature of terrain.

f. Light and visibility conditions.

g. Whether to land with the undercarriage raised or lowered.

5. Sound airmanship can either obviate the need for a forced landing or, if one is inevitable, give the pilot the best chance of completing it successfully. Such points of airmanship are:

a. Thorough pre-flight planning, including a review of the weather expected for the flight, a check on the main features of the terrain over which the aircraft is to fly, the radio aids available at each stage and the correct action to take if diverted.

b. Conscientious preparation of the aircraft for flight.

c. Strict adherence to the flight plan and, if flying without a crew, maintaining a mental plot of position during flight and verifying this by the sensible use of best fixing aids available

d. Noting the type of terrain over which the aircraft is flying so that, if a forced landing becomes necessary, as little time as possible need be spent in searching for a suitable landing area.

6. When faced with a potential forced landing, the decision as to the best course of action must be made quickly. Frequent practice of emergency drills and procedures gives the crew the best chance of performing the correct drill instinctively should an emergency arise. When an emergency arises, the captain should not hesitate to request assistance by radio, using whatever degree of priority is deemed necessary, using the procedures outlined in Volume 8, Chapter 8.

Forced Landings

7. The various types of forced landings can usually be considered under two main headings:

a. Precautionary landings.

b. Forced landings without power, or with partial power.

The first deals with situations where the pilot has power available to control the aircraft down to the point of touchdown on a chosen landing area. The second deals with the instances where the pilot has to rely on judgement and skill alone because if there is any power available, it will be only enough for relatively small corrections to the descent path and not enough for a normal circuit and landing.

Precautionary Landings

8. The circumstances of a precautionary landing may vary from the relatively simple condition of landing in good visibility at a diversion airfield, to landing in poor weather in a restricted area such as a field in open country. Certain light aircraft can land safely in grass fields, but generally, precautionary landings are only practised or carried out on airfields.

Forced Landings without Power

9. Engine reliability is such that forced landings without power rarely occur. However, complete engine(s) failure in an operational aircraft type will generally lead to abandonment. Some aircraft, notably those used for training, may be able to make successful landings without power and the following procedures apply mainly to them.

10. The procedure for a power-off forced landing depends on the particular aircraft and the flight circumstances when engine failure occurs, e.g.:

a. Immediately after take-off, or when flying at very low level with insufficient surplus speed to gain height, or when flying beneath low cloud.

b. At higher altitudes.

c. Failure of one or more engines on a multi-engine type, when the pilot is unable to maintain or gain height and has no alternative but to land.

11. **Engine Failure after Take-Off**. For twin and multi-engine aircraft, see Asymmetric Flight Performance at Volume 8, Chapter 24. On single-engine aircraft, if the engine failure occurs soon after becoming airborne, the throttle should be closed, and a landing made straight ahead. Care should be taken to maintain gliding speed and moderate changes of heading can be made to avoid obstacles or to turn into wind. If the area ahead does not appear to be suitable, pilots of aircraft fitted with ejection seats may decide to abandon the aircraft, provided the speed and height are above the minimum laid down for safe ejection and the aircraft is in level flight.

12. **Turn-Back Manoeuvre**. In those aircraft types where a turn-back manoeuvre is permitted, it should be considered if the height, speed, wind strength, runway length, etc are within limits. However, this manoeuvre calls for a high measure of skill and judgement and should only be attempted by experienced pilots. The primary aim is to land somewhere on the airfield, as this is usually the largest

area available which is comparatively free from obstructions. Ideally, an attempt should be made to land on the reciprocal of the departure runway but, in some cases, an alternative runway may be reached with comparative ease. An operating authority may authorize and require the practising of the turn-back manoeuvre only by suitably qualified pilots, depending on such factors as the low-level ejection capability of the aircraft, the relative positions of other possible landing sites, built-up areas such as married quarters, or local towns and villages.

13. **Engine Failure at Low Altitude**. Engine failure when low flying has virtually the same implications as those outlined in paragraph 11, except that there will probably be excess speed available which can be converted to height or horizontal distance thus giving the pilot a greater choice of landing area, or more time in which to transmit a distress call and abandon the aircraft.

14. **Engine Failure at Altitude**. Unlike an engine failure on take-off, where very rapid emergency actions are required, engine failure at height usually gives more time to assess the situation. It may give time to find the cause of the failure and even to remedy it, and to select from a number of landing areas. If partial power is available, a forced landing should be planned for in case the failure becomes complete. In such circumstances, it would be most unwise to try to reach a distant airfield. However, if an airfield is reasonably near, and the intervening area no worse for a forced landing than that below the aircraft when the failure occurred, eg over the sea, it would be logical to attempt to reach that airfield.

15. **Possible Causes of Engine Failure**. When an engine fails, the pilot should first select a landing area and turn towards it, and then attempt to locate the cause of the failure and, if possible, rectify the fault.

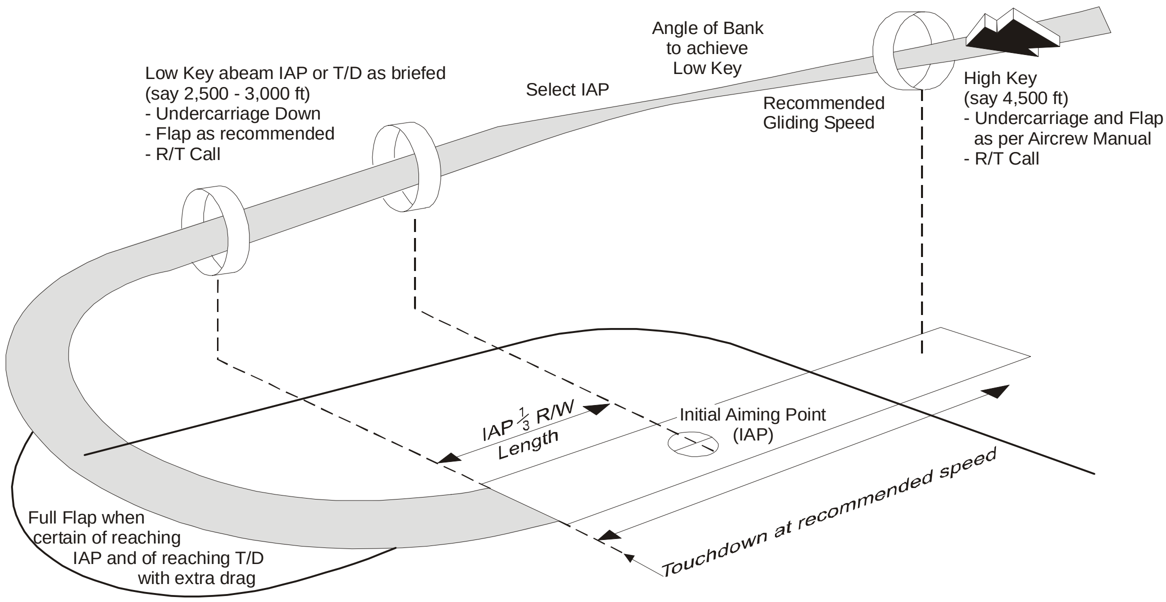
16. **Selection of Landing Area**. When making a forced landing without power there is only a limited amount of time in which to identify a suitable landing area. Generally, an active airfield runway should be used, but a disused airfield may be an option. For light aircraft, any suitable surface that is long and into-wind should be chosen.

17. **Wind Velocity**. Before take-off, a mental note should be made of the lower wind velocities along the route. During flight, the surface wind velocity should be checked regularly by reference to indications on the ground such as smoke. This knowledge can be of great value if the need for a forced landing arises.

18. **Circuit and Approach**. The circuit and approach pattern for a forced landing varies widely between types of aircraft and is primarily decided by the rate of descent in the glide and the gliding speed. The forced landing pattern for any type of aircraft can be built up on two 'key' points; one high, one low. An example pattern for a particular aircraft type landing on a 6,000 ft runway is illustrated in Fig 1. If the emergency occurs at a height lower than 'High Key', then 'Low Key' will be the first checkpoint. When practicing forced landings, it should be remembered that allowance must be made for the strength of the wind. To this end, the Low-Key point should be sited so that the final approach to the touchdown point can be made using a wide turn (for little or no wind) or a more direct course (for a strong wind). As a safeguard against undershooting, an initial aiming point (IAP), situated at one third of the landing distance, upwind of the threshold, should be considered as the touchdown point at the commencement of the procedure. As the aircraft progresses round the pattern, the touchdown point can be re-adjusted back to the threshold area by the use of flaps when the pilot considers it safe to do so. At all times, the landing area should be kept in view and all turns should be towards the field. Violent S-turns on the final stages of the approach should be avoided as the loss of height in such turns may be excessive. By establishing a

Low-Key point, and keeping a constant sight-line angle, the pilot can adjust the approach by turning early if undershooting or delaying the turn if too high.

8-6 Fig 1 A Forced Landing Pattern Showing Key Points



19. **Typical Forced Landing Procedure**. After an engine failure, the pilot should choose the landing area quickly and turn towards it before trying to locate and remedy the cause of the failure. The FRC drills should be carried out, a distress call transmitted, and crew or passengers should be ordered to prepare for a forced landing. The approach should be flown at the FRC/Aircrew Manual recommended gliding speed. After landing, the appropriate FRC drills should be carried out and the aircraft vacated as quickly as possible.

20. **Radar/TACAN Forced Landing**. If engine failure occurs in or above cloud the pilot may use information from a radar controller or TACAN to home towards a suitable airfield and fly a descent pattern to break cloud in a position from which a visual forced landing can be carried out. Weather minima for this type of procedure are stipulated by the operating authority. If the weather is below the minima, the aircraft should be abandoned.

21. **Forced Landings at Night**. The actions to be taken after engine failure on take-off at night are the same as those for daylight, with the addition that the landing lights should be switched on. If engine failure occurs within gliding distance of an airfield and the runway can be seen, a forced landing without power may be justified. If the failure occurs beyond gliding range of an airfield, the aircraft should be abandoned.

Other Landing Emergencies

22. Abnormal landings are covered in the emergency section of the FRC and Aircrew Manual for the particular aircraft type. If a landing is permitted under the particular emergency, then generally a reduction in weight, jettisoning of tanks and stores and whether the canopy should be closed, opened or jettisoned are the usual considerations.

23. **Undercarriage Considerations**. The captain must make the decision whether or not to lower the undercarriage for a forced landing in a particular emergency. It is generally better to land with the wheels down, as the initial landing shock will be cushioned by the undercarriage. However, a longer landing run

will result and although the brakes can be used fully, and the aircraft steered, if there are obstacles ahead that cannot be avoided, it may be necessary to retract the undercarriage to stop the aircraft.

24. **Landing with Wheels Up**. If a wheels-up landing is necessary, it should be made on the runway and not on the grass. Less damage is incurred landing wheels-up on a runway and there is less risk of injury to the crew. A normal approach and gentle touchdown should be made at the normal speed. With swept-wing aircraft approved for a wheels-up landing, it is important that the touchdown speed is not lower than the usual speed so as to avoid touching down in a marked nose-up attitude. An excessively high nose-up attitude may cause the nose to drop rapidly on impact, resulting in possible spinal injuries to the aircrew.

25. **Cushioning**. Lowering a tricycle undercarriage ensures that any heavy impact caused by the nose pitching down on landing is cushioned by the nosewheel and the landing impact is absorbed by those parts of the aircraft intended for this purpose.

26. **Landing with One or More Wheel(s) Unlocked**. If one or more undercarriage legs fail to lower or lock down, subsequent actions depend on the circumstances, the type of aircraft, the experience of the pilot and the restrictions given in orders or the Aircrew Manual. Some aircraft sustain least damage from a wheels-up landing, others from a landing on the remaining wheels. Some aircraft may not be landed with the undercarriage unlocked and must be abandoned. If committed to a landing where a main undercarriage leg has failed to lock down, a normal approach and landing should be made. The runway with the largest possible area of unobstructed ground on the side of the unlocked undercarriage leg should be used since the aircraft may travel as much as 400 metres from the runway before stopping. Immediately after touching down, the engine(s) should be stopped and the fuel and electrical power isolated, provided this can be done without prejudicing the success of the remaining landing run. The ailerons should be used to prevent the wing dropping for as long as possible. When the wing does eventually drop, the aircraft will swing towards the unlocked wheel. Careful use of brakes may help to control the swing.

27. **Landing with Nosewheel Not Locked**. If the nosewheel fails to lower or lock down the subsequent actions depend on circumstances. The nosewheel may have been prevented from lowering by snagging on an obstruction in the wheel bay. Where possible, the main wheels should be bounced on the runway on a roller landing in an attempt to free the nosewheel. If committed to a landing with the main wheels locked down and the nosewheel unlocked or up, the nose should be lowered gently onto the runway before elevator effectiveness is lost. Once the nosewheel is on the runway, the wheel brakes can be applied. Immediately after touching down, the engine(s) should be stopped and the fuel and electrical power isolated. Less damage results from this type of emergency when a hard runway is used instead of grass. On certain aircraft (see Aircrew Manuals) least damage will result from a wheels-up landing.

28. **Landing with a Burst Tyre**. To land with a burst tyre the pilot should fly a normal wheels-down landing unless the Aircrew Manual for the type advises otherwise. The landing should be made on the runway and, after touchdown, the wing on the burst tyre side should be held up with aileron. Asymmetric use of wheel brakes and, in the case of multi-engine types differential use of power, may be necessary to minimize swing after the burst tyre has settled on the runway.

29. **Landing without Wheel Brakes**. Most aircraft need the assistance of wheel braking to stop in the length of the runway available unless the runway is very long and the wind is strong. If the wheel brake system has failed, a safe wheels-down landing may still be possible in suitable conditions. The main factors to be borne in mind are:

a. Where possible a diversion should be carried out to an airfield having the longest into-wind runway and a suitable aircraft arresting system.

b. The runway threshold should be crossed at the correct speed with touchdown achieved just past the threshold.

c. On an airfield without an arresting system, the nosewheel should be held high off the ground on landing to obtain the maximum drag, and the engine(s) stopped. Additional drag may be obtained by opening airbrakes. If fitted, the braking parachute should be deployed in the normal manner after touchdown, or if available, the maximum use made of reverse thrust.

d. On an airfield with an arrestor barrier, aircraft cleared to engage which have nosewheel steering may use the techniques described in sub-para c. provided that a subsequent clean entry into the centre of the barrier is not jeopardized. An engine may have to be kept running to provide the necessary hydraulic power for the nosewheel steering. If nosewheel steering is not available, consideration must be given to maintaining enough speed to ensure rudder effectiveness since a barrier engagement at relatively high speed is preferable to a premature departure from the side of the runway. The canopy must remain closed if a barrier engagement is contemplated.

e. In light winds, the runway giving the best combination of length of run and up-hill gradient should be used.

f. If it becomes evident that the landing distance will be inadequate, the wheels should be retracted. This will normally entail the operation of an override system.

Human Factors and Forced Landing

High stress levels may be experienced and possibly lead to a loss of situation awareness. Knowledge of SOPs and familiarity with the potential scenarios are essential.

CHAPTER 7 - DITCHING

Introduction

1. The ditching characteristics of aircraft vary considerably between types. In general, the larger, transport-type aircraft are likely to survive a ditching better than training or fighter types. It is usually better to abandon the aircraft rather than ditch, as an unsuccessful ditching always has serious consequences.

2. Aircrew Manuals recommend the handling procedures to be adopted when ditching cannot be avoided. This chapter is a general guide to the techniques to be used.

Safety and Personal Equipment

3. **Built-In Liferafts**. On the larger type aircraft, liferafts are carried in built-in stowages and are released either automatically when the aircraft ditches or manually by a crew member. In the multi-crewed aircraft case a crew member should be detailed to assist the liferaft into the water and prevent it from being damaged by the aircraft structure.

4. **Valise Liferafts**. Valise liferafts stowed in the aircraft should be launched by a crew member through one of the escape hatches. It is essential to check that the cord operating the CO_2 bottle which inflates the liferaft is attached securely to the aircraft so that when the valise is thrown into the water, the cord is pulled taut and the CO_2 released. Whenever possible, the liferaft should be launched on the down-wind side to facilitate its clearance from wreckage and to reduce the risk of entanglement with the sinking aircraft.

5. **Lifepreservers**. Lifepreservers are to be worn or carried, by all occupants of aircraft flying over the sea or over land when there is a risk of ditching or a parachute descent into water. In the case of high performance aircraft, lifepreservers are to be worn at all times. Individual commands will issue instructions for those aircraft in which the wearing of lifepreservers is mandatory. Lifepreservers should only be inflated after leaving the aircraft.

6. **Other Personal Equipment**. Before ditching, parachute harnesses, but not combined harnesses, should be removed when practicable; if not removed, then the parachute harness should be released. Helmets should be retained for protection in the liferaft. When an automatic pressure demand oxygen system is fitted, the oxygen mask should be kept in place, 100% OXYGEN selected; this allows the crew member to breathe should it be necessary to escape from a submerged aircraft.

Assessment of Sea State

7. From the air, water always appears to be calmer than it really is. In particular, swell can only be properly appreciated close to the surface and swell may be of far greater consequence in ditching than the more obvious but smaller waves which are caused by the immediate action of the wind.

8. Swell is the undulating movement of the surface caused by past or distant winds. The direction of the swell does not necessarily bear any relation to the surface wind. If the wind is not moving with the swell but across it, a “cross sea” is created with waves running in a different direction from that of the swell.

9. The wind direction may be indicated by wind lanes, ie the streaked effect made on the surface as the wind ruffles the water. When the surface is unbroken, gusts may sometimes ripple the surface in great sweeps which indicate the direction of the wind.

10. If possible, fly low over the water and study its surface before ditching. Captains of aircraft should endeavour to bear in mind the state of water and wind at all times, rather than leave observation and estimation until an emergency arises.

Direction of Approach

11. The aircraft should always be ditched into wind if the surface of the water is smooth or if the water is smooth with a very long swell. If there is a danger of nosing into the waves or there is a short swell of less than twice the fuselage length, it is advisable to ditch along the swell aiming to touch down on the crest or back of the swell, accepting the higher touchdown speed and the resultant drift. A direction of approach which is a compromise between waves, swell and wind direction may be the best choice. The limiting condition is that in which the drift in a cross-wind ditching cannot be counteracted while maintaining control near the stall; if it is known that the aircraft is likely to nose in, the ditching should be made into-wind to reduce the violence of impact.

Judging Height

12. Judging of height over water is difficult, especially when it is very calm or at night. The aneroid altimeter is unreliable for this purpose and the radio or radar altimeter, when fitted, should be used in preference to other methods, particularly at night. During night ditchings the landing light(s) may be helpful in gauging height. It must be borne in mind however, that the bright light may upset the pilot's night vision and in mist the reflection causes a glare which may obscure the surface of the water.

Aircraft Handling

13. Aircrew Manuals give the correct procedure for a given type of aircraft, but the following general considerations apply:

a. Jettison all stores, cargo and drop-tanks if appropriate and, if possible, as much fuel as time permits providing the aircraft C of G remains in mid range. Aircrew Manuals advise on whether or not to jettison the canopy: some aircraft are best ditched with the canopy closed, jettison action being taken after the aircraft has come to rest.

b. The speed and rate of descent should be as low as possible consistent with safe handling, yet adequate to allow a margin after rounding-out, so that sufficient control is available up to the time of touchdown to prevent the tail striking a wave crest or swell top which might cause the aircraft to nose in.

c. The best compromise in relation to waves, swell and wind should be chosen.

d. The wheels should be retracted. If down, or partially down, every effort should be made to retract, or at least unlock, the undercarriage.

e. A tail-down attitude should be adopted when touching down by holding off until excess speed is lost. The speed at the instant of impact should be as low as possible to reduce the subsequent deceleration and the amount of damage to the aircraft.

14. **Use of Flap**. Normal landing flap should be lowered to reduce the touchdown speed prior to ditching. If lowering landing flap impairs the ditching characteristics of the aircraft and also gives an undesirably high rate of descent, then an intermediate setting should be used. The aircrew manual gives the recommended settings.

15. **Use of Power**. The value of power during ditching is so great that when it is certain that the coast cannot be reached, the captain, having decided to ditch, should always do so before fuel is exhausted.

Provided control can be maintained, power should be used to ensure the flattest approach and the slowest touchdown speed. If appropriate the propellers of failed engines, or of engines not needed during the approach, should be feathered.

16. **Lights**. Before ditching at night, all cockpit lights should be dimmed to accustom the eyes to the external darkness. To facilitate the escape of passengers, in large transport types, cabin lights should be left on if practicable. After ditching, all lights should be left on as an aid to search aircraft should the aircraft remain afloat, and to assist when collecting equipment and boarding the liferaft.

Behaviour of the Aircraft on Impact

17. An aircraft ditching in a tail-down attitude will usually encounter a small initial impact as the rear of the aircraft strikes the water. A much more severe second impact and violent deceleration will usually follow as the aircraft is pitched forward and the nose will tend to bury as the aircraft comes to rest. The aircraft may also slew to one side after impact. From the first impact to the time the aircraft comes to rest, the control column should be held steady as any attempt to control the pitching movements may exacerbate the situation. The crew should not relax or move until the aircraft has come to rest.

Preparation for Ditching and Survival Aspects

18. Appropriate FRCs, operating authority SOPs, and Aircrew Manuals should be consulted for details of aircraft and crew preparation for ditching.

Human Factors and Aircraft Ditching

Keep to SOPs and FRC drills to maintain Situation Awareness. Beware with perception of height as the eyes will fool the unwary. Perception of height may be challenging. Make maximum use of cockpit indications and use any visiual references available such as boats or ships.

CHAPTER 8 - DISTRESS and EMERGENCY ACTION

Introduction

1. Emergencies can occur in flight at any time and without warning. It is important therefore that all aircrew have a sound knowledge of distress and emergency action so that, should the occasion arise, their response is swift and thorough. This chapter deals with various emergency procedures and outlines the emergency organization of the RAF. Reference should be made to the Flight Information Handbook (FIH) and to CAP 413, The Radio Telephony Manual.

EMERGENCY PROCEDURES

Degrees of Emergency

2. Degrees of emergency are internationally classified as being of two standards:

a. **Distress**. "A condition of being threatened by serious and/or imminent danger and of requiring immediate assistance".

b. **Urgency**. "A condition concerning the safety of an aircraft or other vehicle, or of some person on board or within sight but which does not require immediate assistance".

Emergency Transmissions

3. A transmission to be made in an emergency consists of two parts: the emergency call and the emergency message. Pilots are urged to request assistance from the emergency service as soon as there is any doubt about the safe conduct of their flight. If subsequently a pilot considers the problem not to be as serious as first thought, the emergency condition can be cancelled or downgraded.

a. **Emergency Call**. Table 1 sets out the content of the radio telephony (R/T) Urgency and Distress calls. (Refer also to CAP 413, the CAA Radiotelephony Manual).

Table 1 Emergency Calls

Degree of Emergency	Proword (R/T)
Distress	"Mayday – Mayday – Mayday”
Urgency	"Pan Pan – Pan Pan – Pan Pan“

b. **Emergency Message**. The emergency message should include as much of the following information as is relevant and as time permits:

(1) Callsign.
(2) Type of aircraft.
(3) Nature of emergency.
(4) Captain’s intentions and assistance required.
(5) Present or last known position, flight level/altitude and heading.
(6) Pilot qualifications (if relevant e.g. Student Pilot/Instrument Rating etc).
(7) Any other useful information (e.g. persons on board/endurance/aircraft colour etc).

Receipt of the full emergency message will enable agencies to identify the most probable search area for an aircraft in distress in remote areas (e.g. oceanic regions). Although the information should ideally be given in the order listed, the transmission should not be delayed merely to arrange the details correctly. In a sophisticated ATC radar area, such as NW Europe, where the aircraft position is indicated by SSR, the emergency call (which includes the callsign) may be followed by a minimized emergency message, consisting of 'Type', 'Nature of emergency' and 'Intentions' (TNI), plus any other pertinent information.

Emergency Procedures and Fixer Services

4. If an emergency occurs when the pilot is in radio contact with an ATC agency, the emergency call and message should be transmitted on the frequency in use.

5. In the UK, a military pilot, not in contact with an ATC agency when the emergency occurs, should use 243.0 MHz as the primary emergency frequency, and 121.5 MHz as the secondary frequency. Within Continental Europe, the emergency call should be addressed to the nearest suitable agency.

6. **Use of Secondary Surveillance Radar (SSR)**. If an emergency occurs when in contact with an ATC agency, the SSR code already set should remain in use unless advised by ATC. Within the UK, military pilots of aircraft not receiving an ATC service should set their transponder to Mode 3/A code 7700 to indicate an emergency. Code 7500 reports 'unlawful interference' and code 7600 indicates a total radio failure.

7. **Final Transmission**. When ditching, crash landing or abandonment is imminent the aircraft callsign should be transmitted and, where possible, the transmit control switch should be left in the transmit position. These actions should not take priority over abandonment if life would be endangered by so doing.

8. **UHF/VHF Emergency Fixer Service**. Within the UK FIRs a network of stations provides an emergency fixer service. The positions of these stations and the approximate UHF coverage are shown in the FIH. Emergency frequency transmissions are picked up by stations within range. Each station then automatically relays to the ATC Centre (ATCC) the bearing measured to the distressed aircraft. These bearings are all displayed on a screen, giving the controller an instant 'fix' on the aircraft. Auto-triangulation on 243 MHz is accurate at or above 5,000 ft within the London FIR, but at or above 8,500 ft in the Scottish FIR. The VHF service on 121.5 MHz covers most of the landmass to the East and South of Manchester down to 3,000 ft and, in the vicinity of London, down to 2,000 ft. In the Scottish FIR the VHF coverage is the same as for UHF but may be between 2,000 to 5,000 ft over the sea, in lowland areas and and around the Scottish TMA. Transmissions from the ATCC to the aircraft are relayed through the forward relay system, thus extending the range of the ATCC communications equipment.

9. **Cancellation**. Should the emergency cease to exist it is most important that a transmission be made to cancel the original call on the frequency or frequencies on which the call was made.

10. **Search and Rescue Satellite Aided Tracking (COSPAS/SARSAT) False Alarms**. *COSPAS* /SARSAT is an alert and location system detecting transmissions on 406 MHz. The system utilizes 4 near-polar orbital and various geostationary satellites. The near-polar satellites operate to a location accuracy of better than 5 nm but may take up to 90 mins to detect an emergency beacon after activation. The geostationary satellites will detect transmissions almost instantaneously but require positional information to be included in the transmission.

Emergencies Involving Another Aircraft

11. **Observing an Emergency**. An aircraft observing another aircraft or personnel in distress should, if possible, take the following actions:

a. Keep the aircraft or personnel in sight and switch IFF to emergency. At sea, if a surface vessel is in sight and can be contacted without losing sight of the distressed personnel, guide it to the position.

b. If there is any doubt that a distress message has already been transmitted, or if the person observing the distressed personnel/aircraft believes that further help is needed, a message containing all the relevant information should be transmitted to the controlling ground station on the frequency in use. This message should be preceded by the following:

"Mayday Relay" (3 times) this is Aircraft Callsign

c. The captain should then comply with any special instructions given by the controlling authority or remain in sight of the distressed personnel/aircraft until circumstances compel departure.

12. **Relaying of Distress Messages**. If a distress call or message is intercepted, the following actions should be taken:

a. If possible, take a bearing on the transmission and attempt to plot the position of the sender.

b. Listen out on the frequency used.

c. If no acknowledgement of the distress message is heard, call the aircraft in distress and acknowledge receipt. Retransmit the distress message preceded by the call in para 11b (1).

d. Listen out for instructions from the ground and further transmissions from the distressed aircraft, and act as necessary.

e. At the captain's discretion, proceed to the position mentioned in the distress message while awaiting instructions from the ground station.

Navigation and Meteorological Warnings

13. International military rules still accept the Safety Message. However, it is not classified as an emergency message and is not recognized by ICAO. Nevertheless, once transmitted, it is unlikely to be ignored by the receiving agency. The proword SECURITÉ (spoken 3 times on R/T) precedes a Safety Message which may be used to give information concerning the safety of navigation or to give important meteorological warnings.

Communications Failure

14. Detailed actions in the event of communications failure are contained in the FIH and En-route supplement (ERS) for the area of operation. The following sentences précis the actions to be taken. Pilots losing 2-way communications should set the transponder to Mode 3/A Code 7600. Flight conditions then generally determine the procedure. In VMC and in visual contact with the ground the flight should be continued in VMC to land at the nearest suitable aerodrome. As soon as possible after landing, ATC should be informed. In IMC, or anticipated IMC conditions, if the aircraft can be safely navigated, the flight should be continued in accordance with the current flight plan; see the appropriate ERS for detailed instructions. In all cases when the receiver only is operative, instructions from ATC should be complied with. If however, the aircraft is in or above cloud and the pilot is unable to navigate safely, he should reset the transponder to Mode 3 Code 7700 and may elect to fly one of the following patterns to alert a ground radar station:

a. If the transmitter only has failed, fly equilateral triangular patterns to the RIGHT, whilst listening out for instructions (see Fig 1a).

b. If both transmitter and receiver have failed fly equilateral triangular patterns to the LEFT (see Fig 1b) and watch for interception by a shepherd aircraft. Two patterns should be flown before resuming course, and then repeated at 20-minute intervals. Radios should be selected to guard emergency frequencies. The aircraft in distress should, if possible, remain clear of cloud, be flown for endurance and should have anti-collision lights on.

8-8 Fig 1 Distress Procedure for Radar Identification

Fig1a – Receiver Only Operating

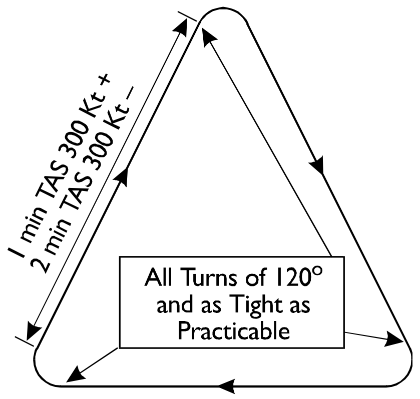
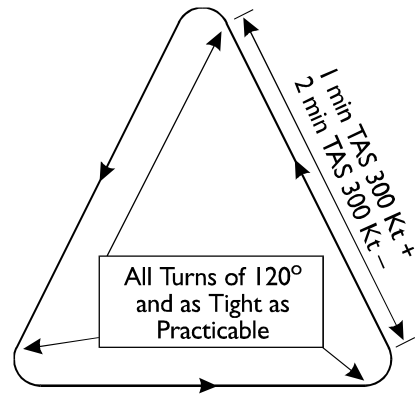


Fig1b.- transmitter and Receiver Inoperative



15. When an aircraft is observed flying right hand patterns, the ATCC will attempt to contact the aircraft on the emergency frequency. If an aircraft is observed flying left hand patterns a shepherd aircraft will, if possible, be despatched to assist it. The shepherd aircraft should position in front and to the left of the aircraft in distress. The shepherd will rock its wings, which should be acknowledged with a wing rock; the shepherd will then start a slow level turn on to course. An attempt should be made to contact the shepherd on 243 MHz.

16. **Speechless Procedure**. If an aircraft is above cloud with an unserviceable microphone, or a radio problem which results in an inability to transmit speech, contact can be established with ATC using the speechless code. When the transmit button is pressed a carrier wave will be transmitted and will be observable on the ATC direction finding equipment. Then, by using the speechless code, it is possible to communicate with ATC as follows:

a. For initial contact, make 4 transmissions as for a Morse 'H' (●●●●), meaning "request homing".

b. One transmission: "Yes" or acknowledgement.

c. Two transmissions: "No".

d. Three transmissions: "Say again".

e. Letter 'X' in Morse (— ●● —): An additional or greater degree of emergency has arisen.

17. **Speechless Let-down**. The speechless let-down procedure is as follows:

a. The transmit button is pressed 4 times as for Morse 'H'. In an emergency select the emergency frequency where possible.

b. The receiving station will pass a course to steer and the speechless aircraft acknowledges.

c. The aircraft is homed to overhead and given a normal controlled descent.

d. During the homing the controller determines the aircraft state by questions requiring "Yes" or "No" answers.

e. During the procedure, the completion of an instruction, e.g. steady on heading or height, is indicated by a two second transmission and also when:

(1) Overhead turn complete.

(2) Steady on inbound heading.

(3) Intermediate approach height.

(4) At decision altitude/height or minimum descent altitude/height.

(5) Aerodrome in sight.

Compass and Gyro Failure

18. The procedures for recovery following failure of compasses and gyros are detailed in The Manual of Military Air Traffic Management (Chapter 4) and are summarized below.

19. **No Compass, Gyro Serviceable but not Correctly Set**. In the event that all aircraft compasses become unserviceable and the directional gyro is not reliably set, assistance can be obtained from ATC. The pilot will be instructed to fly straight and level at a safe height and to make 3 check transmissions at 10-second intervals. The controller will note the bearings from these transmissions and will instruct the pilot to turn on to new refined headings until the 3 transmissions, repeated, give a constant DF bearing. The controller will instruct the pilot to set the bearing on the gyro. A recovery may then be made.

20. **No Compass, No Gyro**. Should the compasses and gyros become unserviceable, the aircraft will be homed to the overhead. A standard controlled descent through cloud is then carried out (if necessary) with all turns at Rate 1 being timed (3º per second) by the controller.

Night Time Emergencies

21. Emergencies which pose additional problems at night include engine failure after take-off, radio failure and total electrics failure. Further details of how to deal with these situations during the hours of darkness are contained in Volume 8, Chapter 26.

EMERGENCY ORGANIZATION

ATCC Distress and Diversion Cell

22. An aircraft in distress may make contact with an ATCC or ATCRU by transmitting an emergency message on the frequency in use, by transmitting on the emergency frequency, by a relay transmission from another aircraft or, after a radio failure by flying the triangular patterns described in para 14.

23. When the ATCC has identified an aircraft in distress, executive authority for the handling of the emergency is passed to the Emergency Controller in the ATCC Distress and Diversion Cell. The aircraft in emergency will normally be transferred to 243 MHz or 121.5 MHz.

Search and Rescue Services

24. In the event of a crash landing or abandonment the emergency controller will advise the Aeronautical Rescue Co-ordination Centre (ARCC) so that the necessary rescue services can be

alerted. The ARCC co-ordinates the activities of all search and rescue facilities which may include SAR helicopters, lifeboats, mountain rescue teams and police and ambulance services.

Human Factors with Distress and Emergency Actions

Human Error accounts for over 40% of aircraft accidents following loss of Situation Awareness where stress may have been a player. Distress and Emergencies are by definition stressful but if drills are carried out methodically in accordance with SOPs and FRCs coupled with sound simulation these situations may not become tragedies. Beware of Focussed Attention when dealing with difficult or emergency situations; don't lose sight of the big picture and remember the basics to avoid further problems.

CHAPTER 9 - AIRCRAFT ABANDONMENT

Introduction

1. In an emergency it should be possible to abandon a military aircraft in flight with a reasonable chance of success. Crew members are therefore normally provided with parachutes and, where appropriate, some method of assisted escape. The exceptions are crew members of military operated passenger-carrying aircraft and aircraft certified to Performance Group A or its equivalent Service group. These aircraft do not need to be configured for in-flight abandonment because they meet the highest standards of safety performance.

2. Military aircraft operate in an extremely large flight envelope - speeds range from zero to well over 1,000 kt, and operating heights from ground level to over 50,000 ft. Escape from aircraft operating in the lower speed range may be possible solely with a parachute, but assisted escape is necessary for those with a wide or high-speed range. Escape systems are designed to aid occupants to get clear of an aircraft and into an environment from which a normal parachute descent is possible.

Conventional Escape

3. Up to about 200 kt, it is possible to escape unaided from an aircraft. At or above 200 kt it becomes extremely difficult and dangerous to escape unassisted. The situation is made worse at any speed if the aircraft is subjected to g forces, e.g. due to a spiral dive. The minimum height at which the escapee must be clear of the aircraft in an unassisted escape is 1,000 ft AGL and it follows that the decision to bale-out must be made at a greater height than this, depending on aircraft type (i.e. difficulty of egress) and rate of descent. At the higher speeds, the slipstream across an exit makes it difficult for the crew member to escape and if he does, it is possible that he will contact a part of the aircraft.

4. **Helicopter Escape**. Most current helicopters are not cleared for the carriage of parachutes, hence escape from them in flight is not possible. Most of the remainder are required to carry parachutes when operating above 3,000 ft or on special test flights. Although helicopters generally fly at speeds below 200 kt, there are many problems associated with clearing the aircraft. Some of these are listed below:

a. Incompatibility of aircrew equipment assemblies with exit path.

b. Inadequate size of escape hatch or door.

c. Failure of the helicopter to stay in a reasonably steady attitude after the cyclic stick has been released.

d. Difficulty in avoiding parts of the airframe after exit.

Assisted escape from helicopters is not provided. Even if the problems listed could be overcome, survival without assisted escape is doubtful from less than 1,000 ft.

Methods of Assisted Escape

5. The current means of assisted escape from fixed wing aircraft is the ejection seat. This has provided many aircrew with a lifesaving facility, but as airspeeds increase, open seats do not give adequate protection against the effects of wind blast.

6. Ejection seats have been developed to provide an entirely automatic escape facility, from ground level upwards, within specified speed limits. The user is required only to initiate the firing sequence, and thereafter all the required operations take place automatically. The firing mechanism first clears the ejection path and then operates the ejection seat. As the seat rises, the seat systems are activated by static rods, services are disconnected, and emergency oxygen turned on. The feet swing back from the rudder pedals due to inertia at the beginning of the upward travel of the seat on its rails, and the legs are restrained close to the front of the seat pan by the automatic action of the leg restraining cords. This prevents fouling of the lower part of the legs on the instrument panel and leg flailing throughout the time that the occupant is exposed to high air blast while he remains in the seat during the subsequent descent.

7. The drogue gun fires about 0.5 seconds after the seat rises; the drogue bullet pulls the duplex drogues from their housing. The drogues stabilize and slow down the seat sufficiently to ensure safe man/seat separation. This occurs 1.2 to 2.3 seconds after ejection or as soon as it is safe (seat deceleration less than about 4g), or at a barometric height of 10,000 ft (3,000 m) or less.

8. Some ejection seats are fitted with rocket packs, which are used to sustain the ejection velocity provided by the cartridges in the ejection gun. The rocket is ignited as the seat leaves the aircraft. The advantages of rocket assistance are:

a. Less ejection force required as rocket increases velocity to 76 m/s (250 fps).

b. Reduced acceleration due to the reduced ejection force of about 11g, and reduced rate of application.

c. Increased trajectory, giving a zero height/zero speed capability which is also beneficial in conditions of low altitude and high sink rate.

Pre-ejection Considerations

9. Many aircrew have failed to survive emergencies which occur at an altitude sufficiently high for a successful escape to be made simply because the decision to eject was taken too late. In single or twin-seat aircraft the decision must be made above the minimum safe ejection altitude (MSEA).

10. **Minimum Safe Ejection Altitude**. It is generally accepted that ejection in straight and level flight at 230 kt and 9,000 ft is the ideal. The rate of descent and aircraft attitude each have an adverse effect on the MSEA, the rate of descent overriding the factor of aircraft attitude except when very close to the ground. The following time increments are critical:

a. **Decision Time**. This is the time taken for aircrew to evaluate the emergency and to inform other crew members. The acknowledgement of orders also affects decision time.

b. **Crew Reaction Time**. This is the time taken to react to the order to eject and to operate the ejection seat.

c. **Time for Equipment to Function.** This is the period from initiation of ejection until the seat clears the cockpit.

d. **Time for Full Operation of the Seat**. This is the time from seat initiation until the aircrew member is descending vertically on a fully deployed parachute.

Note. It is important that aircrew are aware of the fact that an ejection seat with a ground level capability may have a minimum safe ejection altitude of several thousand feet when escape is attempted in other than straight and level flight. The MSEA will be greatest in a high-speed vertical dive; a reasonable approximation is to allow 10% of the rate of descent. Other minima for particular aircraft and situations may be published in Aircrew Manuals and appropriate orders.

Ejection Drill

11. Ideally, the position which the individual adopts, to carry out the task in reasonable comfort, should be that in which the seat can be fired without further adjustment, with a high probability of successful uninjured escape.

12. Pre-ejection drills for individual aircraft are to be found in the appropriate Aircrew Manual, but the ejection handle should, in all cases, be grasped firmly and pulled to the full extent of the operating cable (25 mm to 120 mm or 1 in to 5 in). The pulling action will tend to place the body in an acceptable ejection posture. If time permits, the harness and negative g strap should be checked for tightness (although the shoulder harness should not be over-tightened), and the head pressed against the headrest.

Posture During Ejection

13. The posture of the body is extremely important in determining whether the ejectee will escape uninjured and is directly related to the correct strapping-in procedures. If the back is correctly positioned and supported during ejection by a correctly adjusted restraint harness, it can safely tolerate the accelerations imposed on it by the 24.4 m/s (80 f/s) ejection guns. Poor posture could result in injury even with the lower acceleration of rocket-assisted seats.

14. The back is at its strongest, and thus more able to withstand loads such as those caused by ejection, when it is in its normal position, i.e. straight when viewed from the front and slightly curved like an elongated 'S' when viewed from the side. In the normal position, the back can withstand accelerations of up to 30g at a rate of application of over 300 g/s. If the back is bent or twisted, this figure can fall to 9g to 14g at rates considerably less than above. Poor posture may cause compression fractures of the back, but only very rarely produce spinal cord damage.

15. The nature of the seat pack through which the ejection accelerations are transmitted, the support afforded by the seat back, and the effectiveness of the restraining harness are of the utmost significance in seat ejection. The user can only adopt and maintain a posture as good as the equipment will allow.

a. **Personal Survival Packs**. There is a variety of personal survival packs currently installed as items of aircraft equipment in ejection seats. The main characteristics of these packs are:

(1) **Comfort**. As well as ensuring good ejection characteristics, it is important that the personal survival pack is correctly contoured, and therefore comfortable. In long-range aircraft, this factor is of great importance since the degree of comfort has a marked effect on the efficiency of the user. Moreover, from the ejection point of view, the user is more likely to remain in the correct position on the seat if it is correctly shaped and comfortable. Comfort is improved by the limited slip quality of the top surface, since this permits small movements, when desired, to ease pressure points.

(2) **Shape**. The pack should be of such a shape that it is located firmly in the seat pan, but at the same time is capable of unhampered separation from the seat during the process of

escape. Its top surface should be shaped so that it encourages the user to sit correctly in the best position towards the back of the pack.

(3) **Contents**. The contents of the personal survival pack range from the bulky rubber life raft and its accessories, to small hard objects. These are contained in a rigid box, and the packing of the objects in the container is particularly critical to ensure constant shape and ejection characteristics.

b. **Restraining Harness**. Ejection seats are fitted with a combined harness system. It is important that the harness system is adjusted correctly to ensure the maintenance of good posture during the escape sequence. The location of the straps and harness fastening in their optimum positions, and the correct sequence of tensioning of the system, will restrain the occupant, and also maintain body position.

Post-ejection Considerations

16. As the seat and occupant leave the aircraft they may be exposed to the following stresses:

a. **Wind Blast**. When the seat clears the aircraft, the occupant is exposed to the ram effect of the slipstream. This is proportional to the IAS. At indicated speeds up to about 350 kt, wind blast is not likely to cause injury. As speeds increase above 350 kt, there is an increasing likelihood of injury unless appropriate restraint is provided. The upper limit for the open seat appears to be about 650 kt.

b. **Sudden Deceleration**. On entering the slipstream, the seat and its occupant undergo a marked deceleration caused by the wind drag; the higher the IAS, the greater the deceleration effect. For a given IAS, the maximum linear decelerations are not affected by altitude. As the ejection altitude is increased, however, the deceleration time is prolonged. This is because, for a given IAS, increased altitude results in a greater kinetic energy (higher TAS) which takes longer to dissipate in the lower density. Ejection seats are provided with a stabilizing system so that this deceleration is linear, otherwise an unstable system would produce a variety of forces on the occupant. There are many factors which affect the drag characteristics of the occupant/seat complex, so that it is not possible to lay down a maximum IAS for safe ejection from the point of view of the deceleration effects. Assuming a maximum safe peak linear deceleration of 35 g, it has been calculated that this might be experienced at an IAS between 600 kt and 700 kt.

c. **Tumbling and Spinning**. Unstable seats would tumble and spin, and the high acceleration loads could cause serious injury to the occupant; seats are therefore stabilized by means of drogues. In most seats, two drogues are used; a small one opening first, bringing the seat into alignment with the relative airflow and pulling out a second, larger, drogue. A g stop is incorporated to prevent separation from the seat and delay deployment of the main parachute canopy until the acceleration loads have been reduced to an acceptable level. During stabilized free fall, spinning or swinging about a vertical axis can occur; this may induce sensations of tumbling and the impression that the drogues have not deployed.

d. **Effects of Environment at High Altitude**. If ejection occurs above the barometric level of the automatic system, a fall to the set altitude occurs before occupant/seat separation and deployment of the main parachute canopy. This allows the seat to descend, stabilized by drogues (eg from 50,000 ft to 10,000 ft in approximately 3.5 mins.) The reasons for this delay are:

(1) To prevent explosive opening of the main parachute canopy at an altitude where the TAS would be high enough to cause severe tearing of the fabric and injury to the escapee (see para 16e).

(2) To keep the time spent at altitude to a minimum, as only a very limited quantity of emergency oxygen is carried, and, in the worst case, the oxygen mask may have been lost due to the wind blast on ejection.

(3) To keep the time spent in the low temperature regions of the atmosphere to the minimum. (Note: a 5,000 m (16,400 ft) barometric capsule may be fitted to any aircraft flying over high land masses.)

e. **Parachute Opening Load**. The opening load of a parachute canopy depends on many factors. These include:

(1) The parachute design (in particular, the length of its rigging (or shroud) lines, the method of opening, the size and shape of the vent and the weight and porosity of the material used).

(2) The altitude and speed through the air at the moment of opening.

(3) The air density and humidity.

The opening load of a parachute canopy is proportional to the square of the TAS (V^2) and, as the terminal velocity increases with altitude, V^2 also increases. Thus, parachute opening loads are very much greater at higher altitudes; even at the minimum barometric altitude of 10,000 ft the opening jerk is very often described as severe. Opening the parachute at higher altitudes, particularly after a short period of free fall, can be hazardous as the load may produce physical injury or exceed the designed loads of the parachute or harness system. Fortunately, parachutes tend to fail safe, in that deployment damage relieves the excessive loading and still leaves sufficient canopy for a safe, and stable, descent.

EJECTION SEAT MALFUNCTION

Action in the Event of Failure to Fire

17. Failure of the seat to fire is a very rare occurrence. However, should it fail to fire at the first attempt, initial efforts should be directed towards obtaining a normal ejection. The firing handle should be pulled again, harder. If the handle is immovable, check that the firing handle safety pin has been removed. Any alternative handle, if fitted, should also be pulled. Where it is thought that the canopy jettison system may be the cause of failure, then jettison the cockpit canopy or, if that is unsuccessful, open the cockpit canopy using the normal aircraft system. If these actions are unsuccessful, the situation should be re-assessed and the original decision to abandon reconsidered, i.e. the actual emergency should be reviewed against the likelihood of a successful manual escape.

Hazards of a Manual Escape

18. The seat and the associated aircrew equipment have been designed specifically for gun ejection. The manual override facility is provided to overcome the failure of the automatic separation which occurs once the seat is clear of the aircraft; it is not designed for escape from the cockpit. It can, therefore, be difficult to leave a failed ejection seat unless conditions are ideal. Moreover, the hazards of snagged straps and clothing etc, and of subsequent impact with parts of the airframe after leaving the cockpit, cannot be discounted.

19. If manual escape from the aircraft is a considered option, the appropriate drill will be published in the FRCs and the Aircrew Manual. The actual drill for escaping from the aircraft varies with aircraft type and the make and mark of the seat fitted. The following factors will have been considered when formulating the recommended procedure:

a. The difficulty in freeing the parachute from its housing.

b. The number and complexity of the attachments between the occupant and seat, all of which must be freed before attempting to escape.

c. The best method of actually getting out of the aircraft and the likelihood of snagging of the straps or being struck by parts of the aircraft during and after the escape.

20. Inverted 'fall-out' escapes are not easy, as freeing the parachute pack from its housing requires considerable strength and agility, even under ideal conditions. Furthermore, high airspeed, g loading, or loss, or partial loss, of control will increase the hazards.

Summary

21. An ejection seat is a very efficient means of abandoning an aircraft. Provided that it is operated within its design parameters and crew members do their utmost to maintain the correct posture, the chance of sustaining serious injury is slight. The manual override device is provided to cater for failure of the automatic sequencing of the seat - a very rare situation.

Human Factors and Aircraft Abandonment

> Your autonomic nervous system really does kick in with the 'Fight or Flight' response to this highly stressful situation. High stress can result in the inability to make rational decisions but can be countered by training and practice. Those simulator 'ticks in the box' are life savers; don't cut corners.

CHAPTER 10 - EJECTION SEATS

Introduction

1. Ejection seats enable aircrew to abandon equipped aircraft safely in the most adverse circumstances. The seats are fully automatic and very reliable. The development and improvement of seats is a continuous process and for this reason there are many types in use at any one time. This chapter will give a general description of a typical seat and outline the principles of its operation by tracing the sequence of events during an ejection.

General Description

2. The layout of a generic seat is illustrated in Figs 1 and 2 but specific model may differ. To ensure that the ejection seat is as light as possible the main body of the seat is of light alloy construction. The drogue and parachute are housed in a container at the top of the seat. The seat firing handle, a black and yellow striped flexible loop, is situated at the front of the seat pan between the occupant's legs.

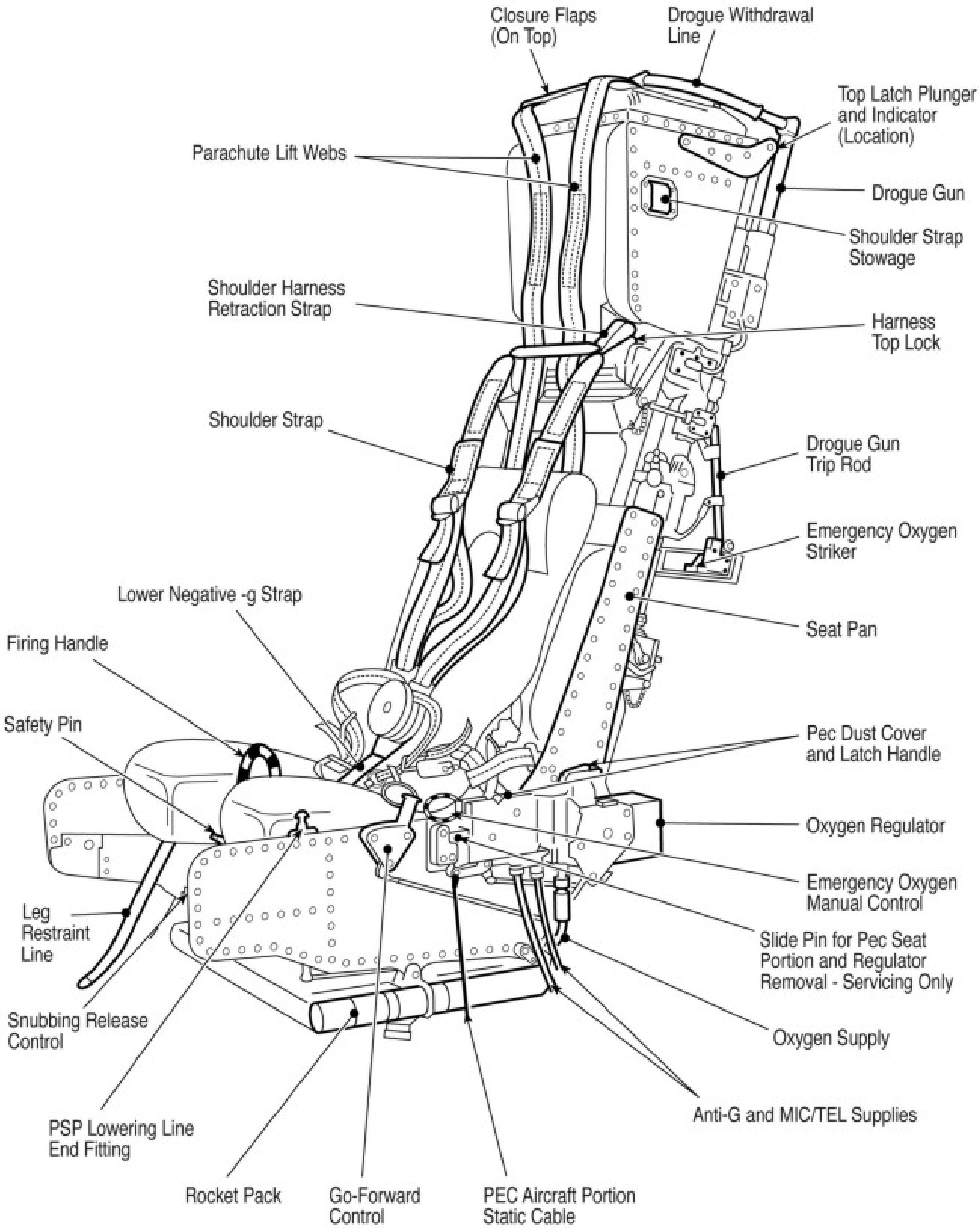
3. The rear structure of the seat carries the ejection gun and two main beams. The gun consists of three telescopic tubes, the outer one of which is attached to the aircraft floor. The gun has three cartridges, two secondary cartridges being ignited by the hot gases of the primary cartridge. The two beams ride on guide rails attached to the ejection gun. The beams carry the parachute container and most of the seat operating devices. The seat pan rides on tubes on the main beams and has an upright backrest and a well to hold a personal survival pack (PSP).

4. The seat pan height can be adjusted to cater for occupants of different back lengths.

5. The PSP has a seat cushion attached to the top of its case. The PSP is attached to the parachute harness and has two quick release side connectors. A lowering line connects the PSP to the life preserver of the occupant. During strapping-in, a quick release connector on an attachment strap on the left side of the life-preserver is secured to the end fitting of the lowering line.

6. The harness secures the occupant to the parachute by lift webs integral with the harness, and to the seat by harness locks on the seat. Two sticker straps on the rear of the harness are retained by spring clips on the seat pan. The harness is secured to the occupant by a quick-release fitting (QRF) on a strap, which in turn is locked to the seat pan. The shoulder straps are routed through the leg loops, and the lugs are then locked into the slots in the QRF. Negative-g restraint is provided by a combination of the straps.

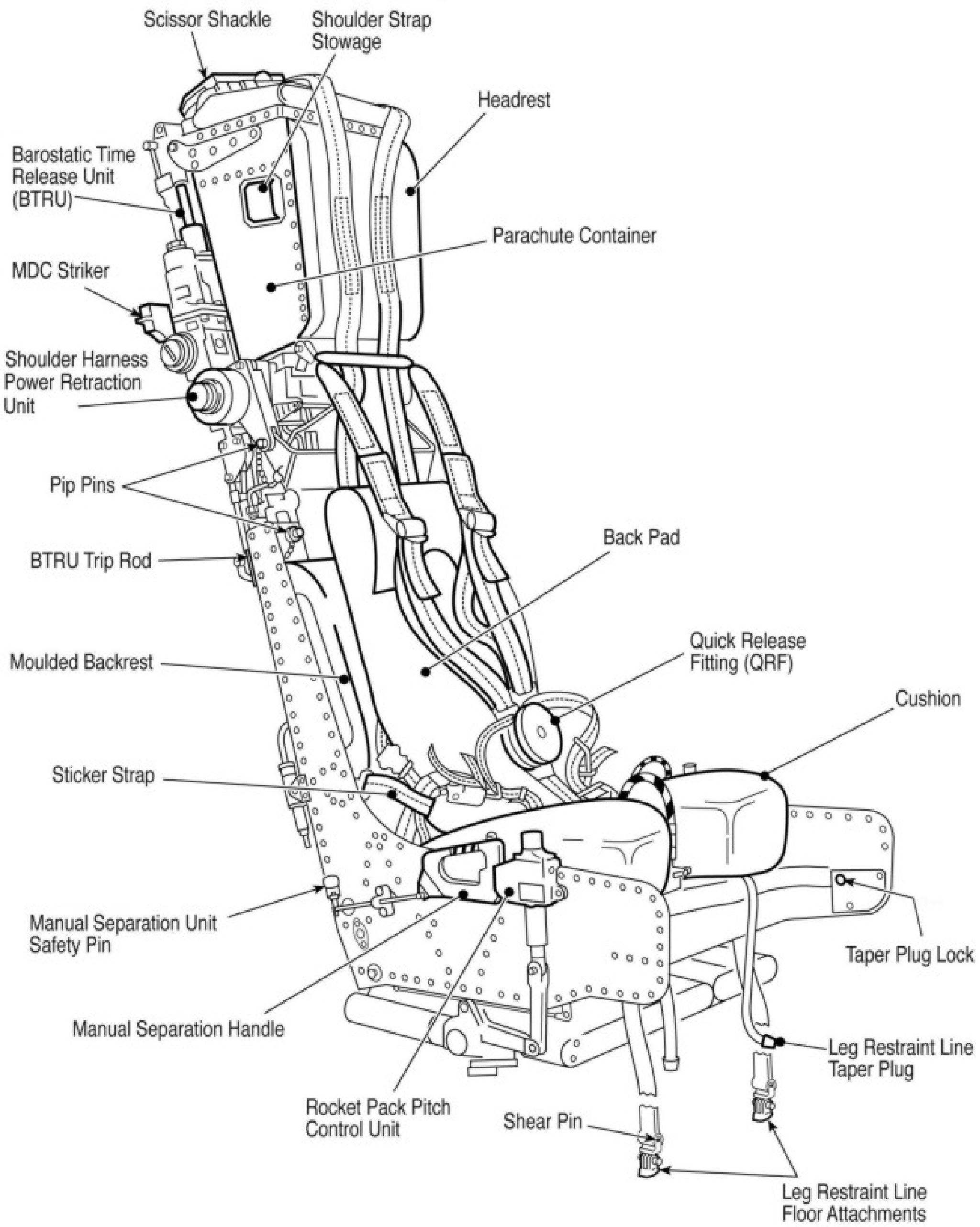
8-10 Fig 1 Ejection Seat - Left Side



7. Shoulder harness power retraction is applied through two looped retraction straps above the seat pan. The retraction straps are attached at one end to individual harness locks and at the other to a cartridge-operated power retraction unit. The retraction unit has two spring loaded spools around which the straps are wound, and a ratchet mechanism which can lock the spools to prevent extension of the straps. The ratchet can be released by a go-forward lever on the left side of the seat. When the lever is forward, the occupant can lean ahead against the spring pressure by a small amount.

8. The harness lock release system frees all of the occupant/seat connections automatically after ejection or when the manual separation handle is pulled.

8-10 Fig 2 Ejection Seat - Right Side



9. The leg restraint system prevents the legs from flailing during ejection. Cords are attached by shear pins to the aircraft floor and are routed through one-way snubber units in the seat pan and rings on the occupant's leg garters to taper locks on the seat. The snubbers allow the lines to be tightened as the seat rises and the shear pins break when the legs are restrained. The snubbers maintain their grip until occupant/seat separation. Arm restraint is also provided on some seat/aircraft fits.

10. The firing handle is the means by which the ejection process is initiated.

11. The drogue gun, on the top left side of the seat, is fired by a trip rod which is attached to the aircraft. The drogue gun ejects a piston which removes a pin that secures closure flaps on top of the parachute container and then deploys the drogue. The drogue gun has two separate cartridges, one mechanically fired by the trip rod 0.6 seconds after the trip operates during ejection, the other is gas fired by the barostatic time release unit (BTRU) or by operation of the manual separation handle. A shear pin is fitted through the top of the drogue gun barrel to retain the piston until the gun fires.

12. The BTRU on the top right of the seat provides for the automatic release of the drogue shackle, deployment of the personal parachute, and separation of the occupant from the seat after ejection. The automatic sequence commences with the firing of a cartridge in the BTRU. A time delay mechanism and a main barostat are able to delay the firing of the cartridge, depending on ejection conditions:

a. The mechanical time delay mechanism is triggered by the trip rod when the seat rises on ejection. If the delay mechanism is unobstructed it allows the BTRU cartridge to fire 1.5 seconds after ejection.

b. If the ejection takes place at altitude the main barostat prevents operation of the time delay until the man and seat have descended to 10,000 ft where a tolerable oxygen and temperature environment exists. After ejection the drogue stabilized seat descends rapidly with the occupant strapped in. At 10,000 ft the barostat removes its restraint on the time delay, which is then free to operate.

When the BTRU cartridge fires, the resultant gas operates a release mechanism to free the restraint on the parachute withdrawal line within the parachute container. At the same time a piston operates to release the drogue shackle and the top harness locks. The release of the drogue shackle frees the drogue from the seat, thereby initiating deployment of the personal parachute. The harness bottom locks are released, and the occupant can now be plucked from the seat as the parachute develops. Finally, the second drogue cartridge is fired, normally a redundant action but necessary in case the mechanical firing of the gun has failed.

13. A personal equipment connector (PEC), on the left-hand side of the seat pan, provides a single action connection for the occupant's mic/tel, oxygen supplies, and g-suit when applicable. The seat portion is coupled to the oxygen regulator. A cover is provided to fit whenever the aircrew portion is not connected. The aircrew portion of the PEC is part of the aircrew equipment assembly and has an oxygen tube and mic/tel lead for connection to the occupant's oxygen mask hose and helmet mic/tel respectively. When released, either manually or during seat separation, the leg restraint cords are also released.

14. The main oxygen system is connected to the seat via an automatic pull-off bayonet connector behind the seat pan and then by pipe to the regulator/PEC. An emergency oxygen cylinder at the rear of the seat feeds into the main supply line and has a release mechanism which is tripped automatically by a striker during ejection or can be operated manually at any time by operating a control handle on the seat pan.

Principle of Operation

15. To operate the seat the firing handle is pulled sharply upwards a short distance to fire a cartridge. The pull force required is between 20 and 70 pounds. Gas from the cartridge operates the harness retraction unit, the canopy miniature detonating cord (MDC) initiator and the seat ejection gun.

16. Before the seat can be ejected it is first necessary to remove the canopy. The canopy may either be jettisoned or, alternatively, disintegrated by using a miniature detonating cord (MDC). The MDC is a fine ribbon of explosive material with a dense backing material, such as lead, to direct the explosive force outwards through the canopy. The MDC shatters the canopy so that the seat can pass through it without resistance. The MDC is operated by the seat firing handle and there is therefore no delay in the ejection. When canopy jettison is required there is a time delay in the ejection sequence to allow the canopy to clear the ejection path of the seat.

17. When the seat gun is fired the acceleration imparted to the seat must be controlled to within limits which are physically safe for the seat occupant. For this reason, the acceleration is staged by using three cartridges which fire in sequence. The gun is fired when the seat handle is pulled. Gas pressure from the firing unit cartridge fires the primary cartridge. Gas from the primary cartridge then initiates the upward movement of the seat, extending the telescopic tubes. As the tubes rise ports are opened which allow the primary cartridge gas to ignite the two secondary cartridges in turn. When the tubes are fully extended, separation of the outer and inner tubes occurs, and the seat is then free of the aircraft.

18. The seat harness is retracted immediately the seat firing handle is pulled so that the occupant is held in the correct posture for ejection. During the first few inches of seat travel the leg restraint system prevents damage to the legs, the seat main oxygen supply is disconnected, and the emergency oxygen supply is tripped on by a striker.

19. The remaining automatic functions are initiated as the static trip rods are pulled from the drogue gun and BTRU. From this moment on, seat separation and personal parachute deployment will occur automatically unless there is a failure of the drogue gun or BTRU.

20. In the event of a failure of the drogue gun or BTRU, or if premature separation is deemed necessary, the manual separation facility may be used. The operation of the manual separation handle fires a cartridge which then operates the same mechanisms as the BTRU and also fires the drogue gun. The manual separation facility should be used with caution at high altitude because the rate of descent in the seat is greater than that of a parachute and exposure to the adverse temperature/oxygen environment will therefore be extended.

Rocket Assisted Ejection Seats

21. Many seats are fitted with rocket packs which fire after the cartridges to sustain the upward thrust of the ejection gun. The thrust angle of a rocket assisted seat can be adjusted in some aircraft types to allow for changes in the seat centre of gravity due to variations in the boarding weights of users. The boarding weight of the user is set on a control on the side of the seat pan; the setting of the weight automatically changes the thrust angle of the rocket pack.

Command Ejection

22. Command ejection systems are fitted to some aircraft types. These allow seat ejection systems to interconnect so that the occupant of one seat can operate both seats simultaneously. Such systems are usually arranged so that the aircraft captain can save time by initiating the ejection of a second crew member though in some cases it may be possible for the crew member to initiate the ejection of the captain in the case of incapacitation.

23. Command ejection is controlled by an ON/OFF selector. When ‘ON’ is selected a cartridge in the selector valve fires when the seat firing handle is operated. Gas from the cartridge is passed to the harness retraction system of the second seat and, after a short delay fires a breech unit cartridge to initiate seat ejection.

24. A seat ejected by a command system will function in the same way as a seat ejected independently. However, on some types, should manual separation then be required, the occupant of the command ejected seat would need to pull the seat firing handle before operating the manual separation lever.

Failure of Seat to Eject

25. If the seat fails to eject, the seat firing handle should be pulled sharply again. If, with the command ejection system operative, the commanded seat fails to eject, the seat occupant should immediately pull their own seat firing handle.

Seat and Canopy Safety

26. To prevent the inadvertent firing of the ejection seat or canopy jettison, or the operation of the MDC, safety pins are provided. The pins should be inserted when the aircraft is on the ground. Precise details of how and where to insert the safety pins vary according to the type of seat and cannot be given here. Personnel who have not been trained in the use of the safety pins should not be permitted to enter a cockpit without supervision.

Seat Limitations

27. Seats with rocket assistance may be used at ground level with no forward speed provided the aircraft attitude is straight and level.

28. Seats without rocket assistance may be used at ground level provided the speed is 70-90 kt, depending on the type of seat. The aircraft attitude should be straight and level. If the aircraft is airborne and descending, the minimum height for ejection is approximately ten percent of the rate of descent, i.e. at 1,500ft/min rate of descent the minimum safe height for ejection is about 150 ft provided the wings are level. More detail for a specific seat/aircraft combination is given in the appropriate Aircrew Manual.

Human Factors and Ejection Seats

Ejection seats are designed to save your life and do so very effectively. However, if you fail to strap in correctly or carry out the checks in accordance with SOPs then the outcome of the life saving ejection sequence may not work as it should and could result in extensive injuries or even death. If you are interrupted whilst strapping in start from the beginning again; it may save your life.

CHAPTER 11 - PARACHUTES AND PARACHUTE DESCENT

Introduction

1. In 1919 Leslie Irvin carried out the first recorded free-fall descent in a parachute of his own design. This was operated by a device which rapidly became known as a ripcord. In so doing, he demonstrated the feasibility of escaping from an aircraft in difficulty by activating a ripcord whilst falling through the air. Although parachutes are now used for a variety of purposes, their original function was for emergency escape in flight. This chapter describes that function. Aircrew must know how to operate and handle the type of parachute that they may have to use for an emergency abandonment.

TYPES OF PARACHUTE

Survival Parachutes

2. There are several types of survival parachute in use today. Details of each can be found by accessing the Aircrew Equipment Assemblies and Survival Equipment (AEA&SE) technical library on the Defence Intranet. The design of a parachute results from a careful study of the conditions under which it will be used including the height and speed of operation, the weight it is required to support, the opening shock (usually about 9 g) and the rate of descent required. Parachute opening shock is discussed in Volume 6, Chapter 5, paragraph 20. The maximum rate of descent at impact, to avoid significant injury, is 8 m/s. The rate of descent at impact will depend upon the suspended weight under the parachute canopy; the values for Type 1000 parachutes are given as an example:

a. Rate of descent for given weights (not including parachute weight of 11.5 lb (5.2 kg)).

Weight	Rate of Descent
150 lb (68 kg)	16.0 ft/s (4.9 m/s)
200 lb (91 kg)	18.5 ft/s (5.6 m/s)
275 lb (125 kg)	23.3 ft/s (7.1 m/s)

Other Types of Parachute

3. Parachutes are not used solely for escape from aircraft and Table 1 lists types used for other purposes. This chapter will discuss only flat and shaped canopies.

Table 1 Types and Purposes of Parachute Canopies

Type of Canopy	Purpose
Flat	Man carrying, supply drop, aircraft braking
Shaped	Man carrying, supply drop, aircraft braking
Ribbon	Aircraft Braking
Ring Slot	Air load extraction, aircraft braking
Shaped, segmented	Heavy supplies drop
Cruciform	Heavy supplies drop
Ram air	Special purpose, man carrying

The Canopy

4. The Canopy is the drag-producing part of a parachute, designed to reduce the rate of descent of the load. It is made from one of a range of textile materials and in most cases is designed to form an umbrella-like shape during descent. The most widely used material in the manufacture of canopies, is nylon, but Cellanese, Fortisan, Rayon and Polyethelene are also used, the latter for canopies intended for dropping equipment and supplies. Previously, cotton and linen were also used, and some canopies made from these materials may still be found in Service use. Rigging lines provide the connection between the canopy and the user and they maintain the shape of the canopy during descent. In most designs of canopy, each rigging line is continuous from one lift web to the apex of the canopy and thence to the opposite lift web, by way of diametrically opposite points on the periphery of the canopy i.e. 12 rigging lines on a 24-gore canopy.

5. All parachute canopies, except ring slot, cruciform and ram air, are constructed of gores extending from the apex to the periphery. Flat, shaped and shaped segmented canopies have the gores further separated into panels; in each panel the material may be cut on the bias in which the warp and weft of the material lie at an angle to the centreline of the gore, or block, in which the warp and weft are parallel to the periphery and the centreline of the gore respectively. Gores may be coloured or camouflaged to suit the theatre of use.

Flat Canopies

6. A flat canopy is so called because it can be laid out flat to form a circle; each gore being a straight-sided segment of that circle. The measurement of such a canopy is its flat diameter.

Shaped Canopies

7. Shaped canopies assume a deeper form when deployed than flat canopies because the gores have curved sides. A shaped canopy cannot be so laid out flat and so its measurement is taken to be its flying diameter. During a descent, the flying diameter of a 5.2 m shaped canopy and a 7.3 m flat canopy are approximately the same.

Aeroconical Canopies

8. The aeroconical canopy has been developed to meet the requirements for an emergency parachute that is suited to the demands of escape from aircraft operating at high speeds and altitudes. In half cross section, the canopy takes the form of an aerofoil with a reflex trailing edge. The canopy is manufactured from virtually non-porous nylon fabric so that airflow over the forward area remains attached, giving a forward lift component almost equal to the drag of the rearward area. The combination of these forces gives a vertical component approximately 80 per cent greater than the drag of a conventional hemispherical profile. The canopy shape confers excellent damping characteristics which ensure rapid recovery to stable flight after the initial swing which develops following ejection. The canopy is fitted with steering lines and also water pockets to ensure rapid canopy deflation in the event of a water landing.

8-11 Fig 1 Flat and Aeroconical Canopies

Fig 1a Flat Canopy

Fig 1b Aeroconical Canopy

Auxiliary Parachutes

9. The function of an auxiliary parachute is to ensure the quick withdrawal of the main canopy from the parachute pack with the ripcord operated. There are several types of auxiliary parachute design but the function of each is the same. This small canopy contains a spring, so that when the closure pins of a pack are removed the spring provides the force necessary to throw the auxiliary parachute clear of the pack and into the slipstream. An auxiliary parachute is fitted to all ejection seat packs but the drogue system normally deploys the main parachute canopy. The auxiliary only functions to deploy the main canopy following a manual separation. An auxiliary parachute is not required on a static line operated parachute.

Ejection Seat Drogue Parachutes

10. Ejection seats are fitted with a duplex drogue system to provide a means of stabilizing the seat after ejection and to slow the speed of the seat and occupant through the air until a safe separation speed is achieved. When the Barostatic Time Release Unit (BTRU) on the ejection seat operates, the drogue system then deploys the seat occupant's parachute assembly. The system consists of a 559 mm diameter controller drogue and a 1.52 m diameter main drogue.

11. During the ejection sequence, the drogue gun is fired, and the gun bolt deploys the controller drogue, which in turn pulls the main drogue out of its housing. The deployment of the main drogue stabilizes the ejection seat and its occupant and starts to slow them down. When the BTRU operates, the main drogue is released from the ejection seat and as the seat falls away from the occupant the main parachute canopy is deployed by the action of the duplex system.

ASSOCIATED EQUIPMENT

Parachute Packs

12. An emergency escape parachute, complete with rigging lines (and normally an auxiliary parachute) is stowed into various types of fabric or solid pack. The type of pack depends on the type of seat used and whether the pack is always worn in the air.

13. All parachute packs fitted to ejection seats are operated automatically. The pack is opened by tension from a drogue. Some parachutes are opened by a static line from the aircraft structure and connected to the pack opening mechanism. This opens the pack after a time delay which is also controlled by a barometric capsule to ensure that the pack cannot open automatically at high altitude. In addition, all parachute packs can be operated manually. In these cases, the main canopy is extracted by the auxiliary parachute. Those packs normally operated by a static line usually have a manual handle to activate the system should the static line fail to work.

14. The parachute packs in Service use fall broadly into one of four types:

a. **Head Box Packs**. Head box packs have the advantage that the parachute cannot be damaged in storage and is less susceptible to damage from contact with the seat structure during extraction. As the pack is fitted to the seat and not the man, manual bale-out is impossible, but there are other methods of deploying the parachute if the seat fails.

b. **Back Type Packs**. Back type packs can be classified into three distinct kinds. One is similar in shape to the seat type pack, but is positioned on the back near the shoulders, the aircraft seat back being suitably shaped to accommodate the pack in this position. The second kind of back pack is commonly called the ‘horse shoe pack’, because of the shape. This also fits into the aircraft seat back near the wearer’s shoulders. These two kinds are fitted to ejection seats. The third sort is worn by aircrew in static seats in high flying aircraft and fits on the back between the shoulders and the hips. A similar pack is worn by air loadmasters and dispatchers whilst carrying out air dropping duties.

c. **Seat Type Packs**. Seat type packs are designed to fit into a shaped pan in the aircraft seat and the wearer sits on the pack. Such packs are normally used by crew members who remain in their seats during flight; this type of pack is used in many static and some early ejection seats.

d. **Chest Type Packs**. Chest type packs are for use in aircraft where the use of permanently fitted assemblies is impracticable. They connect by snap hooks to the front of the parachute harness and are connected only when an emergency appears imminent. Until this time, the pack is kept in a stowage provided in the aircraft.

15. All parachutes, irrespective of type, have water pockets to aid canopy collapse in water.

16. Anti-squid lines are fitted to many parachute canopies. These lines consist of a pair of cords or tapes from the parachute risers to the central vent of the parachute canopy. During the deployment of the parachute, the anti-squid lines transfer the tension from the drogues directly to the crewman. This relieves the tension on the shroud lines and the periphery of the parachute allowing the canopy to open more quickly. As rapid parachute inflation is undesirable at higher speeds, the anti-squid lines are designed to break under these conditions so that the parachute canopy inflates more slowly.

Parachute Harness

17. Several types of parachute harness are in use, differing from one another in design details, to provide for the particular requirements of the seat, aircraft or wearer. In general, they consist of a sling in which the wearer sits, and auxiliary straps to secure this sling to the wearer. The latter usually provide for adjustment in size. The straps meet at a quick release fitting normally fitted to a waist-belt situated in front of the body. Extensions of the sling above the shoulders, called the lift webs, connect to the parachute rigging lines. There are usually four of these lift webs, two on each side, described as left or right, front or rear, as appropriate. On harnesses designed for use with chest type parachute packs there are only two lift webs, known as the left or right lift webs.

18. Most types of ejection seat use a combined harness, which combines the role of both safety harness and parachute harness. Later types of combined harness have only one set of adjusting buckles.

Parachute Care

19. Survival Equipment Sections on all units take great care to ensure that parachutes are issued in perfect condition. However, aircrew must follow the advice given below to prevent damage during handling:

a. Never pick up or carry a parachute by:

(1) Any ring-shaped handle.

(2) Any knob.

(3) A flexible housing.

(4) Elastics or springs.

b. Never drop or throw a parachute.

c. Never place a parachute on an oil drum, battery, dirty bench, ground or damp area. Keep it away from stoves and radiators.

d. Do not hang a parachute by the harness or allow the harness to drag along the ground.

PARACHUTE OPERATION

Manual Operation

20. After an unassisted escape from the aircraft, the parachute is deployed by removing the closure pins from the parachute pack. This is done either by a static line or by pulling either a knob or a D-shaped ripcord handle, which is situated either on the left-hand side of the parachute harness or on the pack itself. This release is normally pulled from left to right across the body. The ripcord handle of manually operated parachutes should be operated as soon as the parachutist is clear of all parts of the aircraft. When the closure pins are removed, the auxiliary parachute springs out of the pack, and as it fills, it extracts and streams the main parachute, which has also been freed by the unfastening of the pack. The rigging lines are hanked inside the pack and are extended as the canopy streams.

Automatic Operation

21. The parachute packs associated with ejection seats and some packs used in static seats are operated automatically. Ejection seat automation, initiated by BTRU, is described in Volume 8, Chapter 10. The automatically operated packs used in static seats are fitted with a device known as the Barometric Power Unit (BPU) which is described below.

22. A BPU is needed to operate parachutes which may have to be used in high altitude escapes from aircraft where an ejector seat is not fitted. Its purpose is to operate the opening mechanism of the assemblies after the wearer has fallen to a pre-set height, or after a pre-determined delay. A powerful spring provides the motive force necessary to drive the time delay mechanism and withdraw the ripcord pins; an aneroid capsule prevents the release from operating above a pre-set height. An escapement and pallet delays operation for a pre-determined time after falling to the barometric operating height. This height is normally 10,000 ft and the time delays are 2 ± 0.5 s.

23. The release is normally housed within the parachute pack and is activated by the removal of a pin; the means by which this is done varies with the type of installation but is either by a static line to a point in the aircraft near the escape exit, or by the manual operation of a D-ring or knob on the parachute harness. The time delay mechanism runs for its set time, but if the height of operation is more than the barometric height, an interference pin controlled by an aneroid device will prevent it from running until the pre-set altitude is reached. At the end of the time delay, the spring is released, and it withdraws the ripcord pins. If for any reason the wearer should suspect that the power unit has failed, or if he has failed to fasten his static line to the aircraft, he can pull the manual parachute which will exert a direct pull on the pack rip pins and the auxiliary parachute will be ejected and extract the main parachute canopy.

PARACHUTE DESCENT AND LANDING

Action to Control Descent

24. Following a manual escape, it is possible that the body may somersault before the parachute is deployed, whether this is achieved manually or automatically. If height permits, body stability can be achieved by adopting the 'free fall' position, i.e. body arched back, legs straight and slightly parted (about 450 mm), arms held straight out at right-angles to the body.

25. It is not possible in this Manual to quote one drill that can apply to all aircraft escapes and all circumstances. However, see para 37 for actions during descent into water. Following a ground level ejection there will be little time to do much more than concentrate on the landing. However, whenever practicable, the Vital Actions listed below must be carried out in the descent as soon as the main canopy is fully deployed:

a. Inflate the life preserver.

b. Unclamp the oxygen mask.

c. Check the security of the PSP lowering line.

d. Lower the PSP unless the descent is likely to be into trees or overhead cables.

26. If time permits, the following subsequent actions may be taken to minimize problems in the descent and landing:

a. Check canopy and lift webs for correct deployment.

b. Disconnect and discard the oxygen mask.

c. Pull up the PSP if oscillations become excessive.

d. Assess landing area for hazards and obstructions and adopt the appropriate landing position.

e. Release the parachute when the landing is complete, or as described in para 37 if in water.

27. Descent by parachute can be influenced by the manipulation of the lift webs. Correct application of this parachute flying technique will:

a. Reduce oscillation.

b. Reduce drift and thereby the horizontal component of the landing impact.

c. Enable the parachutist to attempt to avoid obstacles and, to a limited degree, select his landing area.

28. **Oscillation**. One of the characteristics of the flat canopy emergency parachute is its tendency to oscillate, often violently. During a long descent this can be most unpleasant, resulting sometimes in sickness or panic. Oscillation may be reduced to some extent by pulling down on any lift web or pair of front or rear lift webs. The oscillation of the parachutist may be aggravated by lowering the PSP, as it can swing one way whilst the parachutist is swinging the other, thus inducing a series of violent jerking movements. This oscillation is significant with the flat canopy but does not occur so much with the aeroconical canopy.

29. **Control of Drift**. Pulling on a lift web tends to make the parachutist drift in the direction of the pull, but as air is being spilled out of the canopy, it also causes an increase in the rate of descent. From this it will be seen that pulling on the downwind side will increase the drift across the ground and the force of landing. Pulling on the upwind side will reduce drift and landing speed. When below 1,000 ft it is therefore advantageous to check drift as follows:

a. Look at any suitable fixed point on the ground and assess the direction of drift. As the wind velocity may change significantly below 1,000 ft the drift should then be continually monitored. At heights in excess of 1,000 ft there is little awareness of descent but below this height the rate of descent and drift become progressively more noticeable, especially in the last few hundred feet.

b. If drifting forwards, check drift by reaching as high as possible and grasping the back-lift webs, with the thumb inwards and the palm to the front. Pull down until the hands are level with the face.

c. If drifting backwards, pull down on the front lift webs as described above.

d. If drifting sideways, pull down on the front lift webs and just before reaching the ground let up on the lift web on the side to which you are drifting.

e. As long as the drift continues in the original direction it is not advisable to let up before landing, except in the case of sideways drift when the lift web on the downwind side is let up. Should the pull on the lift webs overcome the drift then the lift webs must be let up gently just before reaching the ground.

30. **Points to Note**. The following points should be considered in the event of a parachute descent:

a. The correct parachute position should be maintained throughout the descent, body relaxed, hands on lift webs when not carrying out vital actions.

b. All manipulation of the lift webs should be positive and steady. They must not be jerked down or let up too quickly due to the risk of re-introducing oscillation.

c. In the event of the parachute turning, or an alteration of drift, change to the correct lift webs; if close to the ground, let up gently.

d. Aeroconical parachutes have a significant glide ratio. This feature, known as drive, may be up to 6 m/s and hence it will have a marked effect on the apparent drift.

e. Chest packs (and some others) have harnesses with only 2 lift webs; one lift web only should be pulled down to reduce oscillation and drift.

f. During the descent the main features of the surrounding countryside should be noted.

31. **Avoidance of Obstacles**. If there is a danger of landing on buildings, trees or other obstructions, it is possible to change the descent path by side-slipping. This is accomplished by pulling down on the lift webs or rigging lines on the side towards which it is desired to move. This causes air to spill from the opposite side of the canopy producing a movement in the desired direction. The canopy may appear to collapse in a violent side slip, but this need not cause alarm as it will recover as soon as the lift webs are released. Side slipping causes a marked increase in the rate of descent and should not be done close to the ground except in extreme emergency. When side slipping is used to avoid landing on rough ground the object should be to land short or steer round to one side of the obstacle. Attempts to glide over an obstacle will invariably fail because of the increased rate of descent.

Parachute Landing

32. When making a forward landing, the lower limbs and feet should be turned across the line of drift to allow the roll after touchdown to be made on the side of the leg and thigh. Feet and legs should be together, knees slightly bent, head tucked well in and the arms, with hands grasping the lift webs, should be bent, with the elbows held forward. The initial landing shock is reduced by the flat of the feet, through comparatively well-braced legs, although the shock is reduced by the relaxed attitude of the body. There should be no attempt to strike or beat the ground with the feet; the body should touch with the feet, leg, thigh and buttock. On touchdown, the near shoulder should be twisted round, and the fall completed diagonally across the back.

33. When making a sideways landing, the sequence of movements is almost identical with that of a forward landing, except that since the body is already across the line of drift, further turning is unnecessary; the final twisting of the shoulders at touchdown need not be so pronounced.

34. When making a backward landing, the parachute position should be held until approaching the ground when the lower limbs should be turned across the line of drift so that the landing is half backward, half sideways. On touchdown the body should touch with feet, leg, thigh and buttocks, and the fall completed in a roll across the back as before.

35. After landing the parachute canopy should be deflated immediately by pulling in on a handful of rigging lines at ground level. This will avoid being dragged. If, in a strong wind dragging takes place before the canopy is deflated, roll onto the back and undo the quick release fitting (QRF).

36. If the descent is made into trees it will not be as dangerous as may be imagined. The drill is:

a. Retain the helmet, keeping the visor down and do not lower the PSP.

b. Adopt the normal parachute landing position but with the arms across the front of the face until the descent ceases. (The parachutist may crash through light branches and land on the ground.)

c. If the parachute catches in a tree, try to get a safe anchorage on a branch or the trunk, but with the minimum of movement. Do not release the QRF until a safe anchorage has been obtained. The PSP may be dropped, and the PSP lanyard used to secure equipment to the tree and assist in the descent.

37. If the descent is made into water, carry out the following actions:

a. Check that the lobes of the life preserver are not trapped in the harness and that it is inflated.

b. Raise the visor and discard the oxygen mask.

c. Lower the PSP as late as possible to minimize oscillation and adopt the parachute position.

d. In the water, adopt the stable position - big X, PSP between the legs. If the parachute canopy falls on top of you, do not panic. There is no danger of drowning as long as the life preserver is inflated. If there is any wind the canopy should drift clear. Should the canopy collapse on top of you this would mean a light wind and a low sea state. Hence there would be little danger and no reason to panic. Float with the head back and, using alternate arms, grasp a handful of material and draw it over the head and down to the chest, grasping another handful before releasing. Where possible, work along an embedded rigging line between two gores; if the apex is reached first continue across it to the periphery. Breathing is no more difficult than normal while under the canopy if the parachute material is held clear of the face.

e. Locate the QRF and rotate it clockwise through 90°. With thumbs behind and fingers in front, press the QRF, release harness and push it clear.

f. Pull in the PSP and pull the handle.

g. Inflate and board the liferaft as quickly as possible.

38. After a descent into water in high winds the you may be dragged in the harness. Should this happen roll onto your back in the dragging position, which is:

a. Chin on chest, shoulders and back rounded.

b. Legs maintained wide apart.

c. Hands on release mechanism.

This position affords a comfortable and stable ride with the face well clear of the water. The protective helmet reduces water splashing on the face. The parachute should be released by squeezing the QRF; if the dragging force is high the straps may bind in the groin. Maintain the legs wide apart and work on the leg straps with the hands.

39. With systems deployed by a drogue bullet and duplex drogues the duration of drag is very short as the bullet falls into the water and sinks. This submerges the drogues which then act as sea anchors and the line rapidly collapses the main chute. In addition, all ejection seats are fitted with parachutes that have water deflation pockets. These pockets rapidly fill with water and deflate the parachute.

Summary

40. The construction, care and operation of parachutes has been dealt with in general terms in this chapter. Further details of individual parachute assemblies may be found in the Aircrew Equipment Assemblies and Survival Equipment (AEA&SE) Technical Library. The parachuting technique is the result of the lessons learned from numerous descents by aircrew and experienced parachutists; the advice given should enable aircrew to avoid serious injury after abandoning an aircraft in flight.

Human Factors and Parachutes and Parachute Descent

It is very easy to assume that parachutes will save your life no matter what. However, there have been occasions when serious injury and even death have occurred following a parachute descent when checks, drills or SOPs have not been adhered to. Assume nothing; prepare for anything.

CHAPTER 12 - GENERAL FLYING

Introduction

1. Because of the variety of aircraft types in service, it is impracticable to discuss every aspect of all exercises that a pilot is likely to perform. The following paragraphs, therefore, contain general considerations applicable to most types of aircraft when performing basic flying manoeuvres. It must be appreciated that many factors affect these considerations and allowance should be made for those not mentioned in this Section.

2. A pilot must be thoroughly familiar with the aircraft, especially the location and function of all controls, instruments and equipment, the airframe limitations and operation of emergency systems. To assist the pilot to feel at home in the cockpit, full use should be made of all training aids, flight simulators, instructional fuselages, and mock-ups of fuel, hydraulic and electrical services. The chief sources of information are Aircrew Manuals, the Aircraft Servicing Manual - Ground Handling, and AP 3456.

Preparation for Flight

3. **Flight Planning**. It is the Aircraft Commander's duty to ensure that, before flight, appropriate members of the crew have carried out the correct flight planning, and that all the information necessary to ensure the safe navigation of the aircraft has been obtained. The degree of success of any sortie will depend on the thoroughness of this pre-flight preparation.

4. **Meteorological Briefing**. No flight should be undertaken without obtaining information about the weather in the operating area, along the route to be flown, and at the destination and alternate airfields.

5. **Passengers**. The Aircraft Commander must be acquainted with the relevant orders governing the flying of passengers (MAA RA2340), Queen's Regulations, and the appropriate Command and Group Orders. The Aircraft Commander is responsible for the safety of his passengers and for ensuring that they are adequately equipped with appropriate safety and survival equipment for the proposed flight. The Aircraft Commander must ensure that all passengers are fully briefed on all of the topics specified in the appropriate Command/Group Orders. These topics will include:

a. **Authority of the Aircraft Commander**. Any person flying as a passenger must be made aware that they are subordinate to the Aircraft Commander and Aircrew for the duration of the flight in all matters relating to the direction and handling of the aircraft and the safety of its passengers, crew and equipment (MAA RA2340).

b. **Procedures Before and After Flight**. The routine to be followed by the passengers both before and after flight should be explained. This can include briefing times, transport, baggage handling and storage, Customs clearance (where appropriate) and any other administrative/ organizational details as required.

c. **Use of Protective Clothing, Safety and Survival Equipment**. The fitting, adjustment, and operation of the appropriate safety and survival equipment (including Protective and Safety Clothing) must be fully explained and, where necessary, demonstrated. Where applicable, the passengers must be suitably instructed in the operation and fitting of oxygen equipment.

d. **Crash, Ditching and Abandonment Procedures**. The crash or ditching positions and emergency exits must be pointed out, and the executive orders relating to these emergencies and to abandonment must be stated.

e. **Restrictions**. Passengers must be made aware of any items which may not be carried or used in UK Military Aircraft. Where applicable, the no smoking/naked lights restrictions must be explained and any limitations on movement within the aircraft pointed out.

f. **Use of Switches/Controls**. Passengers should be shown how to use any switches or controls which they may need to operate for their own comfort or for the safe operation of the aircraft. This briefing should also include any switches or controls which MUST NOT be operated.

6. **Personal and Safety Equipment**. The crew must have the appropriate safety, survival, oxygen and R/T equipment. The serviceability of all equipment taken into the air must be carefully checked pre-flight.

7. **Order Books and Authorization**. Aircrew must be conversant with all relevant Order Books pertaining to the safe and effective operation of the aircraft which they are authorized to fly. Section A of the Flying Order Book must be checked before each flight so that any new orders can be actioned. All flights must be correctly authorized in accordance with MAA RA2306.

8. **Checks Before Starting**. Before starting engines, the following general checks should be made:

a. The aircraft should, if practicable, be facing into wind. This precaution will ensure the best possible cooling in the case of piston engines and, in the case of jet engines, will prevent hot exhaust gas re-ingestion.

b. The aircraft should be standing on level, firm ground which should be free of loose objects that could be drawn into the engine or damage the airframe.

c. The aircraft should be positioned so that the jet efflux or slipstream will not damage any equipment, aircraft, vehicle, building or people.

d. The aircraft's wheels should be securely chocked.

e. A fire extinguisher of adequate capacity must be available to deal with any fires that may occur whilst starting up.

f. The area around the aircraft should be clear of obstructions: this is particularly important in the case of the larger swept-wing aircraft where the wing tips are not visible from the cockpit.

g. The airframe should be free from deposits of frost, ice and snow. When necessary a de-icing fluid should be used but, because under certain conditions the wetted surface can actually enhance the accumulation of wet snow, there should be no significant delay between de-icing and take-off. Particular attention should be paid to the leading edges, control surfaces, flaps, slats and associated mechanisms, hinges and gaps. Deposits on control surfaces could put them out of balance and cause flutter; those on hinges may re-freeze in flight and jam controls. All inlets and vents should also be cleared.

After Start-up

9. On some types of engine, icing of sensors or probes can cause over-reading of power gauges. To prevent this, and also to avoid the possibility of damage to, or flame-out of, the engine, it may be advisable to select engine anti-icing on, if icing conditions are present or possible. As a guide, engine icing is possible if the outside air temperature (OAT) is less than 10 ºC and there is precipitation, standing water, or the runway visual range (RVR) is less than 1,000 metres. If appropriate, propeller de-icing should be used.

Taxiing

10. Any aircraft-specific considerations to be taken whilst taxiing will be described in the Aircrew Manual for the type. On turboprop aircraft, in particular, reduced rpm for taxiing may be selectable by operating a switch but older types and multi-engine turboprops may require manual rpm control. Other multi-engine types may also need adjustment to propeller pitch to assist in manoeuvring on the ground.

11. The wheel brakes should be tested together as soon as possible after starting to taxi, while the speed is still low. When first leaving dispersal, the effects of jet efflux or slipstream on loose ground equipment must be considered and the aircraft halted if damage is likely. Whilst taxiing, the brake pressure(s) should be checked frequently and, if they fall significantly, the aircraft should be stopped before the brakes lose their effectiveness. As a general rule, the amount of power used in taxiing should be kept as low as possible since aircraft brakes can quickly overheat if abused, or if a long period of taxiing is necessary which involves much stopping and starting. Brakes will also overheat quickly if they are continually applied against power.

12. If the aircraft has nosewheel steering, the use of wheel brakes will be confined to slowing and stopping the aircraft. However, when using toe brakes in conjunction with nosewheel steering, care must be taken not to damage the nosewheel steering mechanism by braking against the direction of turn, ie if the aircraft is being turned to the right by using the steering, do not apply the left toe brake to slow the aircraft. In any event, the aircraft must never be turned on a locked wheel or bogie. On aircraft fitted with a tandem bogie under-carriage, very high loads will be induced if sharp turns are made. The severity of the loads does not vary much with aircraft weight but increases rapidly with tightness of turn. Experience has shown that fatigue fractures have occurred, which were attributed directly to repeated application of sharp turning loads. After a tight turn, taxi straight for a short distance before parking or coming to a full stop. This will help prevent stress caused by distortion of the tyre walls.

13. Where an aircraft has the capability of reverse taxiing, it is essential that speed is kept to a minimum and that the wheel brakes are never used to stop any backwards movement. If the brakes were to be applied when moving backwards, it is possible for the aircraft to tip back over the main bogies and the nosewheel to leave the ground. If this happens, damage could be caused initially to the underside of the tail assembly, and then subsequently to the nosewheel unit as the nose of the aircraft drops back to the ground. To stop a reversing aircraft, forward thrust should be applied, and then the aircraft should be allowed to roll forwards sufficiently to remove stress from the wheel/bogie assemblies.

14. Taxiing speeds depend entirely on the circumstances, but the overall consideration must be to limit the speed to that which gives time to cope safely with any emergency and to limit the stresses on the undercarriage. When taxiing among, or close to obstructions, or when turning sharply, the speed must be kept low.

15. In tailwheel aircraft, where the centre of gravity is behind the main wheels, there is a tendency for a turn, once started, to tighten up. In nosewheel aircraft, where the centre of gravity is ahead of the main wheels, a natural directional stability results and the turning force has to be maintained to sustain the turn.

16. The wind strength and relative direction can be an important consideration when taxiing. The effect of the wind on the keel surfaces normally tends to turn an aircraft into wind and this is most noticeable in light aircraft with large keel surfaces. In a strong wind, the effectiveness of the brakes in countering weather-cocking may well be the limiting factor in the use of these aircraft. In strong or gusty winds the controls must be held firmly to prevent them being blown against their stops; Aircrew Manuals indicate when control locks may be used during taxiing. In aircraft fitted with irreversible power-operated controls, the wind has no effect on the controls.

17. In large aircraft, it is normal to post crew members in suitable positions in the aircraft to act as additional look-outs. If the forward view is restricted by the nose, as in some tailwheel aircraft, taxi slowly and weave the nose from side to side to ensure that the way ahead is clear. If doubt exists about the position of obstacles, or their clearances from the airframe, the aircraft should always be stopped.

18. During taxiing in icing conditions, the use of reverse thrust should be kept to a minimum. Excessive reverse thrust can result in ice contamination of the wing leading edges. For the same reason aircraft should not be taxied too close behind another taxiing aircraft.

Take-off

19. Before take-off, ensure that the airframe is not contaminated by ice or snow and that fuel, airframe and engine anti-icing controls are set appropriately. Refer to the relevant Aircrew Manual and ODM when operating from contaminated runways. Leaving the undercarriage down slightly longer than normal, or re-cycling the undercarriage after take-off, will allow the airflow to help clear snow, slush or water which could freeze the undercarriage in the 'UP' position.

Climbing

20. An aircraft will climb if, when trimmed in straight and level flight at a set IAS, the power is increased. The rate of climb varies with the amount of surplus power and the air speed. The maximum rate of climb will be achieved at full power and at a recommended climbing speed, which varies with height and weight. Aircrew Manuals give the engine settings and air speeds, or Mach numbers, to be used on the climb (see Volume 1, Chapter 14 for aerodynamic principles of the climb).

21. Having ensured that the area into which the aircraft is to be climbed is clear, the following techniques should be used for entering and flying the climb:

a. Climb power should be applied and, as the speed approaches the correct climbing speed, the aircraft attitude should be adjusted and the airspeed should be allowed to stabilize.

b. The aircraft should be trimmed, and then small adjustments made to correct and hold the speed, retrimming as necessary.

c. During the climb, the aircraft attitude will have to be readjusted to maintain the climbing speed. Power settings, engine temperatures, oxygen flow and pressurization should be checked periodically.

d. If the forward view is poor in the climbing attitude, the aircraft should be weaved or turned occasionally to check the sky ahead, unless operational considerations require a climb on a constant heading.

In Flight

22. **Icing**. In flight, pilots should avoid icing conditions for which their aircraft is not cleared, as the rate of ice accretion can be very rapid. Even relatively small amounts of ice can have a significant and dangerous effect on an aircraft's performance and control. Instructions given in the relevant Aircrew Manual concerning the use of anti-icing and de-icing equipment should be followed.

23. **Jet Engine Handling**. Engine limitations must be monitored, remembering that different temperature limitations may apply in varying conditions. The amount of power adjustment required to climb is usually small, but attention must be paid to the jet pipe temperature(s) or turbine gas temperature (TGT), particularly at high altitudes where this becomes more critical. If the temperature

exceeds the maximum, it should be reduced by decreasing the rpm; increasing the air speed is not recommended as it may well have the opposite effect. During the climb, small throttle adjustments may be required to maintain constant rpm, depending on the engine characteristics.

24. **Turboprop Handling**. Advice on engine handling techniques for particular aircraft types will be found in the Aircrew Manual. Engines not having the advantage of computerized control may need throttling back to maintain engine temperature and torque limits in the climb and to synchronize engines in the cruise. Some engines, in cold conditions, may become torque limited before being temperature limited in the climb.

25. **Piston Engine Handling**. During a sustained climb the rpm should be maintained as near as possible to the Aircrew Manual recommended figures. At a constant throttle setting, engine power output will fall as height is gained and the throttle must be used to maintain the required manifold pressure. Engine temperatures will tend to increase during the climb because of the combination of high power and low IAS. Engine temperatures should therefore be carefully monitored to maintain them within the recommended limits and, if necessary, rate of climb should be adjusted by either reducing power or increasing speed.

Effectiveness of Controls

26. **Air Speed**. At a given height, the effectiveness of a control surface varies with the speed of the air passing over it. With propeller-driven aircraft, the effectiveness of the rudder and elevator increases appreciably when these lie within the propeller slipstream. In general, however, if the speed of the airflow over a control surface is reduced, a larger control movement is required for a given change and rate of change of aircraft response.

27. **Altitude**. As height is increased, the controls become less effective. This is because, at a constant IAS, the TAS, and thus the directional inertia, increases as altitude increases.

Straight and Level Flight

28. A high standard of straight and level flight is the basis of all accurate flying and is essential to good navigation; it involves flying the aircraft on a constant heading, at a constant height and air speed in balanced flight (see Volume 1, Chapter 13). Engine handling will depend on the requirements of the flight (e.g. maximum range) and should accord with the recommendations in the Aircrew Manual. As in all flying exercises, a good look-out is essential and this should be systematically combined with frequent scanning of the instruments.

29. **Stability and Trimming**. Aircraft are generally stable in pitch and so tend to return to level flight if they have been disturbed from it. Full use should be made of all trimming controls to relieve the pilot of any control column forces and thus reduce fatigue. At higher altitudes, stability is normally reduced and accurate trimming then becomes increasingly more difficult but correspondingly more important.

30. **Flaps**. When flying straight and level at low speed, some advantage may be gained by lowering the flaps to the position recommended in the Aircrew Manual. The stalling speed is thereby reduced, but more power is required to overcome the additional drag of the flaps at a given speed. However, with propeller-driven aircraft, the additional slipstream increases the effectiveness of rudder and elevator controls. In addition, the use of flap will improve the forward view by reducing the high nose attitude associated with flying at low speeds.

Turning

31. The force which turns an aircraft is the horizontal component of the lift obtained by banking. The total amount of lift required for any turn is therefore greater than that for the same speed in level flight but the drag will also be higher since the extra lift can only be obtained by increasing the angle of attack. This increase in drag, which is shown at a given power setting by a reduction in speed, is more quickly apparent in slow aircraft though it applies equally to faster aircraft at much higher angles of attack.

32. **Loading**. As the angle of bank is increased in a turn, the total lift must be gradually increased if the aircraft is to maintain height and obtain the greater horizontal component needed to make the aircraft turn on a decreasing radius. A progressive increase in lift and loading, obtained by gradually increasing the angles of bank and attack, can be continued until one of the following limits is reached:

a. The aircraft stalls when the angle of attack reaches the critical angle.

b. The g threshold of the pilot is reached.

c. The g limit of the aircraft is reached.

The angle of attack must not be increased sharply or rapidly (known as 'snatching') since the instantaneous applied load can be large enough to overstress the aircraft, although the pilot may not black out because of the short duration of the load and/or because an anti-g suit is being worn. The loading imposed on the aircraft will be evident to the pilot from the physiological effects of the increasing g and the indications of the accelerometer.

33. **Stalling Speed**. The stall in a turn always occurs at a higher speed than in level flight and this is known as the g stall. During a turn, the more the power used, the larger the angles of bank and attack applied, the greater will be the horizontal component of the inclined lift vector and the smaller the turning radius; at the same time the g will increase. If, while tightening the turn, the aircraft approaches the g stall (usually indicated by buffeting), recovery is made simply by reducing the backward pressure on the control column and, if not already at full power, increasing the power. If the aircraft stalls fully, the recovery action is to release the backward pressure on the control column to unstall the wings before attempting to roll the aircraft level. This is described more fully in Volume 8, Chapter 15.

34. **Maximum Rate and Minimum Radius Level Turns**. Maximum rate or minimum radius turns are flown at full power and at maximum lift, ie on the fringe of the g stall. Theoretically, the higher the IAS that can be maintained under these conditions, the faster the rate, and the smaller the radius of turn. If less than full power is used, the rate of turn is less and the radius is larger. Stalling speed is proportional to g and therefore increases as the angle of bank increases and the turn tightens. In practice, when gradually tightening a turn at a constant IAS, the initial response from the aircraft is a slight increase in rate of turn and a considerable decrease in radius; as the g stall limit is approached the rate of turn starts increasing rapidly but the rate of decrease of the radius falls off and eventually increases. This is because compressibility and other effects begin to affect the wing at a fairly low Mach number thus reducing the rate at which the radius would otherwise diminish until a point is reached at which they completely cancel any benefit to be gained by increasing the speed. These facts should be borne in mind when flying at high speed or in poor visibility.

35. **Turning at Low Speed**. Low speed implies a high angle of attack giving a relatively small margin above the stalling angle. Any turn commenced at low speed is limited in radius and rate of turn since

the margin of speed between the level flight stalling speed and the g stall is small; power should therefore be used to prevent the speed from falling any lower. At the lowest speeds just above the stall, only fractional amounts of g are required to reach the stall.

36. **Compressibility in Turns**. Any increase in angle of attack and g accelerates the flow of air over the upper surface of the wing. At a high TAS therefore, the increased angle of attack during a turn induces the onset of compressibility effects sooner, ie at a lower speed and Mach number than when no loading is applied.

37. **Effect of Altitude on Turning**. Because of the reducing air density with altitude and the adverse effect of compressibility on the lift obtained at a given IAS and angle of attack, the g to which the aircraft can be subjected without stalling is lower. Maximum rates of turn are much reduced and turning circles increased, and fighter-type aircraft, which could easily be damaged through excessive g at low altitudes, are not able to exceed 1.5 g to 2 g at their highest working altitudes.

Descending

38. A descent can be made at different rates and air speeds, with or without the use of engine, flaps or airbrakes. Aircrew Manuals indicate how maximum rate, cruising or gliding descents are best made.

39. **Slow Descents**. It is a relatively simple matter to obtain a slow rate of descent, whether following a particular method described in the Aircrew Manual or by simply reducing the power. When descending slowly from considerable heights a large distance is always covered and the flight plan should allow for this.

40. **Maximum Rate Descents**. Operational necessity or an emergency may require the maximum possible rate of descent through a large height band from a high altitude. Airbrakes should be opened, power adjusted and speed allowed to build up to the recommended Mach number or IAS. The Mach number used may depend on the degree of control available and compressibility effects whilst at lower altitudes the IAS is usually the limiting factor. The amount of power used varies with the type of aircraft and the requirements of the operation or emergency. Frequently, in rapid descents from high altitude, the large and comparatively rapid change of air temperature and the higher humidity at lower levels will cause frosting or misting of the cockpit windows and even of the faces of the instruments and, if this occurs, full use should be made of the defrosting and demisting devices fitted. It may also be necessary to allow time for the aircraft to warm up at low altitude to disperse this misting before attempting to land. Allowance must be made for the height needed to level out from rapid descents so that the manoeuvre is completed at a safe height above ground level; at a high IAS and angle of descent, this allowance can be of the order of several thousand feet.

41. **Airmanship**. Although the view during the descent is usually good, it may be necessary to turn frequently or weave to check that the descent is being made into a clear space. Descents through cloud should not go below the safety altitude (SALT), unless the pilot is:

a. In visual contact with the ground

b. Under positive radar control, or

c. Performing a published instrument approach procedure.

Note: Procedures for SALT are contained in MAA RA 2307(1), and AP3456 Volume 9, Chapter 23 refers.

Human Factors and General Flying

Mission bubble, game face, get into the groove; call it what you like-but where and when does it start? Flying can be stressful and we know that stress can lead to loss of Situation Awareness and ultimately human error. Prior planning, methodical attention to detail and concentration are all part of flying and starts the day before the flight; food, medication, alcohol, sleep (circadian rhythms?), physical fitness (colds, sinuses). If you feel unfit to fly then communicate the fact.

CHAPTER 13 - TAKE-OFF, CIRCUIT, APPROACH AND LANDING

Check Lists

1. Before take-off, it is essential that flying and engine controls are checked and preset; to this end, detailed checks of actions have been introduced.

2. Flight Reference Cards (FRCs), which are issued with Aircrew Manuals for most types of aircraft, contain the definitive checks to be carried out at the various stages of preparation for flight, and during the flight itself. In multi-crew aircraft, the checks are usually read out by a crew member and actioned on a 'challenge and response' basis.

3. On all aircraft, the flying controls should be tested over their full range of movement for freedom and for operation in the correct sense, before the take-off run is started.

TAKE-OFF RUN

Factors Affecting Length of Run

4. The length of the take-off run depends on:

a. All-up weight.

b. Amount of flap used.

c. Engine power.

d. Wind velocity.

e. Runway gradient.

f. Runway Contamination (water, snow or slush etc).

g. Air temperature.

h. Airfield elevation (pressure altitude).

5. **All-up Weight**. Since the all-up weight affects the stalling speed, a heavy aircraft has to be accelerated to an IAS higher than that required by a lighter aircraft before sufficient lift is generated for take-off. Moreover, because the weight is higher, the inertia is greater and, therefore, the rate of acceleration is reduced; both effects lengthen the take-off run.

6. **Amount of Flap Used**. Thin wings have low maximum lift coefficients and therefore need to be accelerated to higher speeds than comparable wings with thicker aerofoils; so a longer take-off run is required. The use of take-off flap increases the coefficient of lift and enables an aircraft to become airborne at a lower IAS, ie after a shorter run. On aircraft with high rotation speeds and high wing loadings, the take-off flap setting should always be used when taking off at a high all-up weight. The flap setting for take-off is given in the Aircrew Manual.

7. **Engine Power**. For a given airframe, the more thrust that is available for take-off, the higher will be the rate of acceleration, and the shorter the distance required to become airborne.

8. **Wind Velocity**. Taking off into wind requires a shorter run because an aircraft at rest, pointing into wind, already has an IAS equivalent to the wind speed. The additional advantages of taking off into wind are:

a. The groundspeed at the time of rotation is lower.

b. At the lower groundspeed, the stresses on the undercarriage and tyres are reduced.

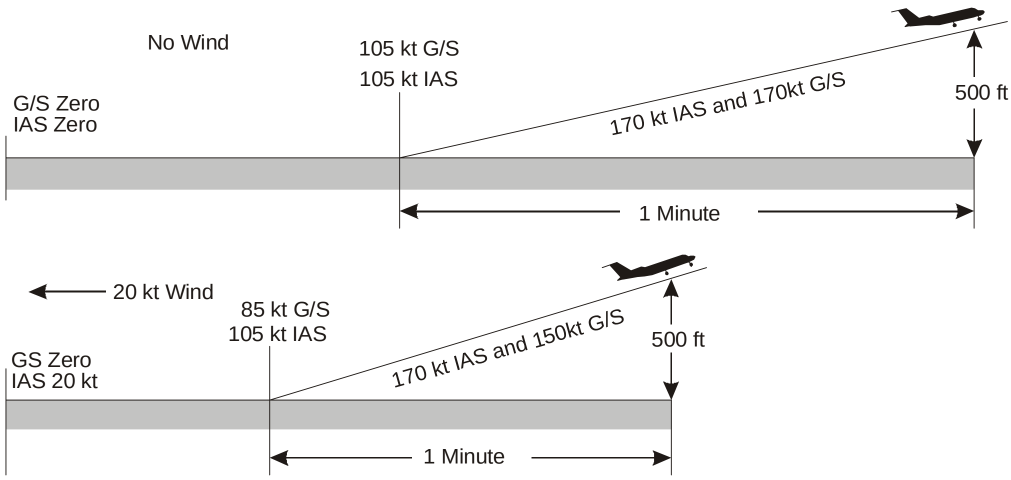
c. There is no tendency to drift.

d. Directional control is improved in the initial stages of take-off.

e. The angle of climb after take-off is steeper because, although the rate of climb is unaffected, the groundspeed is lower (see Fig 1).

f. The groundspeed is lower following possible engine failure or an abandoned take-off, so that the stopping distance is shorter.

8-13 Fig 1 Effect of Wind on Take-off Run and Initial Angle of Climb



9. **Runway Gradient**. If the take-off is uphill, then the aircraft will be slower to accelerate and consequently have a longer take-off run. Conversely, a downhill slope will give a shorter take-off run. An uphill slope of one degree will increase the take-off distance by approximately 10%.

10. **Runway Contamination**. The retarding effect of water, snow or slush on the take-off run can be severe. Comparatively small depths of slush are sufficient to prevent an aircraft from accelerating to its rotation speed. Before attempting to take-off with water, slush or snow on the runway, the situation should be assessed very carefully. If the depth of water or slush exceeds 15 mm (0.6 in), or the depth of dry snow exceeds 80 mm (3.1 in), then take-off should not be attempted. The increased take-off distances will vary with aircraft type but depths of less than 10 mm of slush can give up to a 50% increase in take-off distance. It is essential that the aircraft performance planning tables/graphs contained in the aircraft Aircrew Manual or Operating Data Manual are used when operating from any contaminated runway surface.

11. **Air Temperature**. An increase in air temperature will decrease the air's density; this increases the TAS required to achieve rotate speed, and so lengthens the take-off run. Low air density also reduces the maximum power of jet and un-supercharged piston engines, an effect which adds to the

take-off distance required. The thrust of jet engines at a given rpm is reduced by 4% - 5% for each 5 ºC rise in ambient temperature (above the ISA standard temperature).

12. **Airfield Pressure Altitude**. The reduced density at altitude increases the take-off run for the reasons explained in para 11. The thrust of jet engines is reduced by 2% to 3% for each 1,000 ft increase in airfield pressure altitude.

13. **Operating Data Manual (ODM)**. An ODM is issued for most aircraft types, which allows the factors mentioned in paras 5 - 12 to be taken into account. This enables the operator to make precise calculations on take-off performance (see also Volume 2, Chapter 16).

TAKE-OFF TECHNIQUE

General

14. Take-off techniques vary with different classes of aircraft. The main classes of aircraft from this point of view are:

a. Single-engine, turbojet aircraft with nosewheel undercarriage.

b. Single-engine, propeller-driven aircraft with nosewheel undercarriage.

c. Single-engine, propeller-driven aircraft with tailwheel undercarriage.

d. Multi-engine aircraft with nosewheel undercarriage.

Single-engine Turbojet Aircraft with Nosewheel Undercarriage

15. The aircraft should be taxied forward on the runway for a few yards to straighten the nosewheel. The throttle should then be opened smoothly to full power. In the initial stages of the take-off run, direction should be controlled with the nosewheel steering or wheel brakes but, as soon as the rudder becomes effective, it should be used. A slightly shorter take-off run can be obtained by first opening up to the maximum power that can be held on the brakes, then releasing the brakes and applying the remainder of the power. When take-off power is reached, the engine instruments should be checked. At the recommended IAS, the nosewheel should be raised clear of the runway, thus setting a moderate nose-up attitude which should be maintained until the 'unstick' speed (speed at which the main wheels leave the ground) is reached. As the nosewheel lifts off the runway, and the speed increases, the elevator/tailplane effectiveness increases and, if not corrected, there is a tendency for the attitude to become more nose-up. This must be countered by a suitable control movement because, if the nose-up attitude becomes exaggerated, the drag rises to an extent which reduces the rate of acceleration and, in extreme cases, may prevent any further acceleration. As the recommended rotation speed is approached, smooth backward pressure on the control column should be applied to enable the aircraft to become airborne at the required speed. On many aircraft, the period between nosewheel lift-off and becoming airborne is short and the technique just described is considerably modified. With these aircraft, on reaching rotate speed, steady backward pressure is applied to the control column; the aircraft then rotates and lifts off in one smooth, continuous manoeuvre. This method may not be practicable for all aircraft when taking off from a rough surface, because of the high rotational speeds achieved by the nosewheel assembly. When safely airborne, the brakes should be applied, and the undercarriage retracted whilst a shallow climb is maintained, and the IAS allowed to increase to the initial climbing speed. On some aircraft, this is done automatically. Flaps, if used, should also be raised at a safe height and air speed. If climbing power is less than full throttle, power should be reduced in accordance with the recommendations in the Aircrew Manual.

Single-engine, Propeller-driven Aircraft with Nosewheel Undercarriage

16. On the ground, single-engine propeller-driven aircraft with nosewheel undercarriages are almost in the flying attitude already. The asymmetric blade or gyroscopic effects during the take-off run (see Volume 1, Chapter 23) will not be felt until the nosewheel is lifted off the ground, and even then they will be negligible. Most nosewheels are steerable and can be used to maintain directional control during the early part of the take-off run.

Single-engine, Propeller-driven Aircraft with Tailwheel Undercarriage

17. The aircraft should be taxied forward for a few yards to straighten the tailwheel, and if fitted, the tailwheel lock applied. With the control column held aft of the central position, the throttle should be smoothly opened to take-off power. Any tendency to swing should be corrected with the rudder, the corrections becoming smaller as the rudder becomes more effective with increasing airspeed. As the speed increases, the aircraft should be brought into the flying attitude by a progressive forward movement of the control column, taking care not to get the nose too low. As flying speed is approached, a smooth, backward pressure should be applied to the control column to lift the aircraft off the runway at the correct speed. When safely airborne, a shallow climb should be maintained allowing the IAS to build up to the recommended climbing speed. At a safe height, the flaps, if used, should be retracted. When the flaps are fully retracted, power should be adjusted to the climb setting.

Multi-engine Aircraft with Nosewheel Undercarriage

18. The take-off technique for multi-engine aircraft with nosewheel undercarriage is the same as that for single-engine types, except that the possibility of engine failure during, and immediately after, take-off must be considered. These considerations are detailed in Volume 8, Chapter 24.

Stop Speeds

19. When the ODM is available for use with an aircraft type, the maximum take-off abort speed (also referred to as 'stop' speed) for the take-off conditions and runway length should be ascertained.

Use of Reheat

20. When reheat is used for take-off, no special technique is necessary other than to monitor the reheat operations and raise the undercarriage and flap as soon as possible after becoming airborne. This is necessary (because of the rapid acceleration) to prevent exceeding the limiting IAS for these items.

Taking Off in a Crosswind

21. Because of the advantages listed in para 8, it is usual to take-off as nearly as possible into wind. However, when a long take-off run is required, it may be preferable to use the longest runway regardless of the wind direction, unless the wind is very strong. A crosswind take-off requires a longer run due to the lower headwind component.

22. **Drift**. For a given wind speed, the drift is inversely proportional to IAS, i.e. the lower the IAS, the greater the drift. Consequently, the amount of drift correction when lifting off the runway is less at higher speeds. Nosewheel aircraft, being inherently stable on the ground, have less tendency to weathercock when taking off across wind.

23. **Technique for Crosswind Take-off**. An aircraft tends to weathercock into wind and this tendency must be anticipated. In the initial stages, the controls should be handled as for a normal take-off, paying extra attention to directional control. Aileron may be used to prevent the into-wind wing rising. In multi-engine aircraft, directional control may be assisted by differential use of power, but it must be appreciated that this lengthens the take-off run, as more time is needed to reach full power. When the rotation speed is reached, the aircraft should be lifted cleanly off the runway and must be prevented from dropping back again onto the runway. A clean rotation is especially important when taking off from a rough surface, or in gusty conditions, when an unexpected bump or gust may force the aircraft into the air before full flying speed has been reached. In these circumstances, it is advisable to keep the aircraft wheels on the runway deliberately until a speed slightly above the normal take-off speed is reached. In all aircraft, particularly those with sweepback, a crosswind may cause the into-wind wing to rise during the period from just before to immediately after becoming airborne. This is caused by a 'yawed' airflow over the wings, which increases the lift on the into-wind wing and is aggravated by the partial blanking of the other wing by the fuselage. This is a transitory effect, which disappears shortly after becoming airborne, when the crosswind overcomes the inertia of the aircraft and causes it to drift. It should be anticipated and corrected as soon as it starts. After becoming airborne, and at a safe height, the aircraft should be turned into wind, to counteract drift, and allowed to track along the line of the runway.

THE CIRCUIT

General

24. To reduce congestion and the risk of collision, aircraft should enter the airfield circuit in a planned and systematic manner. To achieve this, a standard circuit procedure is taught.

Preliminaries to Joining the Circuit

25. As the airfield is approached and while maintaining a look-out for other aircraft using, leaving or joining the circuit, the following preparations for the final approach and landing should be made:

a. Establish contact with air traffic control to obtain landing information (runway in use, wind velocity, QFE, details of other traffic etc) and permission to enter the circuit.

b. Reset the altimeter to the required datum.

c. Perform circuit joining checks, as applicable to the type of aircraft.

d. Descend to the authorized minimum height above the airfield.

Procedure for Joining the Circuit

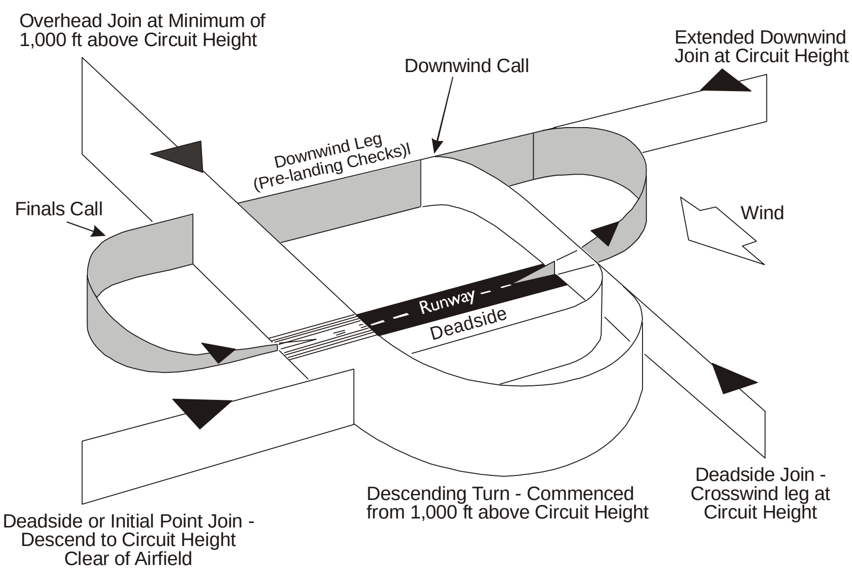
26. Circuit joining procedures are designed to position the aircraft at the start of the downwind leg at the required height and speed, without causing any disturbance to other circuit traffic. The exact procedure to be used will vary in accordance with aircraft type, weather conditions, direction of approach to the airfield and, during training, the pilot’s experience. Normally, one of the following circuit joining methods is used (see Fig 2):

a. **The Join at Circuit Height**. The aircraft should descend to circuit height and reduce to circuit speed during the approach to the airfield. It should then join the circuit pattern, either on an extended downwind leg or on the deadside of the airfield, on a heading parallel to, or at 90^o to, the runway heading.

b. **The Join from Initial Point**. The deadside join on the runway heading, as outlined in sub-para a, can be used to expedite the joining procedure for high-performance aircraft if the run-in onto the deadside of the airfield is made at a higher speed. The level turn onto the downwind leg can then be used to decelerate the aircraft to the correct circuit speed, using airbrakes, or other high drag devices, as necessary. To provide a safe run-in path, clear of aircraft on extended final approach (eg those carrying out radar approaches), pilots wishing to carry out this joining procedure should aim to commence their run-in from an Initial Point (IP). This IP should be a nominated ground feature situated at least three miles downwind on the deadside of the extended runway centre-line. The IP should be approached at a height which will provide vertical clearance from radar approach traffic in that vicinity. Once the aircraft is positively established as running-in on the airfield's deadside, height and speed can be adjusted to arrive abeam the runway threshold at circuit height and at a suitable speed to commence the decelerating turn onto the downwind leg.

c. **The Join from Overhead**. The overhead join (Fig 2) is usually employed during the early stages of flying training, or when weather conditions (e.g. reduced visibility) require a more cautious approach to the airfield and a more thorough lookout whilst flying a safe joining pattern. The airfield should be approached at a height of 1,000 ft above circuit height, and circuit speed should be achieved before reaching the airfield boundary. The pilot should cross onto the deadside of the airfield from a position overhead the runway threshold and commence a descending curved let-down on the deadside of the airfield, aiming to re-cross the runway over the upwind end, at circuit height and circuit speed. During the curved descent, particular attention should be given to lookout.

8-13 Fig 2 The Circuit Pattern



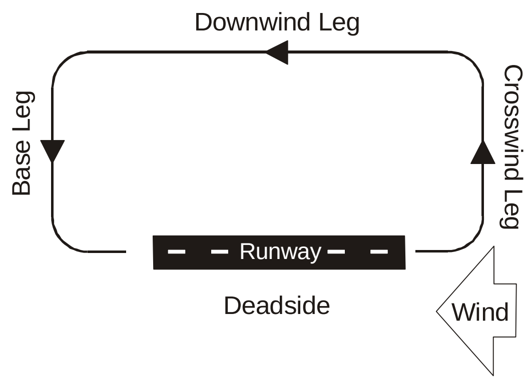
27. **Lookout**. During all types of joining procedure, lookout is of paramount importance. This is particularly relevant prior to turning from the deadside onto the downwind leg, when the pilot must ensure that the turn will create neither a collision risk, nor an interference with the orderly flow of circuit traffic. In the case of a join from the Initial Point, lookout must be diligently carried out well before the decelerating turn because of the higher speed of the manoeuvre. It should also be remembered that, during the turn onto the downwind leg, the upwind half of the circuit will be on the pilot's blind side, so that a good lookout must be done prior to the turn. As a further precaution, the turn should, whenever possible, be routed overhead the upwind runway threshold so that aircraft taking off or overshooting can pass safely underneath.

Circuit Pattern

28. In most cases when joining from the deadside, the aircraft should be flown in a continuous turn to the start of the downwind leg. A 'Downwind' call is made when opposite the upwind end of the runway, with the aircraft turning onto the runway reciprocal track. In crosswind conditions, it will be necessary to make an allowance for drift on the downwind leg. The pre-landing checks should be completed on the downwind leg. When a suitable position is reached, which will depend on the wind strength and the type of approach being made, a turn should be made onto the final approach. This turn should be adjusted to position the aircraft to be lined up with the runway for a final straight-in approach. At this stage, before the final approach is begun, final checks are completed, in particular ensuring that the undercarriage is locked down. The 'Finals' call is made during the turn, confirming, if applicable, that the undercarriage has been checked.

29. Aircraft with low approach speeds may fly a modified square circuit (Fig 3), due to their smaller radius of turn. This modified circuit differs from the circuit described previously, in that the turns across wind onto the downwind leg, and from the end of the downwind leg onto the final approach, are not continuous. In both cases, a straight leg is introduced at the mid-point of the turn, ie at approximately 90^{o} to the downwind leg. These legs are known as the crosswind and base legs respectively and ensure that the correct spacing from the runway is achieved during the downwind leg.

8-13 Fig 3 The Modified (Square) Circuit Pattern



THE APPROACH

General

30. The first requirement for a good landing is a good approach, which may be made with or without assistance from the engine. An engine-assisted approach is the norm, but the pilot of a single-engine training aircraft must be capable of completing a safe glide approach and landing. This skill is essential to perform a safe forced landing in the event of engine failure.

Use of Flap

31. The use of flap during an approach will give:

a. A steeper descent path at a given speed and power setting, and consequently, a better view for the pilot, over the nose.

b. A lower approach airspeed (as the stalling airspeed is reduced) and, hence, a shorter landing run.

The amount of flap used will depend on the type of aircraft and the wind conditions prevailing.

Effect of Wind

32. The two main advantages of making an approach and landing into wind are that the groundspeed is reduced to a minimum for a given airspeed, and drift is eliminated. Consequently, the landing run will be shortened, the undercarriage will not be subjected to unnecessary side loads, and the tendency to swing will be reduced. In addition, if it is necessary to go around again, the aircraft will be in the best position to regain height rapidly.

33. **Wind Gradient**. The change in wind speed and/or direction with changes in height is known as 'wind gradient'. It occurs at all levels of the atmosphere but, as long as it is not too severe, does not usually cause any problems. (A severe wind gradient is known as 'wind shear' and can present serious hazards to aircraft. This topic is dealt with in Volume 8, Chapter 17.) Allowances for wind gradient may have to be made during an approach to land. Below 2,000 ft agl, a progressive decrease in the wind speed and a change in direction are caused by friction between the moving air mass and the ground. The changes in both speed and direction will be most pronounced when a strong wind is blowing over an uneven surface. The effect of this low-level wind gradient can be to cause a sudden reduction in IAS while the aircraft is on the final approach to land. Aircraft which are unable to accelerate quickly enough to counter this loss of airspeed may experience a rapid sink rate, with a subsequent heavy landing, or touchdown in the runway undershoot. Pilots of susceptible aircraft (mainly jets and heavy aircraft) must therefore take the wind gradient on the final stages of the approach into account. The approach should be flown at a slightly higher IAS than normal and the requirement for a rapid application of extra power should be anticipated. The effect of wind gradient is sometimes aggravated by the presence of turbulence which, if encountered, may greatly increase any rate of sink that occurs. If turbulence on the final approach is suspected, reported or forecast, an extra speed allowance should be added to both the approach and threshold speeds. In such conditions, the Aircrew manual will normally give guidance as to the amount to be added.

34. **Gusts**. Gusts are sudden (almost instantaneous) changes in wind speed. They are more severe when the wind is strong. Gusts also tend to be stronger on hot days when the effect of thermal currents, caused by the uneven heating of the earth's surface, is most pronounced. In conditions of moderate to high wind, gusts may also be accompanied by eddies, caused by the horizontal shielding effect of buildings and trees. If gusts are anticipated or reported, the approach and threshold speeds will normally be increased (referred to as 'factoring'). Advice on factoring for gusts will usually be found in the Aircrew Manual. However, in the absence of such advice, these speeds should be increased by half of the gust factor. For example, if the surface wind is reported as "240/15 gusting 35 kt", half the gust factor (ie 10 kt) should be added to the normal approach and threshold speeds. This should ensure that the aircraft will remain safe if a full-strength gust is encountered anywhere during the approach.

(**Note**: Where speeds are increased for wind gradient and gusts, it is essential that the maximum threshold speed, as calculated for scheduled performance, is not exceeded. Other limiting speeds also need to be considered, e.g. tyre limit speed, RHAG engagement speed, etc.)

Manoeuvrability

35. At the relatively low speeds used on the approach, the amount of bank and g that can be applied is limited. The higher the landing weight, the higher the stalling speed and therefore, the amount of bank that can be safely used at a given airspeed is reduced. Whereas, for example, 45º of bank could be safely applied at the speed used when turning in to commence the final approach, the same angle of bank used at a lower airspeed at some later stage of the approach could rapidly increase the rate of descent or induce a stall. This consideration applies particularly to aircraft having combinations of high wing loading and sweepback, and when operating at, or near to, the maximum landing weight.

Engine Handling

36. With many aircraft, Aircrew Manuals stipulate a minimum power setting that should be used on the approach until definitely committed to the landing. If the aircraft undershoots with the power setting below the minimum recommended, the engine acceleration characteristics - particularly with gas turbines - may entail a considerable and possible disastrous delay before sufficient power is reached to correct the approach path. In addition, with the power below the minimum figure, any attempt to hasten its build-up may cause a compressor stall. Steep approaches needing little or no power should therefore be avoided unless absolutely necessary.

Approach Path

37. There are two methods of flying an approach path:

a. The classic form of approach is that during which height, speed and power are progressively reduced until the aircraft arrives at the touchdown point with the engine throttled back and the speed at its lowest value above the stall.

b. The 'Point and Power' method is now in common use. This method requires the pilot to set up a constant angle of approach towards the 'aiming' point on the runway, controlling the airspeed by throttle movements. The airspeed is maintained at the 'approach' speed, which is calculated by adding a certain value to the target threshold speed. The 'threshold' speed (ie speed when crossing the runway threshold) is governed by the landing weight of the aircraft and the flap setting used.

38. The precision approach path indicator (PAPI) is a system of lights, providing pilots with a visual indication of the correct glideslope information during the approach to land. A PAPI installation, which can be used from ranges in excess of 12 km (7.5 nm), consists of a bank of four light units on each side of the runway. The beam of light from each unit comprises a white upper half and a red lower half, separated by a very narrow transition band. The changeover from one colour to the other is so precise that at a range of 3 km (2 nm) an observer has only to move about 1 metre up or down to see the changeover. The four units are set up at different angles so that there is one degree difference between the highest and lowest settings; the highest setting is the one nearest to the runway, the five different indications which a pilot will receive from the PAPI installation in respect of the aircraft's relationship to the glidepath are shown in Fig 4.

39. The PAPI glideslope angle should be identical to the station's precision approach radar (PAR) glidepath. If there is no PAR, the glideslope angle will be determined by local operational and flight safety requirements but should normally be 2½ degrees or 3 degrees. The PAPI units can be adjusted through a range from 2 to 10 degrees. The units should be positioned:

a. To be coincident with ILS touchdown.

b. To be coincident with PAR touchdown where no ILS is fitted.

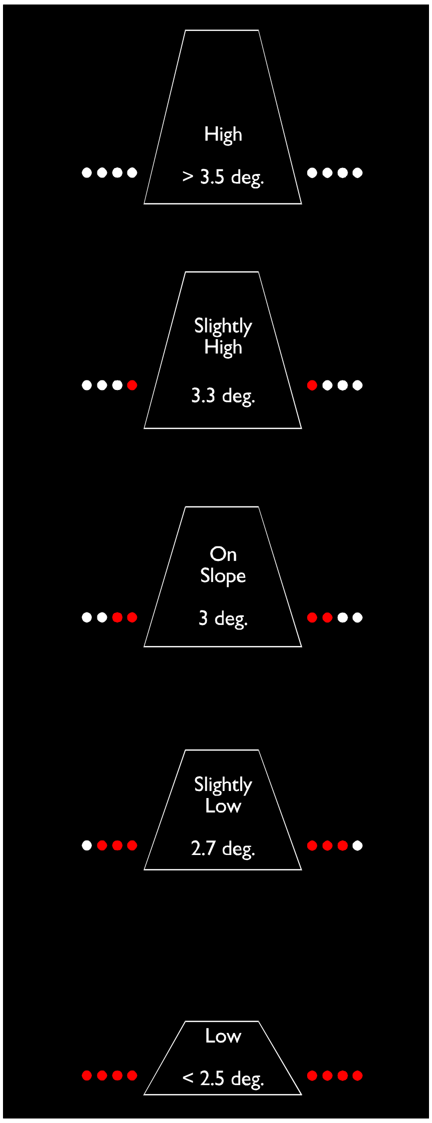
c. Approximately 850 ft ± 260 ft (260 m ± 80 m) from the threshold where neither ILS nor PAR is fitted.

d. To ensure that the minimum wheel clearance over the threshold is not less than 6 m (20 ft). There is a variation in the eye-to-wheel heights from one aircraft type to another, so PAPIs are aligned such that they are correct for the aircraft type which is the major user at each airfield. The eye threshold for each airfield fitted with PAPIs is published in the En-route Supplement (Threshold Crossing Height). Aircrew need to know the eye-to-wheel height for their aircraft type, in the landing configuration, so that when landing at an airfield at which their aircraft is not the major user, they can apply it to the figure quoted in the En-route Supplement, and check that the PAPIs give them an adequate safety margin.

40. Irrespective of the type of approach, the aim should always be to maintain a constant and moderate rate of descent. Although some circumstances may demand steep approaches with a high rate of descent and little or no power, or flat approaches with a low rate of descent and a high-power setting, such approaches should not be used under normal conditions since the margins of safety are reduced.

41. On aircraft having high wing loadings, the rate of descent must be kept moderate. If the rate of descent is high, a comparatively large amount of height and power is needed to check the descent progressively, and any attempt to hasten the correction can easily cause a g stall.

8-13 Fig 4 PAPI Indications



LANDING

Definitions

42. The following terms are used during the approach to land:

a. **Final Approach**. The 'Final Approach' is considered to start at the completion of the final turn in a visual circuit, or when lined up with the runway in the case of an instrument approach.

b. **Round-out**. The 'round-out' is the term used to describe that part of the final approach during which the rate of descent achieved on the approach is reduced to the lower rate required for the landing.

c. **Hold-off or Float**. The 'hold-off' or 'float' is the term that describes the period after the round-out, during which the aircraft is flown parallel to the ground with a steady, high angle of attack and falling air speed until the aircraft touches down.

Nosewheel Aircraft

43. As the aircraft approaches the threshold of the runway, the rate of descent should be checked by a gentle backward pressure on the control column; at the same time, the throttle should be closed gradually. In this attitude, the airspeed decreases, and the aircraft should descend gently onto its main wheels. If, after rounding out, there is a tendency to float or gain height, the nose has been raised too high during the round-out; the nose should then be lowered slightly, and the main wheels deliberately placed onto the runway, so avoiding any tendency to float. The rate at which power is reduced is not the same for all aircraft; some types, particularly highly loaded aircraft and those with swept wings, require power to be maintained during the round-out to prevent an excessively rapid drop in speed due to the high drag in the nose-up attitude. Unless power is used to prevent this, the rate of descent can increase rapidly, causing an undershoot or a heavy landing (see para 41).

44. An aircraft with a nosewheel undercarriage should be landed on the main wheels with the nosewheel held off the ground. This attitude is a little higher than the attitude of the aircraft while on a normal approach and, therefore, only a small change of attitude is required when rounding out. Since the aircraft's centre of gravity is ahead of the main wheels, the aircraft has a tendency to pitch forward onto the nosewheel on touchdown. This reduces the angle of attack so that there is normally no tendency to balloon off the ground. The nosewheel should be lowered onto the ground before the wheel brakes are used, although on some aircraft, the nosewheel cannot be held off the ground once the main wheels have touched down. Wheel brakes should then be used to decelerate and maintain a straight landing run.

45. On some aircraft, the nosewheel may be held off initially and aerodynamic braking employed. Aerodynamic braking consists of holding the aircraft in a marked tail-down attitude for the first part of the landing run. Thereby, the aircraft offers the largest possible cross-sectional area to the airflow, giving increased drag to slow the aircraft down. This technique reduces the amount of wheel brake required subsequently. If aerodynamic braking is used, the landing run will be longer than if the nosewheel had been placed on the runway and the wheel brakes applied at the earliest possible moment. Prolonged aerodynamic braking is useful only when there is sufficient runway available, or if the wheel brakes have failed.

Tailwheel Aircraft

46. **Basic Technique**. The rate of descent is controlled by rounding out and reducing power. However, in tailwheel aircraft, the control column should be moved progressively back, increasing the attitude (angle of attack) as the speed decreases, just holding the aircraft clear of the ground. Too rapid a movement of the control column causes the aircraft to balloon away from the ground, while too slow a movement allows the aircraft to sink onto its main wheels and bounce. In a well-judged landing, the moment is reached when the aircraft will sink onto all three wheels together. This is known as the three-point landing and has the following advantages:

a. The touchdown speed is the lowest possible (little more than the stalling speed) and this, combined with maximum aerodynamic braking due to the high angle of attack, gives the shortest landing run.

b. The wheel brakes may be used early in the landing run.

c. There is less danger of the aircraft nosing over if the wheel brakes are used too fiercely or the wheels enter soft ground.

47. **Wheel Landing**. A wheel landing is one in which the main wheels are placed on the ground before the tailwheel. This type of landing differs from the three-point landing in that, once the aircraft is flying just above the ground, it is not held off, but the main wheels are placed gently, but deliberately, on the ground. The wheel landing may, on occasions, be preferred to the three-point landing because:

a. The change of attitude when landing is less and there is no hold-off, so judgement is easier.

b. It has certain advantages when landing in a crosswind.

c. It provides a safer means of landing a heavily-laden aircraft.

The main disadvantage of the wheel landing is that the speed is higher at the moment of touchdown, making for a longer landing run.

Types of Approach and Landing

48. **Engine-assisted Approach**. The use of power on the approach enables the IAS and the rate of descent to be adjusted safely over a wide range. However, very low, flat approaches using high power are undesirable. Other characteristics of the engine-assisted approach are:

a. By using the required power settings, it is possible to regulate the angle of approach despite varying wind strengths.

b. The change of attitude when rounding out is small compared with that for a glide approach.

c. The use of power reduces the stalling speed, and thus a lower approach speed can be used.

In propeller-driven types only, the increased slipstream gives more effectiveness to the rudder and elevator than when no power is used.

49. **Glide Approach**. The salient features of the glide approach are:

a. As there is no power with which to adjust the track over the ground, a high standard of accuracy is required to judge the constant sight line angle (CSLA) for the approach.

b. The correct gliding speed is maintained by use of the elevator. In turns, the nose of the aircraft must be lowered to maintain that speed.

c. The rate of descent is high, and the angle of descent may be steep, particularly in advanced trainers and operational aircraft. If descending into a strong wind, the rate of sink may appear alarmingly high.

d. A considerable change of attitude is made during the round-out; therefore, to avoid g stalling, the round-out must be started earlier and at a higher IAS than for an engine-assisted approach.

50. **Flapless Landing**. Aircrew Manuals contain advice on the speeds and techniques to be used for a flapless landing. Flapless landings should be practised occasionally to ensure that the pilot is competent to use this method should the flap mechanism fail. On high performance aircraft, the low drag with the flaps up often causes some difficulty in reducing speed after turning onto the final approach. Adjustments should be made to achieve and stabilise the speed early in the approach to avoid arriving over the runway threshold at too high a speed. A flapless approach and landing differs in the following ways from one in which flaps are used:

a. The approach and touchdown speeds are higher.

b. Because of a, the radius of the final turn may be larger.

c. The descent path is flatter, and consequently the approach may be longer.

d. The change of attitude in the round-out is smaller.

e. The landing run is longer.

f. In a tailwheel aircraft, the period of float during the hold-off is longer.

Crosswind Approach and Landing

51. There are two recognized methods of making the final approach in a crosswind (see Fig 5): one maintaining wings level and the other a wing down technique.

a. **Wings Level Technique**. Drift is counteracted by heading the aircraft into wind, so that the aircraft tracks down the runway extended centre line (intended landing path) keeping the wings level (see Fig 5a).

b. **Wing Down Technique**. Drift is counteracted by banking into the crosswind and using rudder to align the aircraft with the runway extended centre line (intended landing path). This involves a slight sideslip (see Fig 5b). Aircraft which have restrictive undercarriage side load limitations may only be cleared to use this technique.

52. **Nosewheel Aircraft**. In the final stages of the approach, there is normally less drift because the wind backs and decreases in speed near the ground. This should be anticipated but the temptation in the wings level technique (Fig 5a) to align the aircraft with the intended landing path or runway too soon must be resisted. Similarly, in the wing down technique (Fig 5b) the bank must not be taken off prematurely. In either case, the round-out, which is otherwise normal, is completed with the drift correction still applied. For the wings level method, once the round-out has been completed, the

rudder should be applied smoothly and firmly to yaw the aircraft into line with the landing path and then the main wheels placed positively onto the runway. In swept-wing aircraft particularly, there is a tendency for the into-wind wing to rise as the aircraft is yawed straight; this must be anticipated and corrected with aileron. Similarly, for the wing down technique, at round-out the aircraft should be rolled wings level, maintaining balance and the main wheels placed positively on the runway.

8-13 Fig 5 Crosswind Approach and Landing

Fig 5a Wings Level Technique

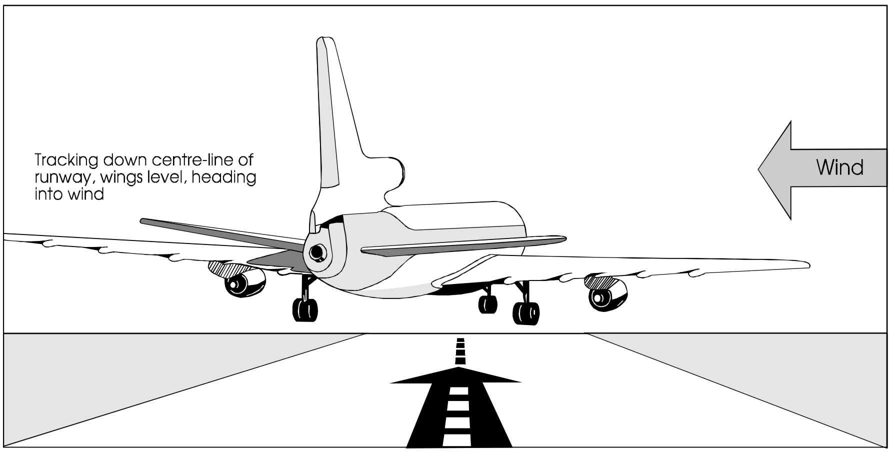
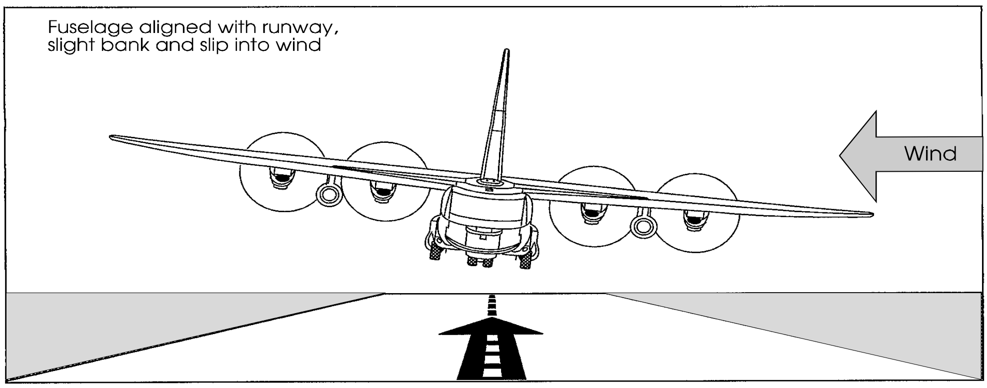


Fig 5b Wing Down Technique



53. **Tailwheel Aircraft - Wheel Landing**. In a strong crosswind, a three-point landing is not advisable. Instead, as soon as the hold-off height has been reached, the aircraft should be yawed into line with the landing path and, without further delay, both main wheels placed firmly on the ground, directional control being maintained with rudder while this is still effective. Although involving a longer landing run, a possible misjudgement of the moment of the three-point landing is avoided.

Overshoot Procedure

54. To overshoot, the throttle should be opened smoothly to the power required, the wings levelled, and the undercarriage raised whilst the IAS is allowed to increase to the recommended figure. Flaps should be retracted in accordance with the Aircrew Manual. Once a decision to overshoot has been made, particularly at night or in instrument flight conditions, no further height should be lost and the aircraft should be held in a steady climb while overshoot actions are completed.

BRAKING AND SUPPLEMENTARY METHODS OF RETARDATION

Braking

55. It is obvious that a considerable amount of energy must be developed by the engine(s) to accelerate the aircraft to take-off speed; therefore, a similar amount of energy has to be absorbed to bring the aircraft to rest. Some of this energy can be dissipated by the use of reverse thrust, aerodynamic braking, brake parachutes, flaps etc; the wheel brakes then have to absorb any remaining kinetic energy by converting it to heat. The kinetic energy which an aircraft's wheel brakes absorb can be calculated for a normal and an emergency case.

56. **Maximum Braking Speeds**. Two maximum braking speeds are generally quoted for an aircraft:

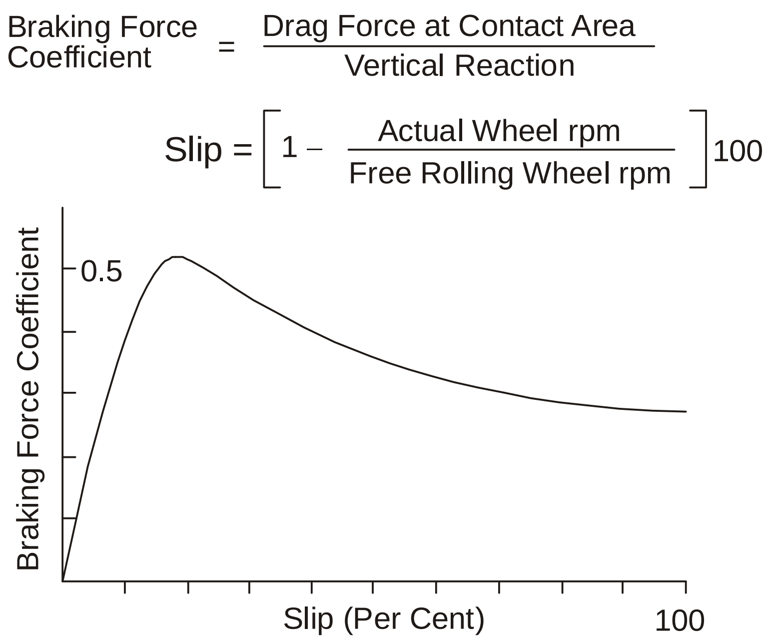
a. **The Maximum Normal Braking Speed**. The maximum normal braking speed is that speed at which maximum continuous wheel braking may be applied and the aircraft brought to rest without the brakes sustaining lasting damage.

b. **The Maximum Emergency Braking Speed**. The maximum emergency braking speed is that speed at which continuous maximum wheel braking may be applied to bring the aircraft to rest, accepting that the brakes will be rendered unfit for further use. If the brakes are applied at a speed higher than the maximum emergency braking speed, they will overheat and fail before the aircraft is brought to rest.

The relationship between speed and energy is not straightforward however, and the fact that the wheel brakes are applied at a speed 10 kt in excess of the emergency speed does not mean that the aircraft will be slowed to 10 kt; the brake units will, in fact, fail at a considerably higher speed.

57. **Maximum Braking Efficiency**. When it is necessary to operate on a marginal runway length, maximum braking efficiency is required. This is obtained by continuous application of brake pressure at a level just below that which will operate the anti-skid units. Tests show that, on any surface, maximum braking efficiency is obtained at about 16% slip (locked wheels representing 100% slip). Depending on the type of surface, the coefficient of friction obtained with locked wheels may be as low as 50% of the maximum efficiency obtainable (see Fig 6).

8-13 Fig 6 Braking Force Coefficient vs Slip



58. **Aircrew Manual Advice**. The braking techniques for different aircraft depend upon many variables (e.g. runway length and condition, wind, supplementary methods of retardation, aircraft weight, etc) and the appropriate Aircrew Manual should always be consulted for the best methods of braking and retarding particular aircraft types.

Supplementary Methods of Retardation

59. The following are supplementary methods of retardation:

a. **Brake Parachute**. On some aircraft, a brake parachute is streamed after touchdown, giving a large and immediate increase in drag. When operating in strong crosswinds, care must be exercised when using a brake parachute, due to the increased weathercock tendency of the aircraft (see Volume 1, Chapter 11).

b. **Reverse Thrust**. On some jet engine aircraft, it is possible to change the direction of thrust to oppose the direction of travel of the aircraft.

c. **Reverse Pitch Propellers**. On many propeller-driven aircraft, it is possible to bring the propeller beyond the normal flight fine pitch limit. This will achieve either a maximum amount of aerodynamic drag from the propeller discs or reverse thrust - in which case thrust is used to oppose the forward movement of the aircraft.

60. In general, when using supplementary retardation, the threshold must be crossed at the correct speed, the throttle closed (to obviate float) and touchdown made at the desired point. Once firmly on the runway, the nosewheel should be lowered before using brake parachute or reverse thrust. Recommended maximum wheel braking should be applied with the weight firmly on the main wheels. After a fully braked landing, it is essential that sufficient time should elapse before a further take-off is attempted. This time period will enable the brakes to cool, and thus restore their heat capacity. This is essential, to cater for possible abandonment during the subsequent take-off.

Braking on a Contaminated Runway

61. When landing on a contaminated runway, retardation may be considerably reduced depending on the degree of contamination and the type of runway surface. The touchdown techniques for a short landing should be adopted. Maximum braking efficiency is obtained by making a firm touchdown and applying light, continuous braking as soon as the aircraft is firmly on the runway and the wheels have had time to spin-up. The full length of the runway should be used.

Emergency Retardation

62. Rapid retardation may be achieved by certain aircraft types designed and approved for the purpose by engaging an arrester barrier or cable arrester gear. Full details of techniques and engagement limitations are in the relevant Aircrew Manuals and a brief description of airfield arresting systems is to be found in the Annex to this chapter. Aircraft limitations vary widely but the following factors are generally applicable and need to be taken into account before contemplating an arrester engagement.

63. **Arrester Barriers**. Some runways are equipped with a net arresting barrier at the upwind end. These barriers are designed to stop aircraft in an emergency, preventing them from going into the overrun area (see Volume 8, Chapter 14). Considerations are:

a. Propeller aircraft are not permitted to engage net barriers.

b. Some types will not be permitted to engage if the net has a steel top cable which might penetrate the canopy.

c. Pilots should aim for the coloured panel in the centre of the net, leaving power and brakes off so that the net becomes slack when the aircraft is brought to rest.

d. Aircrew Manuals will specify barrier entry speed limitations which will depend upon all-up weight and whether the barrier is tensioned for light or heavy engagement.

e. External stores and full fuel tanks should normally be jettisoned before engagement, preferably whilst airborne.

f. The canopy must remain closed during engagement until the aircraft has finally stopped.

64. **Cable Arresting Gear**. Arrester cables are installed at both ends of certain runways. Only aircraft approved in the Aircrew Manual, and with a serviceable hook fitted, may engage cables. Either the approach end cable or the overrun cable may be engaged as the situation demands. Considerations are:

a. Limitations on trampling rigged cables, and on hook lowering, are given in the Aircrew Manual, as are maximum engagement speeds for the all-up weight.

b. Cables are of differing diameters and may not be suitable for some hooks.

c. The cable should be engaged at right angles near the centre. It is normally recommended to avoid the exact centre if the runway has centreline lighting, which may cause hook bounce and result in a missed engagement.

d. Brakes should be off on engagement and remain off when arrested. Brake assistance may or may not be recommended during the deceleration phase.

e. Power should be set to idle (no reverse thrust) on engagement. Subsequent use of power to reduce any excessive cable pull back may be recommended.

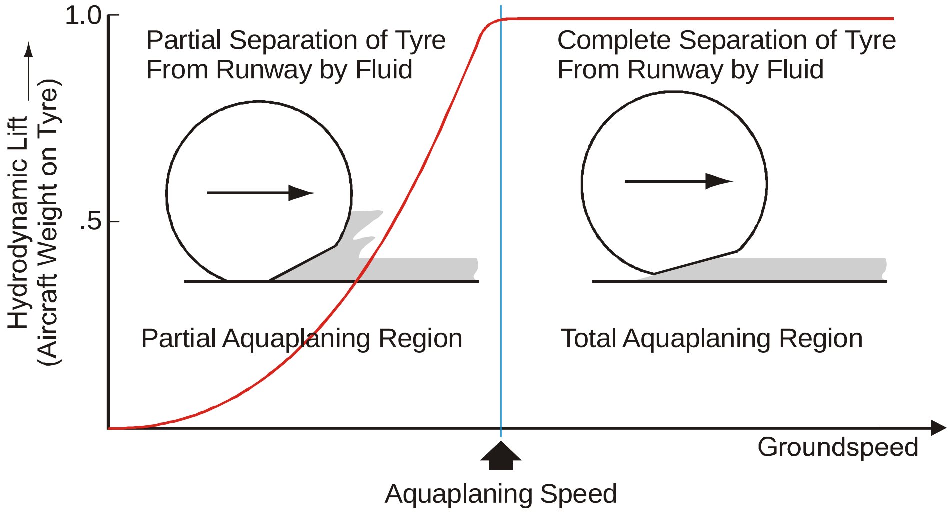
f. Nosewheel steering, if fitted, may be used for directional control during any pull back after engagement.

AQUAPLANING

Definition

65. As an unbraked pneumatic tyre rolls along a water-covered runway, it contacts and displaces the stationary water. The resulting change in momentum of the water creates hydrodynamic pressure which reacts on the runway and tyre surfaces. This hydrodynamic pressure tends to increase as the square of the groundspeed. As the groundspeed increases, the inertia of the water tends to retard its escape from the tyre/ground contact area, and a wedge of water forms, which begins to lift the tyre from the ground (see Fig 7).

8-13 Fig 7 Development of Tyre Aquaplaning



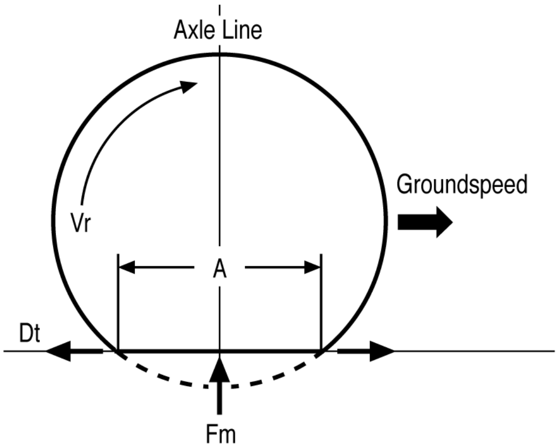
Further increase of groundspeed increases the hydrodynamic lift until the lift developed equals the weight supported by the wheel. Any further increase in groundspeed will result in the tyre being lifted off the runway surface. This is the condition of full aquaplaning. Partial aquaplaning, as its name implies, occurs when only part of the tyre is lifted from the surface as shown in Fig 9.

Spin Down of Unbraked Wheel

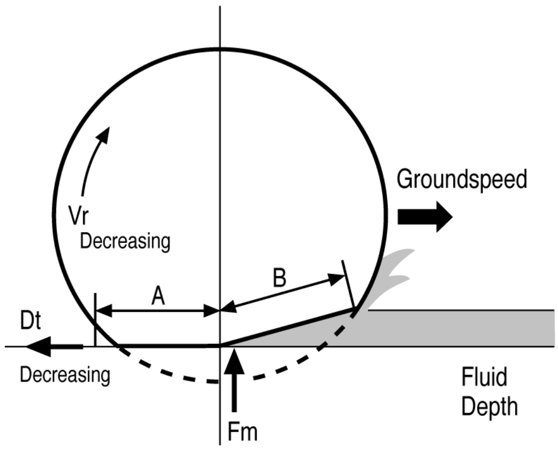
66. When aquaplaning occurs, perhaps the most unexpected feature is the condition in which free-rolling (unbraked) wheels slow down or stop completely. This wheel spin-down arises from hydrodynamic lift effects which combine to provide a total wheel spin-down moment in excess of the wheel spin-up moment caused by all tyre drag sources. In Fig 8, which illustrates the force on a tyre from a dry runway, 'A' indicates the size of the tyre 'footprint' on the runway and 'Dt' is the drag force caused by all the tyre drag sources, which combine to form the wheel spin-up moment. 'Fm' is the vertical load on the tyre due to aircraft mass. 'Vr' is the wheel rotational speed.

67. On a water-covered runway, as in Fig 9, a fluid wedge has started to penetrate the tyre footprint, and the wheel is partially supported by the hydrodynamic force produced by this wedge. 'B' is the tyre/water contact area, and the tyre footprint (A) is decreasing in size. Because of this, the tyre drag (Dt) is decreasing and the force (Fm) is moving forward of the axle line, causing a wheel spin-down moment. In Fig 10, full aquaplaning speed has been reached and the tyre has been completely lifted off the runway surface. The wheel spin-up moment (Dt) is approaching zero and the vertical force (Fm) has moved even further forward of the axle line. The wheel spin-down moment is thus at a maximum and the wheel's rotational speed will be decreasing fairly rapidly towards zero.

8-13 Fig 8 Development of Tyre Aquaplaning



8-13 Fig 9 Partial Aquaplaning



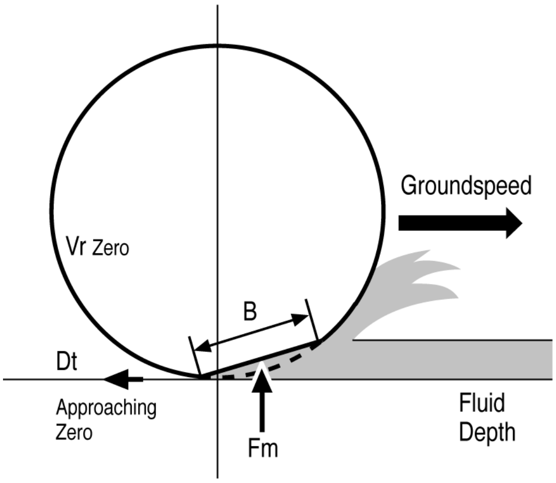
Factors Affecting Aquaplaning

68. **Effect of Weight and Tyre Pressure**. Changing the weight on the tyres appears to have little effect on the speed at which full aquaplaning occurs. As the weight on the tyre changes, so the contact area changes and the ratio of weight to area remains constant; this is essentially due to the tyre inflation pressure. It is this pressure that the hydrodynamic lift pressure must equal over the entire contact area before total aquaplaning occurs. A simple expression based on hydrodynamic lift theory can be used to predict full aquaplaning speed:

$$V = 8.6\sqrt{P} \quad (\text{lb/in}^2)$$
$$\text{or } V = 33\sqrt{P} \quad (\text{bars})$$

where V = full aquaplaning speed (kt) and P = tyre pressure in units indicated. It must be remembered, however, that aquaplaning is a progressive phenomenon, and significant losses in braking and directional control will occur below this speed. Once aquaplaning has started, the wheels spin-down and stop fairly rapidly. However, if groundspeed is reduced, the time for the wheels to spin-up again is much longer, and aquaplaning will persist to a lower speed than that given by the formula; how much lower depends upon the surface texture.

8-13 Fig 10 Total Aquaplaning



69. **Water Depth and Runway Surface**. The actual depth of water required to initiate full aquaplaning depends on surface texture. Trials have shown that when puddles form to a depth of as little as 1 mm to 2 mm there is a potential risk of aquaplaning.

Human Factors and Take off, Circuit, Approach and Landing

Take off, Circuit, Approach and Landing are fundamental abilities for any pilot. It is not easy for the beginner but with focus, practice and time in the seat these basics will become second nature. However, practice, practice and more practice can lead to low arousal, complacency and boredom. Loss of Situation Awareness in the circuit does happen and can be a killer; wheels up landings, flaps left down and so on do occur and are inevitably costly and even fatal.

CHAPTER 15 - STALLING AND SPINNING

STALLING

Introduction

1. An aircraft stalls when the smooth flow of the air over its wings changes to a turbulent flow and the lift decreases. As this may happen suddenly, a pilot must be able to recognize the approach of a stall and know the recovery action for minimum loss of height.

Stalling Characteristics

2. The stalling characteristics of an aircraft should be taught during aircraft familiarization. In general, stalling follows a common pattern. As speed is reduced, warning of the impending stall is given in the form of buffeting. This can vary from being fairly severe to almost imperceptible, depending on the aircraft type and configuration. The buffet may start approximately 5 kt to 15 kt before the stall, and usually increases in strength as the stall is approached. On some aircraft, an artificial indication of the approaching stall is provided. One method of doing this is to make the whole control column, or an inset portion of the handgrip, vibrate strongly at a preset speed close to the stall.

NOTE: Artificial stall warning systems (stick shakers) and automatic stall recovery devices (stick pushers) are essential for safe flight and should never be deliberately de-activated in flight.

3. On all aircraft, as speed is reduced, the controls become less effective and larger movements are needed to correct or achieve a given displacement of the aircraft. On aircraft without power-operated controls, the feel of the controls becomes noticeably slack and their effectiveness decreases as the stall approaches.

4. At the stall, either wing and/or the nose may drop suddenly, and to a varying degree. With power on, the stalling speed is lower, the nose-up attitude of the aircraft at the stall is higher and any tendency to drop a wing is aggravated. The lower stalling speed is due to the vertical component of the upwards-inclined thrust line, which provides an additional lifting force and so allows level flight at a lower speed. Propeller slipstream over the mainplane also produces additional lift. The greater the power used, the lower the stalling speed.

5. On many types of aircraft, when the initial wing or nose-drop occurs, the control column may not be fully back. In such circumstances, any further backward movement of the control column will make a wing drop more likely and may induce a spin. Therefore, in general, recovery should be made when the initial nose or wing-drop occurs.

6. If an unintentional spin occurs when stalling with the flaps and undercarriage down, consideration should be given to raising them, to ensure that they do not affect the recovery, and to minimize damage due to excessive speed. The Aircrew Manual will give appropriate advice if aircraft handling or safety is likely to be affected.

Stalling in Manoeuvres

7. If an attempt is made to change the flight path in the pitching plane too quickly (for example, by turning at too high a rate or by recovering from a dive too sharply) a stall may occur. Such an occurrence is known as an 'accelerated stall', or 'g stall'. It is also sometimes referred to, less accurately, as a 'high speed' stall. This term is not altogether appropriate, since the speed may be only a few knots above the level flight stalling speed when the control column is moved back to apply the g.

8. Warning of the approach of an accelerated stall is normally given by airframe buffeting, which increases in intensity as the stalling angle is approached. The stick force and control effectiveness are proportional to the IAS at which the stall occurs, which may be any speed of which the aircraft is capable.

9. The manoeuvres described in para 7 involve accelerations in the pitching plane and result in an increased loading on the aircraft. Although the accelerated stall occurs at the same angle of attack as the normal stall, the IAS at which it occurs is roughly equivalent to the level flight stalling IAS multiplied by the square root of the load factor. For example, during a 60º banked turn (i.e. with a load factor of 2) an aircraft having a normal stalling IAS of 100 kt would stall at an IAS of 100 $\times$ 1.41 kt, i.e. 141 kt.

10. At the lowest speeds, even slight g loading is sufficient to cause a stall, particularly on aircraft with high wing loadings. In consequence, steep approaches for landing should not normally be made on these aircraft, as the large backward movement of the control column, required to round-out for the landing, may apply sufficient g to stall the aircraft at the low speed used on the approach.

11. During diving manoeuvres at low altitude, and dive recoveries such as those used in air-to-ground weapon delivery, ample height must be allowed for recovery. Over-concentration on target acquisition and aiming may result in the aircraft having insufficient height for a safe recovery. If, in the subsequent attempt to recover, excessive g is applied, the aircraft will stall and possibly autorotate. If the speed is high, even though the stalling angle may not be reached, the g threshold of the pilot and/or limitation of the aircraft may be exceeded.

12. Any pitch-up tendencies possessed by a swept-wing aircraft are exaggerated when enough g is applied to stall the aircraft in a manoeuvre. The higher the g applied to cause the stall, the stronger is the pitch-up and as a consequence, there will be an unavoidable increase in g before the motion can be checked by a forward movement of the control column. This resultant extra g caused by pitch-up can be serious at high IAS and low altitude and any temporary increase might exceed the g limitations. However, the g limitations placed on swept-wing aircraft do take this possibility into account and, unless the g limitation is exceeded, pitch-up should not occur on an aircraft with its centre of gravity within the specified limits. At the highest altitudes, although forming an operational weakness, pitch-up does not usually result in a serious increase in g, as both the initiating g and the resultant g are low, as a result of the reduced IAS at these altitudes.

13. When the stall occurs in a turn, depending on which wing stalls and drops first, the aircraft will roll either into or out of the turn. During recovery from a dive, either wing may drop. In certain aircraft types, the wing-drop is sudden and may be severe. If this occurs, and the control column is held back, the aircraft may autorotate. At high speed, this can cause severe overstressing.

14. Recovery from any stage of an accelerated stall is made by moving the control column forward until the buffeting stops.

Stall Recovery

15. Stall recovery must be made as quickly and decisively as possible with a minimum loss of height, using full power.

16. **Straight-wing Aircraft**. The recommended recovery action for straight-wing aircraft is to move the control column forward far enough to un-stall the wings and simultaneously apply full power, as quickly as engine limitations permit. Care must be taken not to move the control column too far forward; otherwise unnecessary height will be lost. If sufficient thrust is available, it should only be necessary to move the control column forward slightly, as the thrust will be adequate to accelerate the aircraft to a higher speed and, as stated at para 4, the use of power reduces the stalling speed. If a wing drops, the standard stall recovery action given in the Aircrew Manual should be taken. The aircraft must be eased gradually out of the dive following recovery; any attempt to rapidly achieve level flight may induce a g stall and cause a further loss of height.

17. **Swept-wing Aircraft**. The general stalling characteristics of aircraft with swept-back leading edges may differ considerably from those of straight-wing types. The Release to Service and Aircrew Manual should be consulted to check the minimum permitted flying speed, and whether or not the aircraft is cleared for stalling practice. As on a straight-wing aircraft, as the stall is approached it is usual for the buffet to be felt, increasing in strength as the stall approaches, although the amount of buffet may be barely discernable in some cases. On all swept-wing types, it is imperative to recover as soon as the initial wing or nose drop occurs. Advice on handling during the approach to the stall, the stall, and stall recovery can be found in the Aircrew Manual.

SPINNING

Introduction

18. The following paragraphs on spinning are general remarks only. Aircrew Manuals should always be consulted for entry, recovery and emergency actions before spinning an unfamiliar aircraft.

19. The spin is not a normal flight manoeuvre; it is the result of yawing or rolling at the point of stall. As it is possible to enter a spin through mishandling the controls during aerobatics, steep turns and other quite normal manoeuvres, the pilot must be able to recognize a spin and recover promptly. This is achieved by practising spinning and spin recovery on suitable types of aircraft, so that the pilot becomes accustomed to the physical sensations of spinning and appreciates the rapid rates of roll, yaw and pitch of the aircraft. On some aircraft, the control column forces experienced during a spin may be high, necessitating the use of both hands to effect recovery. On other aircraft, the forces may be so low that little or no effort is required to move the control column. In certain cases, considerable snatching occurs on the control column and some strength is needed to hold the control column in a desired position. During a high rotational spin, or if a pilot is unaccustomed to spinning, considerable disorientation and mental confusion should be anticipated. There have been instances when experienced pilots have diagnosed the direction of spin incorrectly. In such cases, what appeared to be the correct recovery action actually prolonged the spin.

Airmanship

20. Before practising spinning, the following checks should be carried out:

a. Before take-off, ensure that:

(1) The exercise is permitted and authorized, and the correct entry, recovery and emergency actions for the type are known.

(2) Full control deflections can be made and the neutral positions for the controls are known.

b. In the air, before entering the spin:

(1) Ensure that the weather conditions are suitable.

(2) Carry out the pre-aerobatic checks for the aircraft type.

(3) Brief the pupil or crew of the intended manoeuvre and the emergency actions to be taken should the aircraft not recover from the spin.

Abandoning a Spinning Aircraft

21. If a pilot considers that the height is insufficient to recover from a spin, the aircraft should be abandoned. Minimum heights for abandonment are specified in Aircrew Manuals and Group Orders.

Human Factors with Stalling and Spinning

When Stalling and or Spinning is carried out deliberately such as for demonstration or as part of air testing these events are well planned, briefed and executed in accordance with SOPs. However, inadvertent stalling and spinning have potentially fatal consequences following a loss of situation awareness by the pilot. The onset of physical and mental Stress can be immediate and place the pilot in a situation requiring rapid inputs to recover. Disorientation and focussed attention may be factors during the recovery; so adhere to SOPs and practice for such situations where possible.

CHAPTER 16 - AEROBATICS

Introduction

1. Aerobatic manoeuvres form an essential part of a pilot's training because:

a. They increase confidence, judgement and flying co-ordination.

b. They teach the quickest methods of recovering from a 'g' stall, incipient spin, unusual attitude or temporary loss of control.

c. They form the basis of some tactical manoeuvres.

d. They harden and accustom the pilot to the effects of positive and negative 'g', which will be experienced during later stages of pilot training.

2. The regulations concerning aerobatics are designed to safeguard life and property and should be adhered to at all times; they are laid down in MAA RA 2309(9).

Airmanship

3. Before starting any aerobatics, in addition to observing the regulations, the following checks (mnemonic - **HASELL**) should be carried out:

a. **H**eight - sufficient to perform the complete manoeuvre without descending below the prescribed minimum.

b. **A**irframe **-** check that flaps and undercarriage are UP, airbrakes tested and IN.

c. **S**ecurity **-** all equipment and loose articles should be stowed and the seat harness locked and tight. Particular attention should be paid to the lap straps and negative 'g' strap.

d. **E**ngine **-** all temperatures and pressures indicating normal and fuel sufficient for the exercise.

Note: If fuel is carried in overload or external tanks, ensure the aircraft is cleared for aerobatics with fuel in these tanks.

e. **L**ocation - make sure that the aerobatics will take place in airspace clear of **A**ctive airfields, **B**uilt-up areas, **C**ontrolled airspace and horizontally and vertically clear of **C**louds (remember **ABCC**). To avoid the possibility of disorientation during a series of aerobatics, select a suitable landmark (an 'anchor' point) and keep a position check with reference to it.

f. **L**ook-out - keep well clear of all other aircraft and clouds throughout the exercise.

Engine Handling

4. All throttle movements should be made smoothly and progressively, especially with jet-engine aircraft. Full power should be used only if the particular manoeuvre requires it. In some piston-engine aircraft fitted with a carburettor, the throttle should be closed if the engine cuts after negative loading. It may also be necessary to close the throttle before reaching an inverted position to prevent a rich cut.

Vertical Attitudes

5. If, at any time, the aircraft is inadvertently positioned in a vertical, or near-vertical, nose-up attitude at a low IAS, subsequent mishandling may cause it to spin. Any recoveries from this type of attitude should use the techniques detailed in the Aircrew Manual.

BASIC AEROBATICS

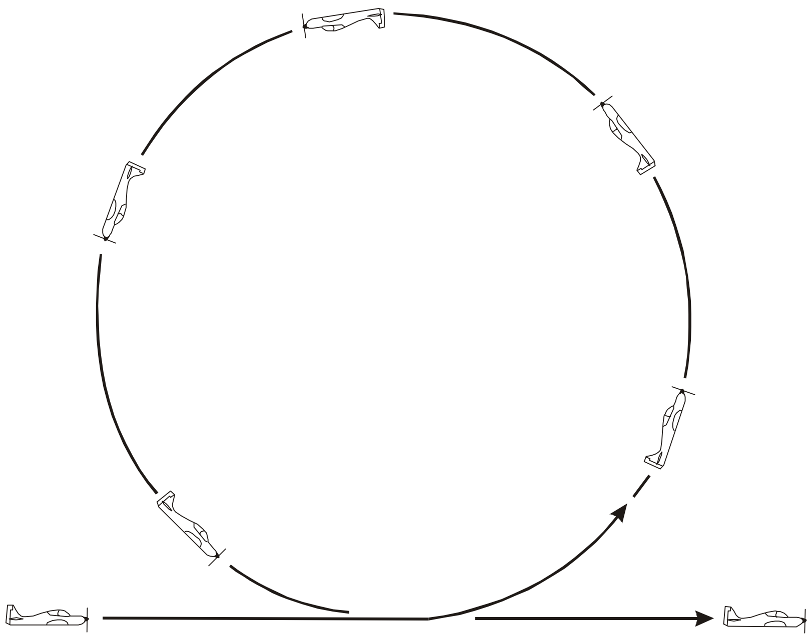
Recommended Speeds

6. Aircrew Manuals detail the recommended speeds for the standard aerobatic manoeuvres. However, with experience, the entry speeds may be reduced slightly, but it is not necessary to increase them.

Loop

7. In the loop, shown in Fig 1, ideally the aircraft starts from the straight and level attitude and returns to it, having pitched through 360º in the vertical plane. However, aircraft with low performance may have to commence from a shallow dive to achieve the entry speed. Positive 'g' loading should be maintained throughout, but its intensity will vary depending on the position in the loop. The required entry speed for the loop is based on the loss of speed during pitching to the apex whilst retaining sufficient speed to maintain control when inverted at the top of the manoeuvre.

8-16 Fig 1 Loop

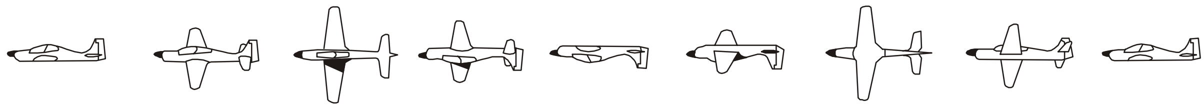


8. A loop should preferably be flown along a line feature to assist in keeping straight. If a shallow dive is required to achieve the required entry airspeed, the aircraft should not be retrimmed but the nose-up pitching tendency should be held by forward pressure on the control column. The area above and behind the aircraft must be confirmed clear before starting the manoeuvre. At the entry airspeed, the nose is pitched gently to maintain a constant pitch rate throughout the whole loop. When in the inverted position, the speed will be low (even below the level flight stalling speed) and care should be taken not to stall the aircraft. During the whole of the manoeuvre, rudder should be used to balance the aircraft and the ailerons used to keep the wings level. On aircraft with manually operated controls, and power-operated controls with 'q' feel, the control column forces required to maintain the pitch decrease to a minimum at the top when the speed is low. However, with power-operated controls where the artificial control column force is proportional to control column movement, the larger control column movements at the lower speeds at the top of a loop result in a greater control column force at this point.

Slow Roll

9. An aircraft is said to roll when it is rotated round its longitudinal axis through 360º (see Fig 2). This definition applies to all types of roll. Although the precise speed at which a roll is performed is not important, it must allow a good margin above the stalling speed. The higher the entry speed, the easier it is to control the roll and height loss is reduced. If the engine runs when inverted, the power assists in maintaining speed and height and controlling the attitude. The rate of roll depends on the type of aircraft, the entry speed to the roll and the amount of aileron deflection used.

8-16 Fig 2 Slow Roll

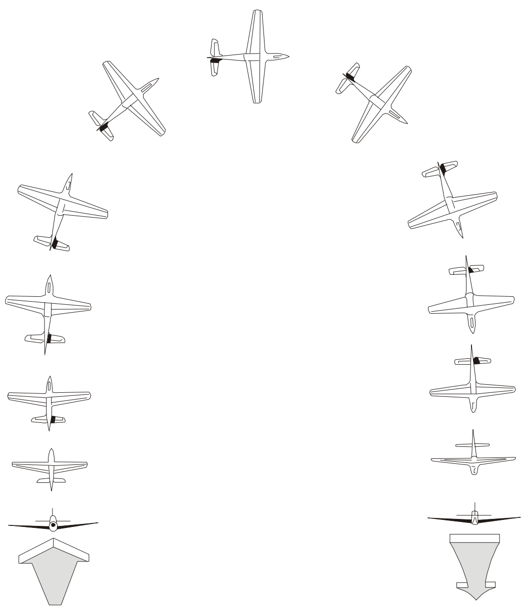


10. To fly a slow roll, a reference point should be chosen ahead on the horizon to assist in keeping straight. A good lookout is made into the area ahead and, at the required entry speed, the nose should be eased up to slightly above the straight and level attitude, and held. Aileron is then applied to maintain a constant rate of roll, with elevator and rudder being used as required to keep the reference point on the nose. As the inverted position is approached, the control column is eased forward to keep the nose above the horizon, the rudder being used to keep straight. As the aircraft continues to roll, and approaches the vertically banked position, top rudder is applied as required to stop the nose yawing below the horizon; aileron deflection has to be reduced to maintain a constant rate of roll. When rolling towards level flight, the controls should be centralized smoothly. With practice, a roll can be done without first raising the nose, constant height and direction being maintained throughout. It should be noted that some swept-wing aircraft have limitations on the use of rudder during rolling manoeuvres because of inertia cross-coupling (see Volume 1, Chapter 21, paras 109-118). The Aircrew Manual for the appropriate type of aircraft must be consulted before using rudder in any rolling manoeuvre.

Stall Turn

11. The stall turn, shown in Fig 3, is a method of changing direction by 180º. The Aircrew Manual should be consulted for advice on entry speed.

8-16 Fig 3 Stall Turn



12. To fly a stall turn, a ground feature should be chosen as an aid to orientation. From level flight, or a shallow dive if extra speed is needed, after checking that the area above and behind the aircraft is clear, the control column is eased back to pitch the nose up to a vertical climb, keeping the wings level by use of ailerons. The vertical attitude is checked by reference to the angle made by the wing tips to the horizon. The control column then has to be eased forward to maintain this attitude. As the speed reduces to the recommended speed, rudder is applied to cartwheel the aircraft around the wing tip and, if necessary, the engine is throttled back as the nose falls through the horizon. Ailerons are used as required to prevent roll whilst the aircraft is yawing. As the vertically down attitude is approached, the rudder is centralized and, keeping wings level, the aircraft is eased out of the dive.

Barrel Roll

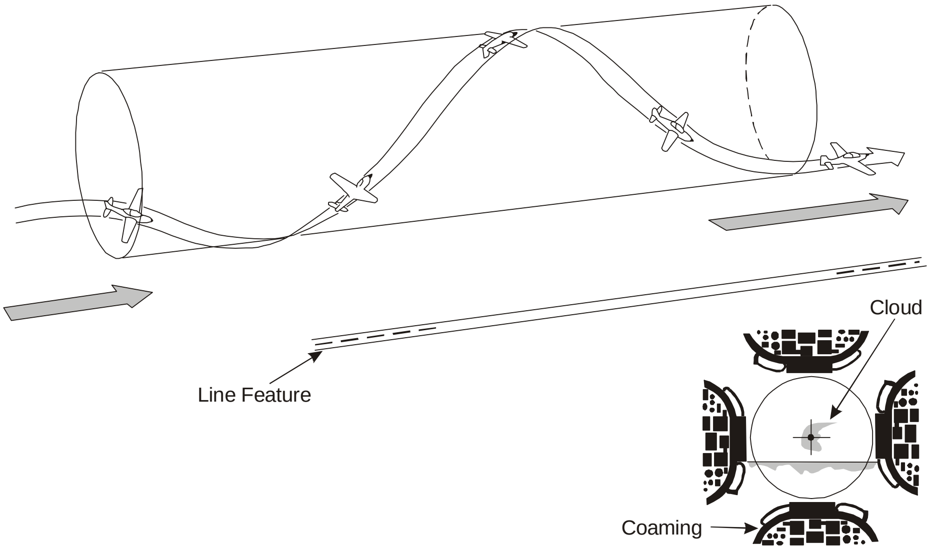
13. In a barrel roll, the aircraft both rolls and pitches through 360º. The flight path is helical with height and direction changing as the aircraft is flown round the outside of an imaginary barrel. The manoeuvre has to be co-ordinated, positive 'g' being maintained throughout the entire roll. Rudder is used to balance the aircraft. The manoeuvre is normally flown with a horizontal axis and, when viewed from the cockpit, the nose of the aircraft appears to describe a circle about a real or imaginary reference point on the horizon.

14. There are two methods of entering a barrel roll:

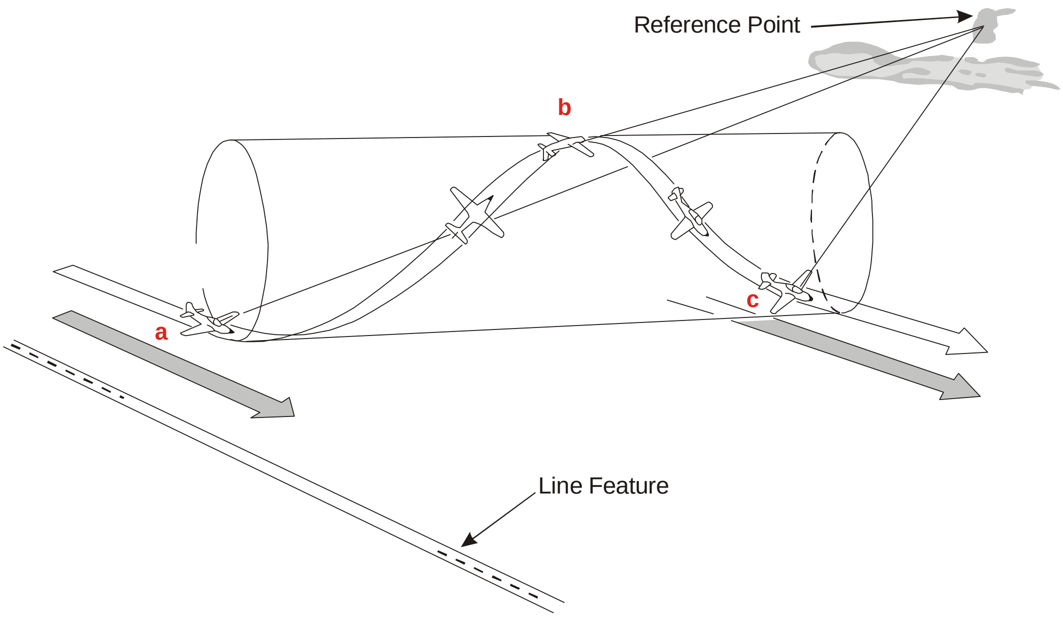
a. **Offset Entry** (Fig 4). A reference point just above the horizon is selected and an imaginary circle drawn around it. The aim is to track the nose of the aircraft around the circle. Starting from straight and level, the aircraft is flown in a descending turn using 45º of bank to intercept the circle in the 4/8 o'clock position, depending on the direction of the intended roll. After a good lookout to ensure the area above and ahead is clear, a rolling pitch-up is started, aiming to be wings-level at the bottom of the manoeuvre, just before the nose comes up through the horizon. The roll rate is maintained so that, at the top of the barrel roll, a wings-level inverted attitude is achieved, just before the nose comes down through the horizon. The amount of aileron deflection used is generally small compared to the amount of elevator required. The amount of control deflection required to achieve a constant rate of roll and pitch will vary according to the changing speed; rudder is needed to maintain balance in propeller driven aircraft. If the nose tracks inside the imaginary circle, then the roll rate is too high. In the second half of the manoeuvre, there is often a tendency to allow the pitch and roll rates to increase as no compensation is made for increased control effectiveness as the speed increases.

b. **Entry From Straight and Level** (Fig 5). From straight and level, the barrel roll is entered at the 6 o'clock position. The required entry speed is slightly higher than for the offset entry. The aircraft should be aligned along a line feature at base height and a reference point on the wing tip in the direction of roll should be selected (point 'a' in Fig 5). After a good lookout, ensuring the area above and ahead is clear, the aircraft is pitched up and rolled, initially using a small amount of aileron. A constant pitch rate is maintained, and the roll is adjusted so that the nose passes through the reference point whilst inverted at the top of the manoeuvre (point 'b' in Fig 5). The roll and pitch rates are maintained back to the straight and level attitude, flying parallel to the line feature, with the pull-out being adjusted to achieve the required base height. The reference point should re-appear on the wing tip (point 'c' in Fig 5).

8-16 Fig 4 Barrel Roll - Offset Entry



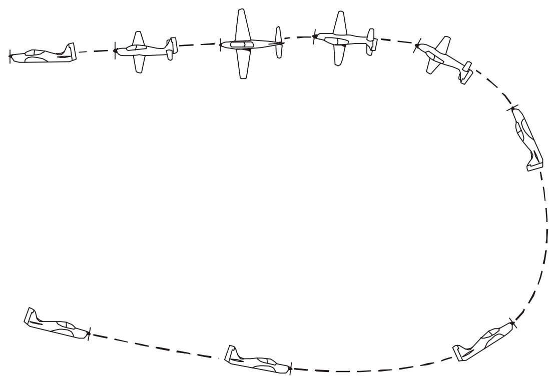
8-16 Fig 5 Barrel Roll - Straight and Level Entry



Half Roll off the Top of a Loop

15. The half roll off the top of a loop consists of the first half of a loop followed by half of a slow or barrel roll, the aircraft reversing direction and gaining height. A little more speed is required than for the loop so that sufficient speed is available for the half roll (see Fig 6).

8-16 Fig 6 Half Roll off Top of a Loop



ADVANCED AEROBATICS

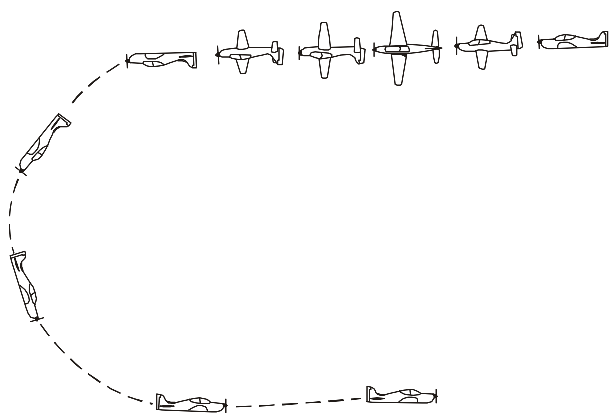
Introduction

16. Advanced aerobatics consist of variations or combinations of the basic manoeuvres already described.

Half Roll and Pull Through

17. The half roll and pull through is the opposite of a half roll off the top of a loop, consisting of the first half of a slow roll followed by the second half of a loop. The area below and behind the aircraft must be clear before commencing the manoeuvre. The speed of entry should be low, not more than that for low cruising speed, otherwise the maximum permissible air speed or 'g' limits may be exceeded in the second part of the manoeuvre. The power should be reduced and, if necessary, the airbrakes opened to limit the speed. This manoeuvre involves a considerable loss of height, see Fig 7.

8-16 Fig 7 Half Roll and Pull Through



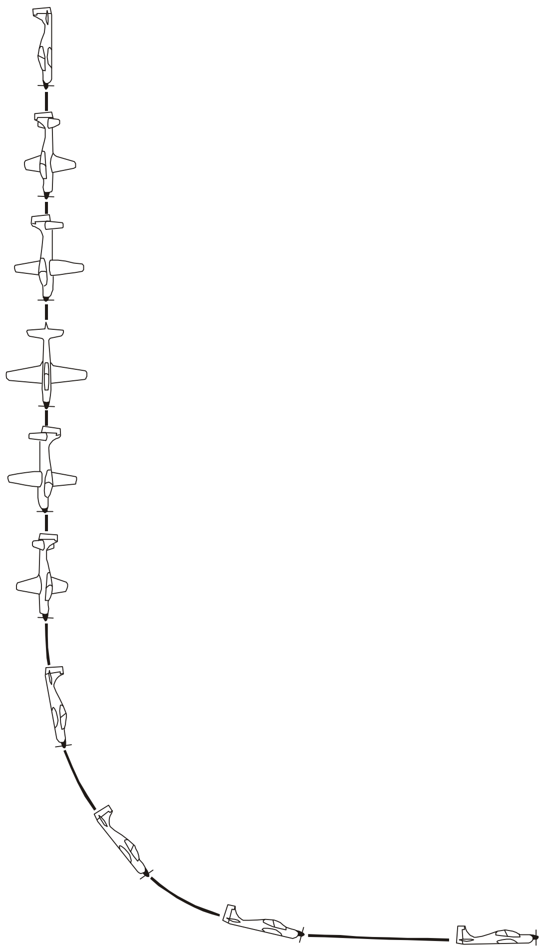
Upward and Vertical Rolls

18. **Upward Roll**. The term 'upward roll' includes all rolls that are performed in a climbing or steep nose-up attitude. Upward rolls are flown using the same techniques as a slow roll in level flight (para 9 refers). Upward rolls are difficult to perform accurately, and low-powered aircraft are unable to perform them satisfactorily.

19. **Vertical Roll**. A vertical roll can be flown upwards or downwards (the vertically downwards roll is detailed in para 20). After pitching up to the vertical, the attitude is best judged by checking that the chord of the wingtip cuts the horizon at right angles. In a true vertical roll, only a very small rudder deflection is required, to oppose adverse aileron yaw. It is essential to complete an upward rolling manoeuvre with sufficient airspeed to enable the aircraft to be pitched out of the manoeuvre safely, or stall turned, as too low an airspeed may lead to a loss of control and a tail slide, with possible damage to the aircraft. Again, the vertical upwards roll is difficult to perform accurately, and is beyond the capabilities of low-powered aircraft.

20. **The Aileron Turn**. The aileron turn is a roll flown vertically downwards. It may be started from a half roll or from the second half of a loop; in either case, it is started when the aircraft is pointing vertically down. In this manoeuvre, speed increases very rapidly and considerable height is lost. Power should be reduced, and airbrakes opened to control the speed, if necessary. An aileron turn is shown in Fig 8.

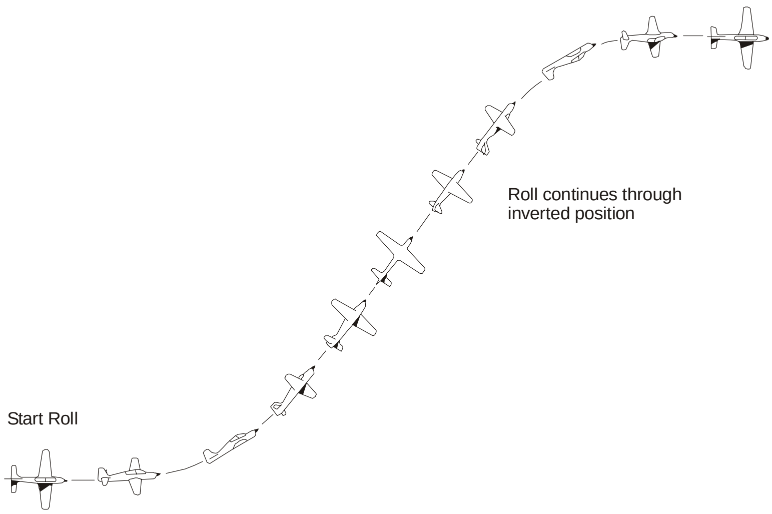
8-16 Fig 8 Aileron Turn



Derry Turn

21. In the Derry turn, the aircraft reverses a steep turn in one direction to a steep turn in the other direction by rolling through the inverted attitude. The control movements and pressures are similar to those used during a roll, but the backward pressure on the control column should be released when the manoeuvre is started (see Fig 9).

8-16 Fig 9 Horizontal Derry Turn (Plan View)



Inverted Flight

22. There are few military aircraft in which it is permitted to perform prolonged inverted flight or inverted gliding. For those so cleared, the main features of inverted flight are:

a. Aircraft are not designed to take large inverted loads, and the loading must therefore be kept to a minimum.

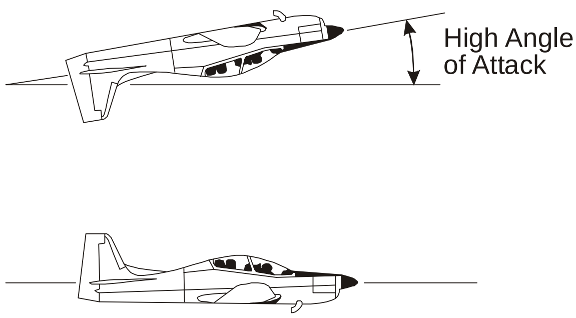
b. The aircraft responds normally when the controls are moved, but the movement of the aircraft relative to the horizon will be the reverse of that for the same control movements in normal flight.

c. During inverted flight at a given speed, the lift coefficient is much lower, resulting in an increased stalling speed. Because of the lower lift coefficient, the wing must be set at a higher angle of attack than for the same speed in normal flight (see Fig 10).

d. Due to the lower wing efficiency and the high stalling speed, the gliding speed is higher when inverted; about 33% more than the normal gliding speed is generally suitable.

e. The aircraft may be sensitive laterally because any dihedral now has a destabilizing effect.

8-16 Fig 10 Inverted Flight



23. It is emphasized that, before doing any inverted flying, reference must be made to the Aircrew Manual to ascertain whether inverted flight is permitted. If it is, the following limitations must be checked:

a. The negative g limit.

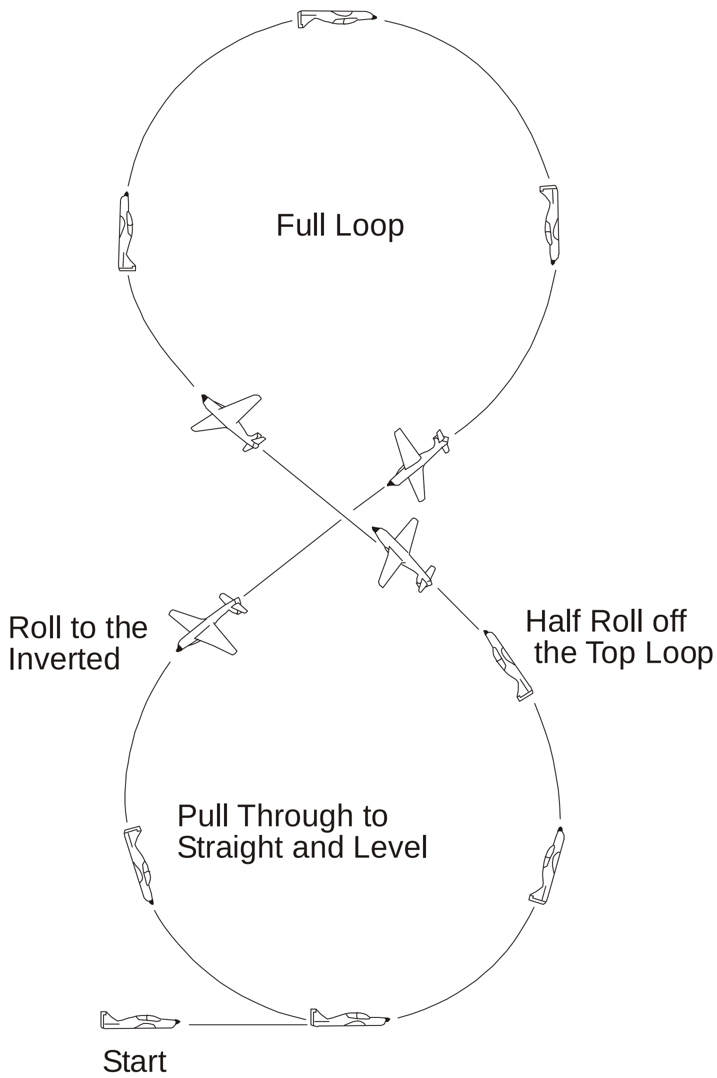
b. The maximum permitted duration of inverted flight.

c. Whether or not power may be used when inverted.

Vertical Figure Eight

24. A vertical figure eight is a combination of a half roll off the top loop, a full loop, and a half roll and pull through (see Fig 11). Entry and exit speeds are high and care is needed to avoid exceeding speed and 'g' limits. After a good look out to ensure that the area above is clear, the manoeuvre is started with a half roll off the top of a loop; this is immediately followed by a full loop. Upon completion of the loop, the aircraft is rolled to inverted and pulled through to straight and level. Speed is controlled by the use of throttle and airbrake during the descending parts of the manoeuvre.

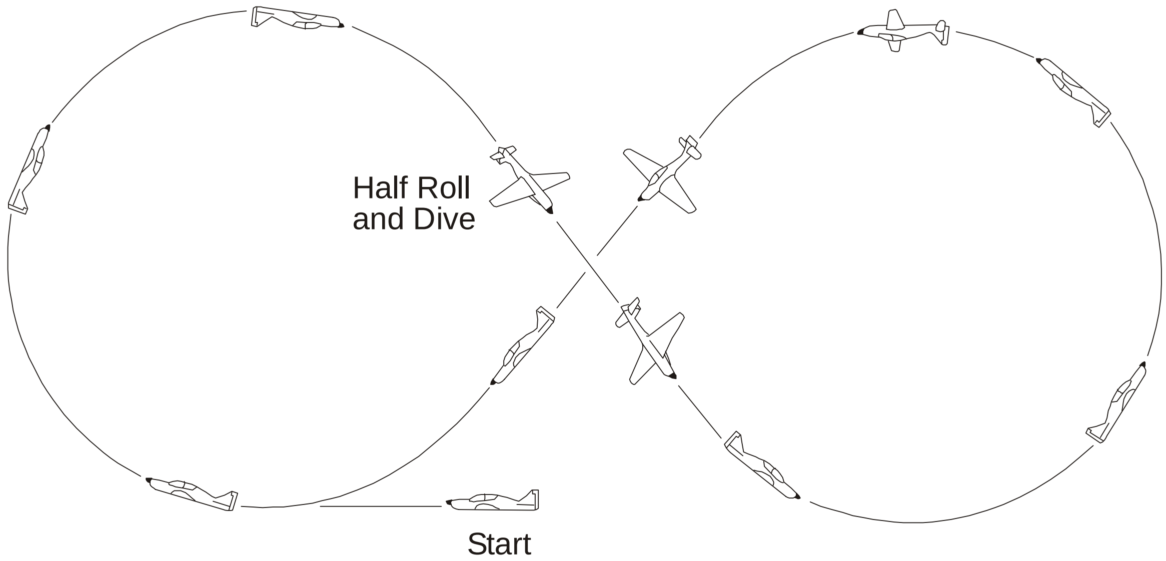
8-16 Fig 11 Vertical Figure Eight



Horizontal Figure Eight

25. A horizontal eight is started as for a loop. The loop is held until the nose is below the horizon on its way down, and the aircraft is then half-rolled and dived to gain sufficient speed to enter a further loop as shown in Fig 12. It is essential that a good lookout is maintained throughout the manoeuvre. A variation on this manoeuvre is the 'Cuban Eight', in which the aircraft is half-rolled on pulling up into the first loop, completing the loop and half rolling again when pulling up into the second loop. Again, lookout must be maintained throughout.

8-16 Fig 12 Horizontal Figure Eight



Hesitation Rolls

26. Hesitation rolls differ from normal rolls in that the roll is temporarily halted at intervals. They are normally halted after each 90º (four-point roll) or after each 45º (eight-point roll). This manoeuvre can be flown more easily on some aircraft than others, but the higher the speed of entry the greater is the control available and the accuracy of the roll.

Human Factors and Aerobatics

Such dynamically demanding sequences can be challenging to fly. Dissorientation, loss of situation awareness, G loc, distraction and rushed checks or SOPs are potentially lethal. Planning, briefing and supervision can mitigate these risks but when did you last practice the techniques with an instructor?

CHAPTER 17 - FLYING IN TURBULENCE

Introduction

1. The aim of this chapter is to give guidance to pilots, and aircrew generally, on some of the hazards that may be experienced when flying in extreme weather conditions, when marked wind shear and severe turbulence may be present. Whilst this chapter discusses aircraft handling in many of the meteorological conditions that may be encountered in worldwide flight, the reader is recommended to undertake further research from other specialised publications such as the Handbook of Aviation Meteorology (HMSO).

2. Turbulence may be defined as perturbations in the atmosphere which disturb the smooth progress of an aircraft through it. These perturbations may be produced by terrain or obstacles, local convection, artificial disturbances or natural phenomena. The effects range from short sharp bumps to much longer smooth up and down draughts which may be several miles long.

3. Penetration of severe turbulence can be hazardous and aircrew should be aware of the types of turbulence which may be met, and of the best techniques for flight in turbulent conditions.

EFFECTS OF TURBULENCE

General

4. The effects of turbulence may be dealt with under four headings:

a. Structural effects.

b. Handling effects.

c. Physiological effects.

d. Overall considerations.

Structural Effects

5. Rapid changes of aerodynamic loading of the airframe may be encountered in turbulence which can impose severe varying structural loads on the airframe. The severity of the structural loading will increase with the aircraft's rate of traverse of the area of turbulence and thus with its TAS. Since the structural load imposed on an aircraft is a direct function of g loading and TAS, airspeed is the most important single factor to consider from the structural viewpoint when flying in turbulence.

6. The basic design strength of the aircraft is a vital factor in deciding what level of turbulence can be accepted by a particular type of aircraft. Fighter aircraft, and most training aircraft, are sufficiently strong to withstand any turbulence they may meet in flight, although handling may be a problem. Large transport and similar types of aircraft are built to different (usually lower) standards of structural strength and should therefore, not be exposed to severe turbulence, except in emergency. Although the aircraft may not be damaged as a direct result of turbulence, it may well suffer a catastrophic structural failure by a combination of disturbance due to turbulence, and the effects of pilot control inputs to correct the disturbance. A number of large transport aircraft have been destroyed as a result of the aircraft having first been disturbed by severe turbulence, then entering a steep dive and being broken up during the recovery by excessive g and airspeed.

Handling Effects

7. The effects of turbulence on the aircraft's handling characteristics are of primary interest to a pilot. It is necessary to be able to maintain the desired flight path (within certain limits) and, above all, to contain the aircraft's attitude in pitch and roll.

8. Thus, an aircraft must be flown in turbulence at an airspeed that gives a safe margin over the stalling speed, and sufficient control power to restrain the aircraft's attitude excursions, but at a sufficiently low speed to ensure that the airframe is not overstressed or control is lost. The Aircrew Manual will give type-specific advice.

Physiological Effects

9. The physiological effects of turbulence are caused by the rapid and frequent reversals of motion imposed on the human body. The most common effects are fatigue, nausea and, in certain circumstances, deterioration of vision. Fatigue is generally aggravated by a prolonged period of flight in severe turbulence, particularly when the physical forces needed to control the aircraft are large. Nausea is a well-known effect of flight in turbulence and is generally more of a problem to passengers than aircrew. Vision can deteriorate quite markedly in severe turbulence, and particularly so when the frequency of the turbulence is close to one of the natural frequencies of the human body. In such cases it is difficult to read the instrument panel and prolonged instrument flight becomes tiring and extremely hazardous.

Overall Considerations

10. The overall effects of turbulence are an increased workload in flying the aircraft, the presence of structural and control hazards and, not least, discomfort. As already mentioned the most important single feature in turbulence flight is TAS, and the Aircrew Manuals for the majority of aircraft contain a recommended speed for flying in turbulence, which is sometimes referred to as Vra (or Mra) the 'rough air' speed. Where no specific turbulence speed is recommended, a guide can be obtained for most aircraft by multiplying the clean stalling speed by 1.6. For light aircraft, a penetration speed of about twice the stalling speed should be used.

TYPES OF TURBULENCE AND FLYING TECHNIQUES

General

11. The main types of turbulence encountered are:

a. Convective turbulence.

b. Wind shear.

c. Ground effect turbulence.

d. Clear air turbulence.

e. Aircraft wake turbulence.

Convective Turbulence

12. **Thunderstorm Hazards**. General convective turbulence is encountered in unstable air masses and is most severe in and around cumulo-nimbus (Cb) or towering cumulus cloud. Vertical currents

with an extreme velocity of 6,000 fpm (but more commonly 1,000 fpm to 2,000 fpm) may be encountered, and rapid gust reversal may be met both in and out of cloud. Flight through Cb clouds should be avoided whenever possible, since penetration will expose the aircraft to the risk of damage due to overstressing the airframe in the associated severe turbulence. In aircraft fitted with weather radar, it may be possible to identify and avoid storm cells but, without weather radar, identification of Cb clouds is often difficult, especially when they are embedded in more general cloud layers. Other specific hazards that may be encountered when flying in or near Cb clouds are:

a. **Hail**. The size of hailstones encountered in, or close to, a Cb cloud varies greatly, and is generally a function of the strength of the vertical currents within the cloud and thus the length of time the hailstones have been supported by these currents. Damage sustained by aircraft encountering large hailstones can be severe (see Fig 1) and is a function of TAS and the size of the hailstones. To minimise the risk of hail damage, the penetration of likely areas should be made as far below the freezing level as possible. Flight below the 'anvil' cloud of a thunderstorm is one of the most likely areas to encounter hail and should be avoided as stringently as the penetration of an actual storm cell.

5-16 Fig 1 Hail Damage

b. **Icing**. Thunderstorms frequently contain large quantities of super-cooled water droplets. Thus, aircraft flying in areas where the outside air temperature is below 0 ºC are likely to accumulate ice. Airframe ice accretion, though it may occur at a very high rate, is likely to be limited since the horizontal extent of a Cb cell is generally small. All available de-icing and anti-icing equipment should be turned on if Cb penetration is likely. Engine damage to axial-flow turbines due to ice ingestion is likely to be a more serious problem. Engine anti/de-icing systems should be used as directed in the Aircrew Manual. Ingress of water or icing of the pitot/static systems is a serious hazard in Cbs containing large quantities of moisture. In the event of loss of pressure instruments, the aircraft attitude and power settings should be maintained until clear air is reached or the pitot/static system clears. The pitot/static system should be treated as suspect for the remainder of the flight.

c. **Lightning**. There is always the possibility of a lightning strike when flying in the vicinity of a Cb. A lightning strike to the airframe is a very unpleasant experience, usually consisting of an intense flash on discharge, an explosive noise and a smell of burning. Generally, damage to the aircraft is confined to small burns near the extremities of the airframe or near to aerials, and/or loss of static discharge wicks. Whilst there may often be no visual evidence of a strike, the magnetic compasses may be badly affected and should be checked for accuracy after flight. In extreme cases, disturbance of certain aircraft electrical or electronic systems may be encountered. To assist in reducing the effect of a lightning strike on aircrew sight, cockpit lighting should be turned fully up, even in daylight. Where two pilots are carried, one should wear dark glasses or a visor to minimise the effects of dazzle.

d. **Static**. High levels of static interference can be met in Cb. This is generally manifest as heavy background noise on R/T, especially HF, and particularly at night, as a continual or intermittent display of 'St Elmo's Fire'. This phenomenon consists of a persistent series of blue electrical discharges generally around cockpit coamings and windscreen arches, sometimes appearing as a 'spike' emanating from any sharp projection from the airframe such as a windscreen wiper. It is not dangerous but is a good indication of high levels of static discharge.

e. **Line Squalls**. Cb clouds sometimes develop in lines, frequently as a result of interaction between two large conflicting air masses, one usually warm and dry, the other colder and wetter. The result is rather like an intensive frontal system and, in temperate and sub-tropical zones, often results in a line squall development. A line squall consists of a long line of storm cells, generally moving across the ground at an angle to the squall line. If penetration of such a line squall is necessary, it is best performed at right angles to the line. Weather radar, if fitted, should be used to plan the best route through the line squall. Large and varied changes in high-level winds often accompany a line squall system and both turbulence and high-level cirrus clouds can extend some way down-wind of the line. This high level 'blow-off' cloud frequently obscures the presence of storm cells from an approaching aircraft. Because line squalls are generally associated with the interaction of two conflicting air masses, they are often accompanied by clear air turbulence at medium and high levels

13. **Up-draughts and Down-draughts**. As well as the hazards noted in the previous sub-paragraphs, the biggest hazard when flying in, or close to an active Cb, is encountering severe up and down draughts. The Aircrew Manual advice for flight in turbulence should always be followed, especially so in aircraft equipped with a flight management system but, in the absence of such specific advice, the following techniques should be adopted:

a. Disengage the autopilot. (In some aircraft it may be safe to leave the autopilot engaged in Attitude Hold, but with no other locks selected).

b. Tighten safety harness and secure loose articles.

c. If fitted, reel in trailing aerials and refuelling hoses.

d. Adjust speed to the recommended turbulence speed. (Vra/Mra).

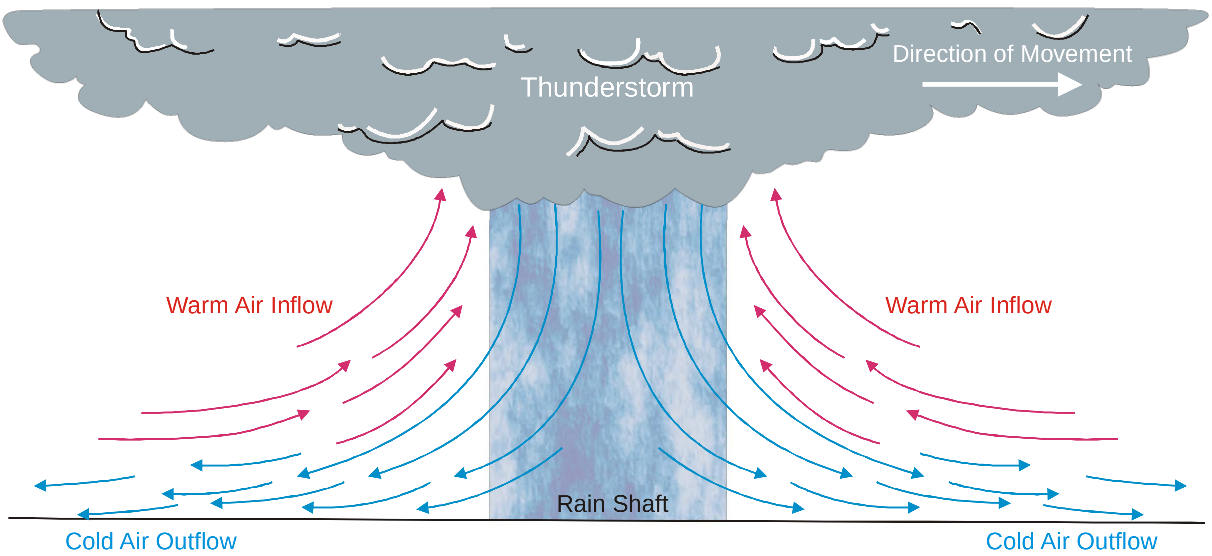
e. Concentrate on maintaining a constant attitude in pitch, and keeping the wings level by smooth and deliberate control movements. Do not correct for height changes in vertical draughts unless it is vital to clear obstacles, but let the aircraft ride the gusts. Use the controls as little as possible to avoid overstressing the airframe, and do not 'chase' the airspeed fluctuations. Very occasionally, gusts may be met which, at a constant power setting and attitude, will cause the aircraft to exceed its flight envelope, particularly at high altitude. In such cases, use the controls smoothly and deliberately to reduce or increase airspeed as required.

f. When flying in a Cb, it is normally advisable to maintain the original heading. If weather radar is available, and Cb penetration is unavoidable, use the radar to pre-plan an escape route in the direction of the least threatening echoes (see Volume 11, Chapter 11), otherwise use the radar to avoid them by as wide a margin as possible.

Wind Shear

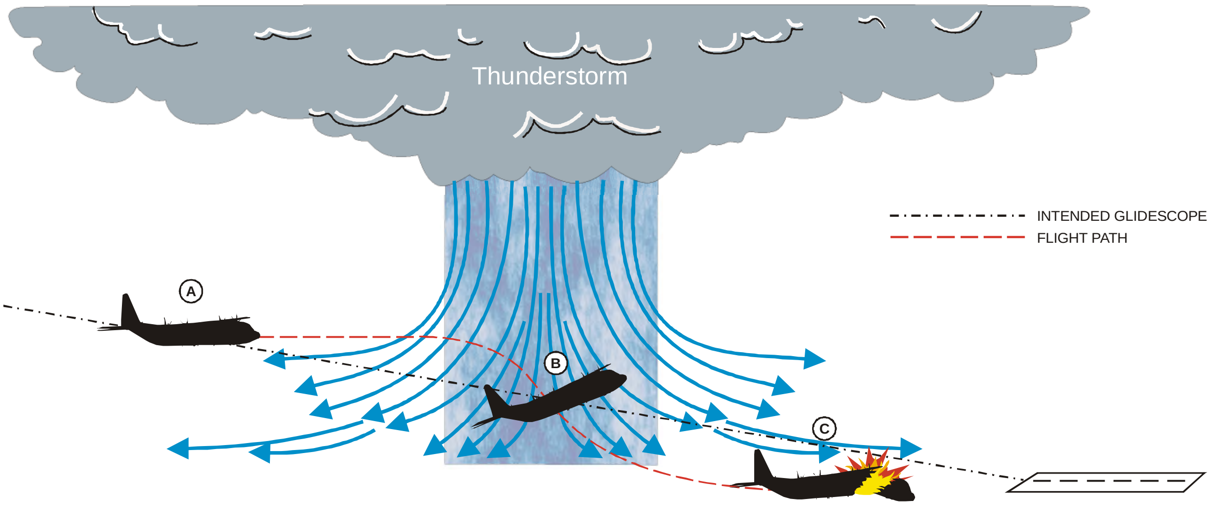
14. Wind shear may be defined as variations in the wind along the aircraft flight path of a pattern, intensity and duration that displace the aircraft abruptly from its intended path such that substantial control action is required. It can occur in the vicinity of active frontal systems, rotor systems and Cb cloud (see Fig 2) and also beneath cloud where the precipitation from the cloud does not reach the ground (a phenomenon known as 'virga'). It may present a major hazard to aircraft whilst landing and taking-off. The most dangerous wind shear conditions are associated with small scale, very localised highly energetic air motions called 'microbursts'. In a microburst, it is possible for an aircraft to encounter an increase in head wind, a severe downdraught and a sudden tailwind, in rapid succession.

8-17 Fig 1 Wind Shear Pattern Beneath a Thunderstorm



15. **Aircraft Performance in Wind Shear**. Incidents of wind shear exceeding the performance capabilities of transport type aircraft have been observed below 1,000 ft AGL. It should be noted that even fast jet aircraft, when heavily loaded, may have a thrust to mass ratio similar to that of a transport aircraft and therefore may be similarly vulnerable. The worst cases of wind shear occur beneath thunderstorms, particularly when a microburst develops (see Fig 3), where a wind shear which tends to increase height or airspeed can be a precursor of a shear which decreases height or airspeed. Where significant wind shear is reported, or forecast, the normal decision should be to delay take-off until the conditions have improved. If however, operational reasons decree that a take-off is imperative, data should be computed using factored take-off distance available (TODA) if appropriate. If a longer runway is available this should be used. Subject to Aircrew Manual, ODM or airfield limitations (TODA, tyre limit speed, obstacle clearance criteria etc) rotation and climb out speeds may be increased for expected wind shear. Lowering the nose after take-off to accelerate is dangerous and should be avoided. Once airborne, a significant undemanded change in airspeed or unusual control force can be an indication of wind shear and the imminent need to take corrective action to maintain terrain clearance.

8-17 Fig 2 Microburst



16. **Encountering a Microburst on the Approach**. Fig 3 shows the effect on an aircraft where a microbust has occurred on the approach to land. When the aircraft passes point A, it will experience a rapid undemanded increase in airspeed and, if this is not checked, the aircraft will climb. As the aircraft approaches point B, the airspeed will fall because of the loss of headwind, and the aircraft will descend in the downdraught. Continuing towards point C, the tail wind will come into effect causing the airspeed to decrease. If this tail wind increases faster than the thrust of the aircraft can overcome inertia, ie accelerate, the aircraft will develop a high rate of descent. Unless this descent is countered, a critical situation may develop rapidly, with as little as 5 seconds available to recognise and react to a degrading vertical flight path. In critically low altitude situations, flight path control must be maintained through the effective use of pitch attitude and full thrust. An increase in pitch, even though the airspeed may momentarily be decreasing, increases lift and provides a more favourable flight path angle. Full advantage should be taken by climbing at the best climb performance speed, and the pilot should be aware of which control cue (eg angle of attack, airspeed or stall warner) must be used to obtain maximum climb performance. A smooth, steady pitch control input is very important during recovery, to avoid the onset of a stall and the attendant degradation of performance, especially if changes of pitch attitude close to airspeed minima are required.

17. **Recovery Procedure**. The Aircrew Manual is the primary authority for the actions to be taken if wind shear is encountered on the approach. In the absence of other advice, below 1,000 ft AGL, or if an approach has to be abandoned because severe wind shear is experienced, the following recovery actions should be taken:

a. Disengage the autopilot, if appropriate, and apply maximum thrust.

b. Adjust smoothly towards a maximum climb performance, wings level, climb. This pitch attitude should be held until the threat of terrain contact is removed. Heavy out of trim control forces can be expected initially until they can be trimmed out.

c. Use primary instruments to monitor attitude, and unless directed to the contrary by the Aircrew Manual, disregard or isolate any instruments giving suspect indications or commands.

d. Do not attempt to regain lost airspeed until possible terrain contact is no longer a factor.

e. Do not change the aircraft configuration until the vertical flight path is under control.

18. **Wind Shear at Low Level**. Encounters with severe wind shear when close to the ground should always be regarded as an emergency situation. Attempts to regain the glide slope after a large height/speed excursion with the aim of continuing the approach, are not recommended. However, in the extreme circumstance, where a landing has to be made during wind shear conditions, large thrust reductions or trim changes in response to a sudden increase in airspeed should be avoided, since this can be expected to be followed quite rapidly by an airspeed decrease of similar magnitude. If the approach speed has been increased (factored) to allow for expected shear which is not subsequently encountered, it must be accepted that the landing will be long. In such a case, large reductions in thrust earlier than normal before the flare should not be made in an attempt to reduce airspeed.

Ground Effect Turbulence

19. **Mountain or Lee Waves**. Lee waves are often formed in stable atmospheric conditions when the normal horizontal airflow is disturbed by a mountain range or substantial ridge of high ground. The resulting waveforms may persist up to very high levels in the atmosphere and for many miles down-wind of the high ground that caused the initial disturbance. The characteristics of these waveforms are shown diagrammatically at Fig 4, and consist of powerful vertical draughts in the lee of the ridge, 'rotor' systems in the crests of the ensuing waves at low level, and high-level waves often characterised by the presence of lenticular clouds. Vertical velocities in the lee of large mountain ranges may well reach 5,000 fpm. The chief danger in high-level waves is the rapid increase/decrease in height which may suddenly become apparent on an otherwise smooth flight in the lee of high ground. If the autopilot height lock is engaged, for example, at a high indicated IAS or Mach number, it is possible for aircraft speed/Mach number limitations to be exceeded in the autopilot’s attempts to hold the selected height in a strong up-draught. In strong down-draughts at very high altitude, the aircraft may be stalled in an attempt to hold the selected height. Any advice in the Aircrew Manual must be followed, but in the absence of any suitable advice the following action should be taken:

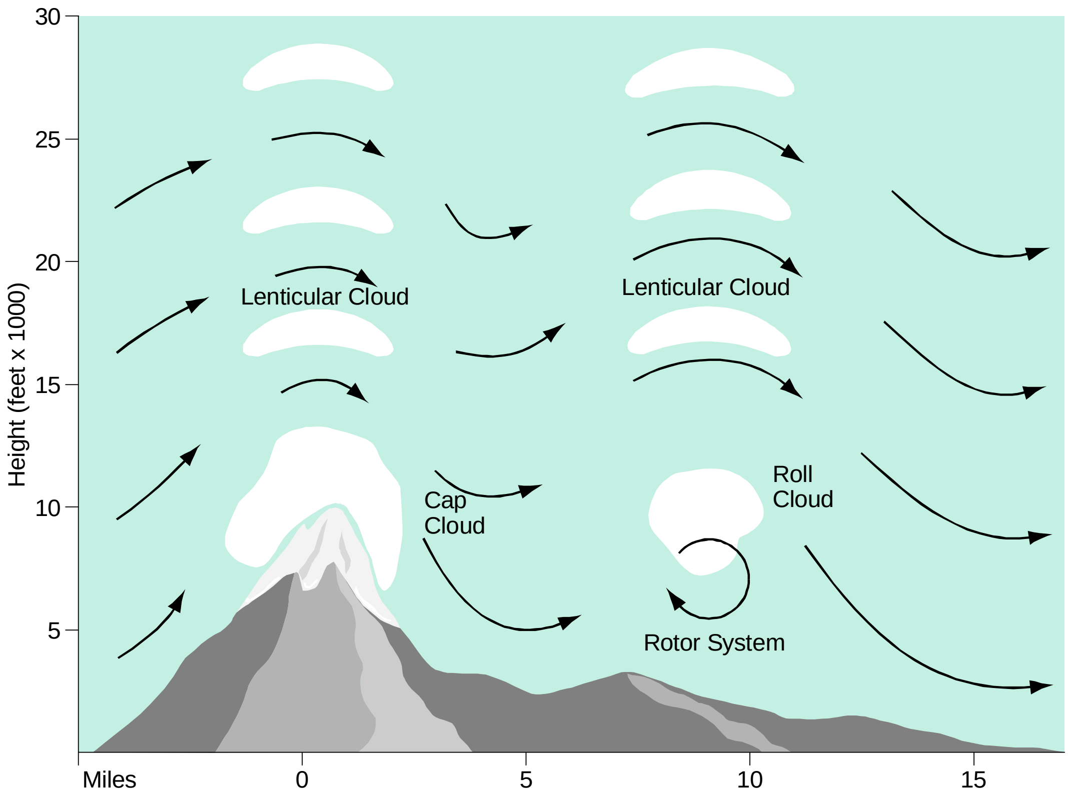
a. Disengage the autopilot (where appropriate) and if the speed is rapidly decreasing apply maximum thrust.

b. Adjust the speed to the recommended turbulence speed (Vra/Mra).

c. Concentrate on maintaining a constant attitude in pitch and keep the wings level by smooth and deliberate control movements. Do not correct for large height excursions unless it is vital to clear obstacles or maintain a cleared flight level in controlled airspace.

d. Transmit a weather report without delay (see Volume 8, Chapter 8, Para 13).

8-17 Fig 3 Mountain or Lee Waves



20. **Low Level Turbulence**. In medium to high strength surface winds, turbulence is generated by the disturbance to the smooth airflow caused by ground friction and obstacles. The effect on the wind of ground friction in the very low levels (below 500 ft) causes the sharp wind gradient often experienced during the latter stages of an approach to land. Gusts due to disturbances in the lee of obstacles, such as hangars or wooded areas, are frequently superimposed on this wind gradient effect. Low flying aircraft are also equally liable to meet these effects.

Clear Air Turbulence

21. Clear air turbulence (CAT) may be defined as turbulence not associated with convection or with airflow over terrain or obstacles. It is generally encountered at higher levels in the atmosphere in the vicinity of jet streams where vertical and horizontal wind shear exists. It may also be encountered when flying over sharp troughs and deep depressions. The severity of CAT is very varied although it tends to be more of a 'cobblestone' effect and is generally less severe than the turbulence associated with mountain waves. CAT may be experienced whenever any of the following features are present:

a. Vertical wind shear greater than 4 kt per 1,000 ft.

b. Horizontal wind shear greater than 25 kt per 90 nm. If the shear exceeds 50 kt per 90 nm, the level of CAT may be expected to be severe.

c. Horizontal temperature shear of 5 ºC or more per 100 nm. If the indicated outside air temperature rises sharply over a short distance, CAT may be expected in the immediate future.

d. If a jetstream crosses a mountain range or high ridge at right angles, severe CAT may be expected.

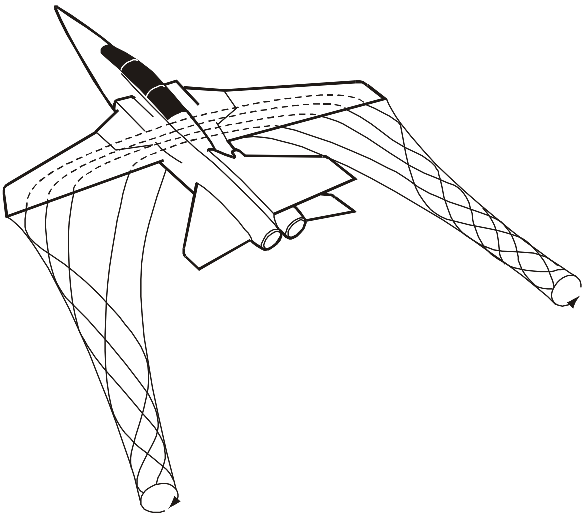
22. The actions to be taken when encountering CAT will depend on the degree of severity of the CAT experienced. For a small 'cobblestone' effect, it may only be necessary to reduce speed. If the CAT is

more severe, immediate reduction to the recommended turbulence speed is essential, as is making sure that all crew members/passengers are secure. The autopilot should be use in accordance with the recommendations in the Aircrew Manual. The most expeditious way out of the turbulent layer is to request a change of flight level whilst reporting the CAT to air traffic control. A change of flight level of 2,000 to 3,000 ft will often clear the area of turbulence.

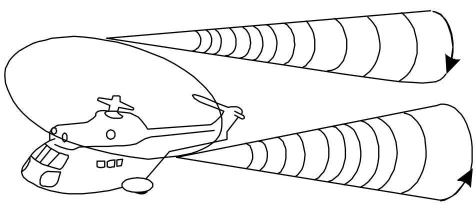
Aircraft Wake Turbulence

23. The efflux from jet engines, or the wake from propellers, generally has little lasting effect on the airflow (wake) behind an aircraft. Tests have shown that such wakes are effective for only a short distance. The main danger arises from the twin vortices formed behind the wings of an aircraft in flight (Fig 5). Similar vortices are formed by the rotor blades of rotary wing aircraft, particularly where the forward speed is high (Fig 6).

8-17 Fig 4 Fixed Wing Vortices



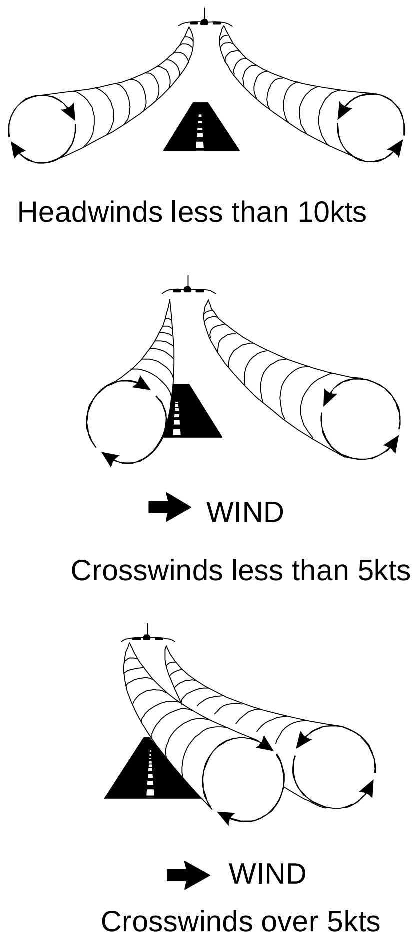
8-17 Fig 5 Helicopter Vortices



a. **Vortex Formation**. The vortex sheet shed by the wing, rolls up into two vortices (one at each wing tip) which rotate in opposite directions. The vortices expand and eventually make contact with each other and interact. A downward deflection is imparted to the wake, which eventually stabilises as the vortices decay at about 900 ft below the level of the aircraft. If the vortices are generated close to the ground, but out of ground effect, the wake will descend and the vortices will move laterally apart. The effect of surface wind on the wing tip vortex patterns is shown at Fig 7. The wing tip vortex will persist on the approach to land up to the point of touchdown.

b. **Vortex Intensity**. The intensity of the vortices generated behind an aircraft in flight depends upon the aircraft mass, wing aspect ratio and the angle of attack. Thus the strongest vortices, and therefore the most severe turbulence, are to be expected in the wake of a very heavy aircraft with low aspect ratio wings at low airspeed (ie high angle of attack). Highly swept wing delta aircraft of low aspect ratio develop particularly powerful vortices at low speeds. Flight tests have shown that the rate of decay of the vortex pattern depends largely upon the state of the air mass and, in calm stable air, the vortex turbulence may persist for several miles behind a large aircraft.

8-17 Fig 6 Effect of Surface Wind on Wake



c. **Flying Techniques-General**. If it is necessary to follow directly behind another aircraft (for instance, in controlled airspace) or to cross the wake of another aircraft, passing above the preceding aircraft's wake or maintaining 1,000 ft vertical separation below the other aircraft, should suffice to remain clear of the wake turbulence. If an aircraft inadvertently enters the wake of a preceding heavier aircraft, as well as experiencing turbulence, large deflections in yaw may be induced by the rotating vortices. It is essential that any control inputs to the rudder (to counteract yaw) are performed smoothly and deliberately, and that they always remain within the yaw angle structural limits of the airframe, especially when exiting the vortex, where the direction of yaw may reverse rapidly. This is of particular importance to large transport aircraft.

d. **Flying Techniques - Take-Off**. When taking-off behind another aircraft, the possibility of encountering wake turbulence must be allowed for. As well as applying the standard time separation between departing aircraft as contained in the Flight Information Handbook (FIH), a pilot should attempt to fly on or above the flight path of the preceding aircraft. An attempt to take-off from an intermediate point on the runway after a heavier aircraft has used the full length of the runway for take-off, or has carried out a low go-around, is particularly dangerous. To minimise the effect of wake turbulence on a formation take-off, the alternating 'high-low' technique is used. Pilots briefed to pull 'high' should make a positive initial climb to approximately 200 ft, and pilots briefed to stay 'low' should ensure that they have passed the take-off point of the preceding aircraft before commencing their take-off. Briefed distances and time intervals between elements must be strictly observed. In crosswind conditions, the formation leader for a stream take-off normally takes the down-wind side of the runway.

e. **Flying Techniques - Landing**. On the approach to land, pilots should bear in mind the dangers of the vortex patterns (see Figs 5 and 6) generated by the preceding aircraft. In IFR conditions, the standard Wake Vortex Spacing Minima for arriving traffic, as promulgated in the FIH must be observed. In VFR conditions, the criteria are advisory, but form an important guide on which to make a judgement. If possible, advantage should be taken of the downward motion of the decaying vortex by staying on, or above, the flight path of the preceding aircraft. In light crosswind conditions (<5 kt), the upwind vortex will lie on, or close to, the runway centre-line (see Fig 7b) and strong turbulence should be anticipated until into the ground effect. In such a case, an additional reserve of speed should be allowed over the normal approach speed. This will provide an increased margin over the stalling speed and increase the aileron response to any adverse rolling moments that may be encountered.

Planning Considerations

24. When planning a flight, aircrew should bear in mind the structural, handling and physiological effects of turbulence. A sound level of knowledge and understanding of Aviation Meteorology, will assist in planning the flight and avoid flying into conditions liable to lead to penetration of areas of turbulence. Provided that the foregoing elementary precautions are observed, even severe turbulence can often be tolerated for short periods without reducing the operational potential of the aircraft, and without exposing the aircraft and its occupants to excessive risks.

CHAPTER 18 - FLYING AT HIGH SPEED/ALTITUDE

Introduction

1. 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. This chapter, therefore, concerns certain flight characteristics which may be encountered when flying some high speed aircraft, particularly at high altitudes.

2. No reference is made in this chapter to the principles of flight concerning compressibility and the significance of the speed of sound. Information on these subjects is contained in Volume 1, Chapter 21.

Aircraft Limitations

3. Speed limitations are imposed for structural reasons alone and may be expressed either as an IAS or as a Mach number. The reasons for imposing these limitations are as follows:

a. 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 IAS. In fact the dynamic pressure at 100 kt, increases by a factor of 25 as speed is increased to 500 kt. 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 manoeuvring at high g.

b. A further consideration is that at high IAS 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.

c. The maximum permissible IAS given as the service limitation in the Aircrew Manual is lower than the design maximum IAS which is the highest figure for which the aircraft is stressed. The difference between the two gives the pilot a safety margin. If the design maximum IAS were permitted, even the slightest inadvertent exceeding of it would almost certainly cause damage to the aircraft.

Mach Number Limitations

4. 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 clearance to a higher Mach number. When a Mach number limitation is imposed it may be quoted as a definite figure, or as a specific condition of flight, eg 0.88M, or when a nose-up trim change occurs.

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

6. Mach number limitations are also imposed whenever the addition of external stores has an undesirable effect. 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 to affect control.

Effects of High Speed/Altitude on Aircraft Performance

7. **Compressibility**. Compressibility characteristics differ even between aircraft of the same type, and although Aircrew Manuals 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 different 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.

8. **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; Aircrew Manuals advise when exceptions occur.

9. **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 airbrakes.

10. **Change 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 change of trim, or vice versa. The rate of change of trim varies with the rate of change of speed and, in addition, the suddenness of the trim change also varies. A fairly rapid fluctuation, alternating between nose-up and 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 controlling this symptom and some rudder in the direction of the dropping wing may be helpful, ie 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.

11. **Control Effectiveness**. The effectiveness of the controls and trimmers deteriorates at high Mach numbers and, due to the low IAS, at high altitudes.

a. **High Mach Numbers**. At transonic Mach numbers, ie after the first shockwaves have formed on the wing, the control surfaces only affect the airflow up to the shockwaves ahead of them. 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**. The aerodynamic force exerted by the deflection of a control surface is proportional to the IAS, whereas the kinetic energy of the aircraft depends on the TAS. Therefore at high altitudes, where a low IAS corresponds to a high TAS, the controls are less effective in manoeuvring than at lower levels for the same IAS. The high kinetic energy of the aircraft must be appreciated and allowed for when manoeuvring at high TAS and high altitude, e.g. during aerobatics, formation flying, interceptions and spinning. It is for this reason that the time taken to recover from a spin is greater at high altitudes.

c. **High Indicated Air Speeds**. Control effectiveness may be reduced or lost at high IAS for reasons other than compressibility. The air loads caused by a high IAS 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 IAS 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 direction of the air loads on the surfaces and are independent of compressibility effects. This type of distortion is called “aeroelastic distortion” and to some degree is inevitable and is allowed for in the design of the aircraft. It is more pronounced in denser air at lower levels, where high IAS 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 IAS 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. **Jack Stalling of Power-Operated Controls**. At high IAS 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, ie the jacks, or servos, stall when the air load in the surface equals the jack output force. When this situation arises the manoeuvrability is reduced at high IAS in that the amount of g that can be applied is limited; this calls for special care when diving at high IAS and low altitude because the height lost during recovery is unavoidably increased. The maximum obtainable loading may be as low as 3g at speeds of about 500 to 550 kt, the precise figure varying with the type of aircraft involved.

Variation of Compressibility Characteristics with Altitude

12. 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 IAS and air loads are higher, thereby giving greater accelerations and possibly causing overstress.

Use of Trimmers

13. **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 - the Aircrew Manual sometimes lays down a Mach number beyond which the trimmers should not be used.

14. **Variable Incidence Tailplanes**. On some aircraft the loss of elevator effectiveness may be such that the use of a variable incidence tailplane is a valuable aid in controlling, manoeuvring and trimming at high Mach numbers. However, even when a variable incidence tailplane is used, a fairly coarse setting may be needed at some high subsonic Mach numbers 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 the Aircrew Manual. The type of behaviour described above can be likened to pitch-up but is due to faulty use of the tail trim and not instability. Under suitable conditions of altitude, air speed 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.

Manoeuvring at High Altitude

15. Manoeuvring 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 IAS, an appreciable reduction in compressibility Mach number is often experienced. 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 one, or a combination of, the following conditions:

a. If, due to increasing g and drag, there is a reduction in an indicated Mach number (IMN) which gives a flight path maintained by a certain control deflection and degree of effectiveness, there would be an increase in the control effectiveness which would tend to tighten the turn or pull-up 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, due to wing tip stalling at high angles of attack and wing flexing at high air speeds, the centre of pressure moves forward causing the turn or pull-up to tighten and the g to increase automatically. This effect occurs at a g loading that reduces with increase 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 pitch-up at high altitudes, although not sufficient to overstress, forms an operational handicap. For example, if a turn is tightened slowly at high altitude, pitch-up becomes evident as a reduction in the pull force required to tighten the turn; this pull force eventually becomes zero and then changes to a push. The quicker the g is applied the quicker does that 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 the centre of gravity position, applied g and altitude. Aircrew Manuals 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 IAS 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 the Aircrew

Manual or the Operating Data Manual. In practice, when manoeuvring at the higher altitudes, the speed should not be allowed to drop below the best climbing speed otherwise 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 IMN giving the best turning circle at altitude is much lower than the best climbing IMN and in these cases the pilot must decide which figure is the more important in the prevailing circumstances.

17. **Effects of Altitude on Manoeuvre***.* The ability to manoeuvre (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 due to the falling IAS and the increased inertia forces due to the increasing TAS (The amount of thrust available from all but rocket engines is also reduced). The lift is further reduced because of compressibility effects.

18. The much smaller speed range, ie the difference between the indicated stalling speed and the indicated maximum level speed, available at the higher altitudes also drastically limits the manoeuvrability. For a given altitude and applied g, the higher the IAS the larger is the radius of turn and the lower the rate of turn; conversely, for a given altitude and IAS the higher the g that can be applied without stalling, the smaller the radius and the higher the rate of turn.

Climbing

19. The climbing speeds for jet aircraft are given in Aircrew Manuals as IAS or IMN. The exact relationship between IAS and IMN during the climb cannot be dealt with generally since the technique for climbing depends largely on the role and performance of the aircraft.

20. 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 air speeds at which the aircraft can climb quickly; the peak rate of climb being achieved at a certain air speed in this band. As height is increased, the speed 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 kt 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 slow and the best method of regaining climbing speed quickly is to dive but, 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.

Recovery from Dives at High IAS

21. At low altitudes jet aircraft gain speed rapidly, even in shallow dives, and the height loss may be comparatively large. The height required to regain level flight depends on the altitude at which the recovery was started, the IAS, the angle of dive, the g applied and the all-up weight.

22. The g that can be applied when recovering from a dive is limited either by the g stall, the pilot's g threshold or aircraft limitation. If a constant g value is applied to a recovery, the amount of height required to recover from the dive increases rapidly with an increase in angle of dive or IAS, or both. If a g stall occurs during recovery more height is lost because the aircraft "mushes" due to the loss of lift.

IAS Versus IMN in a Dive

23. In a dive the Mach number may increase rapidly and it is important to realize the changing relationship between the IAS and IMN. The main features are discussed in the following paragraphs.

24. 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 TAS but making one dive from 40,000 ft and the second from 32,000 ft. The following figures are typical:

Dive from	40,000 ft	32,000 ft
Peak Mach number	0.89	0.85
Which is reached at	29,000 ft	20,000 ft
IAS then being	330 kt	380 kt

25. In any dive at a constant angle the Mach number reaches its peak and begins to fall while the IAS 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 IAS 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.

26. Tabled below are the indicated speeds corresponding to 450 kt TAS at various heights, the speed of sound in standard atmosphere conditions at each height and the Mach number. The changing IAS/IMN relationship in a dive is clearly shown:

Height (ft) (a)	IAS (kt) (b)	TAS (kt) (c)	Speed of sound (kt) (d)	IMN at 450 kt TAS $\left(\text{equals } \frac{c}{d}\right)$ (e)
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	0.70
Sea level	450	450	660	0.68

It can be seen that if the TAS is constant, or even increasing slowly in a dive, the Mach number is falling although the IAS is rising rapidly.

The Total Energy Concept

27. 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 potential and kinetic energy of the aircraft.

28. The total energy possessed by an aircraft in flight is the sum of its potential and kinetic energy. The energy possessed at any one combination of altitude and TAS can be exchanged for a higher altitude and lower TAS or lower altitude and higher TAS. Thus if an aircraft is at sea level at a high TAS it can be 'zoomed' to, say, 15,000 ft and a lower TAS. The aircraft has no more total energy at 15,000 ft than it had at sea level: its potential energy has increased and its kinetic energy decreased, but the total energy has remained constant. If the aircraft is then dived back to sea level it will arrive back at its original high TAS. (This example assumes that thrust is adjusted constantly to equal drag so that the kinetic and potential energy alone carry out the changes of height and speed.)

29. 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 most effectively. The best energy-increasing technique is, therefore, the use of climbing power and the IAS/altitude combination given by the climbing schedule in the Aircrew Manual.

30. Consider an aircraft flying at a medium altitude and slower than its optimum climbing speed that has to be climbed to a high altitude and to a speed above its climbing speed for that altitude. The normal technique would be to accelerate to climbing speed in level flight, climb to the required altitude at the correct climbing speeds and then accelerate to the new speed, again in level flight. However, if the 'energy' technique is used, i.e. put the aircraft onto its best climbing basis as soon as possible and keep it on this basis for as long as possible, some time can be saved. This technique would involve an initial dive to accelerate to the correct speed/altitude combination as quickly as possible, then a climb using the recommended speeds to an altitude higher than that required, then a further dive to achieve the required speed at the required altitude. The height to climb above the required altitude is obviously dependent upon the final speed: the higher the speed the higher the climb required.

31. In practice, the accelerating dives are done under power and not with thrust equal to drag and this means that the aircraft would not be moving along a constant energy line, but diverging from it. A further complication is that the flight path has to be changed from a dive to a climb so that g and, therefore, drag is increased - energy being dissipated in the form of the extra drag. Therefore, for 'energy' flying the technique is to enter the climb or pull-up smoothly without excessive g and to ensure that the climbs and dives are made in as short a time as possible so that the energy is not markedly affected by thrust or drag.

32. 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 or more above its normal climbing ceiling. Level flight may not be possible at the greater heights, but operational advantage would be obtained in the right circumstances.

Effects of Icing

33. **Airframe Icing**. Generally, airframe icing does not constitute a hazard to high speed, high altitude aircraft because it is normally operating outside the severe icing level and can quickly climb through an icing region. However, when flying through severe icing conditions at high IAS, the rate of ice accretion may be as high as five centimetres per minute. Apart from the normal problems associated with icing, external radio aerials subjected to severe icing vibrate excessively and subsequently fracture.

34. **Misting**. Another 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 stand off at low level after a rapid descent to allow time for the canopy to warm up and demist before landing. The more rapid the rate of descent, the heavier will be the misting and its rate of spread.

35. **Engine Icing**. On piston engine aircraft the only significant difference between engine icing at low and 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 jammed, and if ice forms on a guard ahead of the compressor, the reduced and uneven airflow causes a reduction in thrust and a rise in jet pipe temperature. 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.

Instrument Flying

36. When instrument flying at high speeds, the following considerations should be borne in mind:

a. The attitude change required to climb or descend is so small that the change of attitude on the artificial horizon may not be noticeable; it is therefore essential to cross-refer to all the instruments.

b. Altimeter errors in the order of 500 ft or more can be encountered at the higher Mach numbers and it is particularly important to bear this possibility in mind when flying at low altitude.

c. Large angles of bank are required for even low rates of turn.

37. Similarly, at high altitudes, these considerations apply:

a. The machmeter is more sensitive than the air speed indicator: for a small change in IAS there is a much larger corresponding change in the IMN.

b. The vertical speed indicator gives the quickest indication of change of attitude in the pitching plane, in the terms of thousands of feet per minute, whereas the air speed indicator initially shows a difference of only a few knots for a large change in pitch attitude.

c. At the highest altitudes, due 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.

Look-Out

38. At high speeds a good look-out 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 there is rarely any object on which the pilot can focus his eyes and under these circumstances the eyes tend to focus at a very short range. To focus the eyes further away, the distant scanning should be interrupted about every three or four seconds to look at a definite object such as another aircraft, the clouds below or one’s own wing tip, although the last should be at least 20 ft away.

Human Factors with Flying at High Speed/Altitude

Perception can affect the way we see and feel things. Time and space can be distorted and aircraft controls are more sensitive to inputs. All of the above can lead the pilot into making errors of perception. Planning and anticipation coupled with practice is the way ahead.

CHAPTER 19 - LOW FLYING

Introduction

1. Operational low flying often involves very high speeds and very low altitudes in order to make full use of the cover provided by the terrain itself and to avoid detection by ground-based enemy radar. At other times, circumstances such as poor weather may force any aircraft to fly lower to maintain in-flight visibility. The techniques and problems associated with low flying should, therefore, be thoroughly understood by all aircrew. This chapter should be read in conjunction with Volume 6, Chapter 9 which outlines some of the physiological and psychological problems of low flying, and Volume 9, Chapter 23, which concentrates on low level planning and navigation.

2. In training, exercises should be flown at the lowest height consistent with safety, bearing in mind the object of the exercise and the pilot's experience. Low flying exercises are designed to:

a. Increase confidence near the ground.

b. Teach low level navigation techniques and the estimation of distances.

c. Acquaint pilots with their own limitations under the conditions.

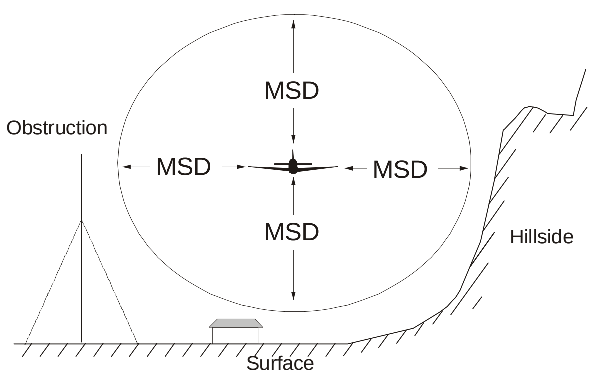
d. Acquaint pilots with the limitations of the aircraft and its associated equipment under low flying conditions.

Low Flying Regulations

3. Military low flying is to be conducted in accordance with MAA RA 2330 and the regulations and restrictions contained in the UK Mil AIP Vol 3, Pt 1.

4. **Minimum Separation Distance (MSD)**. When flying at less than 2,000 ft above the surface, the authorized minimum separation, in all directions, between any part of an aircraft in flight and the ground, water or obstacle is known as the MSD (see Fig 1). MSD does not apply during take-off or landing, or to the separation between aircraft in the same formation.

8-19 Fig 1 Minimum Separation Distance



5. **Definition of Low Flying**. Service fixed-wing aircraft (except light propeller-driven aircraft) operating below 2,000 ft MSD are considered to be low flying. Helicopters and light propeller-driven aircraft are considered to be low flying when operating at less than 500 ft MSD.

6. **Authorization of Low Flying**. Low flying is not permitted except in the following circumstances:

a. When specifically authorized in accordance with MAA RA 2330.

b. When taking-off or landing.

c. During an emergency or when making a precautionary or forced landing.

d. When compelled to do so by weather.

e. When so directed by an Air Traffic Control authority.

f. When engaged on search and rescue duties.

Low flying training is to take place only in those areas designated for such operations.

7. **Unauthorized Low Flying**. Whenever it has been necessary for an aircraft to carry out unauthorized low flying, for any reason, the occurrence must be reported to the authorizing officer immediately after landing.

Problems of Low Level Flight

8. Some hazards to flight assume a much greater importance when operating at low level. Crew planning must take into consideration extra factors, some of which are discussed briefly in the following paragraphs.

9. **Ground Obstructions**. In normal flight, planned to be above a safe altitude, ground obstructions are only significant in the terminal areas, and clearance is assured if standard take-off and landing procedures are adopted. In low level flight, obstructions such as electricity pylons and high tension cables, radio masts, wind turbines, tall chimneys, and ski lifts across valleys are significant and a potential hazard whenever they occur along or near the route. A suitable and properly annotated low flying chart must be used.

10. **Bird Hazards**. Information on migratory birds is often of a general nature or scanty. However, where information on bird concentrations is available, or where there is local knowledge of particular bird colonies, it should be taken into account by the crew when selecting the route. Bird activity at coastlines presents a permanent hazard and caution must be exercised when operating near the coast or crossing it.

11. **Surface Visibility and Low Cloud**. When flying at low level, the weather along the route is of vital importance. The pilot will require sufficient visibility to maintain a safe awareness of hazards ahead, and a safe horizontal and vertical separation from cloud. The forecast weather should be taken into account when planning the route to avoid a combination of low cloud and hilly ground. Another commonsense precaution is to avoid flying 'into sun' in areas of industrial haze.

12. **Low Level Weather**. Weather at low level can change drastically over relatively short intervals of both time and distance. Commonly encountered phenomena include:

a. Rain/snow showers.

b. Turbulence, particularly in the lee of hills.

c. Local cloud produced orographically.

d. Valley winds caused by funnelling through or around hills.

13. **Airspace Reservations**. Low level training flights must avoid all airspace reservations, industrial hazards etc. Some airspace reservations are pertinent only to low flying aircraft. These may be established (sometimes seasonally) around such places as nature reserves, animal breeding centres, or parachute training areas. Airspace reservations, avoidance areas and hazards pertinent to low flying are listed in the UK Mil AIP Vol 3, Pt 1. A pre-flight check of flight planning displays and NOTAMs is mandatory.

14. **Nuisance**. Low flying aircraft can be a source of complaint from the public. The sudden, unexpected passage overhead of noisy jet engines is undoubtedly disturbing, irritating, and sometimes potentially dangerous to human or animal life. It is up to the crew, when flight planning and in-flight, to reduce the nuisance to the minimum consistent with carrying out the briefed training task. They should observe meticulously any restrictions imposed on low flying in training areas and, whenever possible, avoid direct overflight of villages and isolated communities.

Flight Planning

15. The importance of thorough pre-flight planning and painstaking study of the low flying area or route cannot be over emphasized, particularly in the case of the pilot-navigator. The aircraft's crew will be pre-occupied with operating the aircraft in an environment that allows very little margin for error and therefore the route or area should be studied carefully and the position of salient features noted and memorized. The type and scale of the maps used should be considered and it may be advisable to use large-scale maps for turning points or target areas. Good timing and track maintenance is most important and any speed or heading alteration should be made as soon as the need is appreciated. Low level navigation is covered in detail in Volume 9, Chapter 23.

16. In hazy conditions the visibility up-sun is reduced and particular attention should be given to memorizing those landmarks on track and on the down-sun side of track. When flying near towns, obscuration from drifting smoke should be anticipated. Where there is some freedom in the choice of route, these points should be considered at the planning stage.

17. If forced to deviate from the original flight plan for any reason, pilots should be particularly vigilant because they may be over-flying an area or route which they have not studied thoroughly during pre-flight planning.

18. The fuel flow rate at low level must be ascertained from the aircraft's Operating Data Manual. Checks of fuel before the start of low level flying, and at regular intervals of time thereafter, are essential.

Speed

19. When flying low because of bad weather, the selected speed depends on the prevailing conditions. If the visibility is good, the aircraft should be flown at, or near, the range speed. In bad visibility, on the other hand, flight at the minimum safe cruising speed allows more time for avoiding unexpected obstructions and accurate navigation.

20. With turbojet aircraft it may be necessary to fly faster than minimum safe cruising speed so that the power is high enough to ensure a ready response to the throttle. In piston-engine aircraft a higher rpm than that normally used at minimum safe cruising speed should be selected so that more power may be applied quickly.

Height

21. At any time during low flying, the MSD may be increased, at the pilot's discretion, for safety reasons. Furthermore, altitude may be increased to facilitate map reading. However, in compliance with the weather limitations required for low level visual flight, the aircraft must always maintain the prescribed vertical distance from cloud base. In practice therefore, the height flown is likely to be a compromise, depending on the nature of the terrain, the cloud base, visibility, and the skill and ability of the pilot.

22. Terrain following radars and radar altimeters provide the means of flying accurately at pre-determined levels of ground clearance in suitably equipped aircraft. However, height monitoring at low level in training aircraft is predominantly by visual assessment. The pressure altimeter will be set to a regional pressure setting, and thus indicates altitude above sea level. For this reason, it is not to be relied upon to give height above the ground.

23. **Safety Altitude**. As part of route planning, the crew should calculate a series of en route safety altitudes (SALT) at which the aircraft can be safely flown (above terrain and obstructions) in the event of bad weather or other emergency. Normally, a SALT will be calculated for each leg of the route, but some operators may base it on geographical regions.

24. **Ground Avoidance**. The onus is on the aircrew at all times to monitor the aircraft's proximity to the ground and obstacles, particularly in emergencies, unplanned situations and when under ATC direction.

Effect of Wind

25. At low speeds drift angles may be large. Furthermore, when flying up-wind or down-wind the decrease and increase in forward speed may be marked; any tendency to adjust power settings according to such visual cues should be resisted.

26. Turns made near the ground at low IAS can be deceptive because of drift. When turning down-wind there is an illusion of slipping inwards during the turn, and when turning into wind of skidding.

Turning Radius

27. The effect of what may be termed 'directional inertia' is not very apparent at normal heights but it becomes an important factor when low flying. Turns must be entered in time for them to be completed within the space available. Similarly, during recovery from a dive, the pull-up must be started early enough to allow for the aircraft continuing for a short while along its descent path. In a rate 1 turn, the diameter of the turning circle in nautical miles is roughly equal to two-thirds of the speed in nautical miles per minute; for example, at 180 kt, or 3 nm per minute, the diameter is 2 nm. At 420 kt, or 7 nm per minute, the diameter is 4 nm. A nomogram for determining radius of turn is at Fig 2.

28. In low speed aircraft, turning near the ground necessitates the utmost vigilance. In bad visibility the ability to turn tightly is desirable as it helps in taking sudden avoiding action and/or keeping a landmark in view. As small radius turns require a large angle of bank, the turn must be accurate, a slipping turn particularly being potentially dangerous. During the turn the power should be increased to keep the airspeed constant.

Turbulence

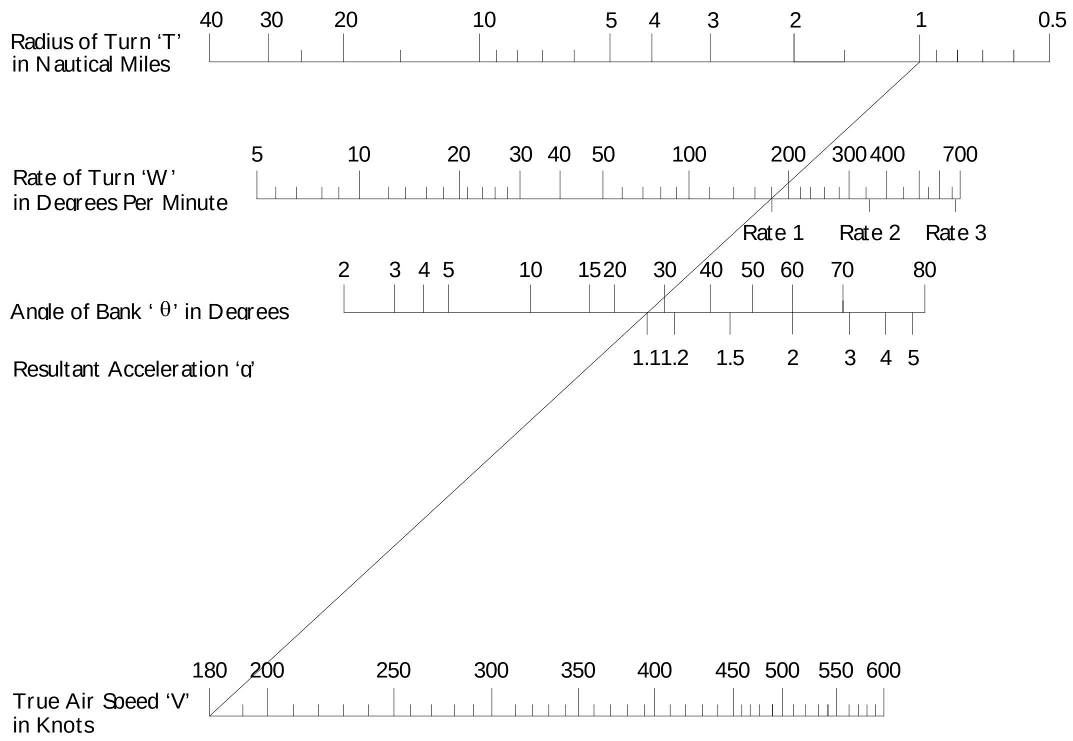
29. Turbulence can be caused by a gusty wind, by the passage of air over undulating terrain, and by irregular heating of the Earth's surface. In strong wind conditions, it is often encountered when flying within a few hundred feet of the ground, and can be severe. Air is often turbulent in the lee of obstacles and, moreover, wind speed may vary considerably. Strong downdraughts may also be experienced on the leeward side of large hills and mountains. In such conditions, a safe margin of speed above the stalling speed, and an increased separation from terrain should always be maintained, particularly in the case of low performance aircraft. For a more detailed discussion on the effects of turbulence see Volume 8, Chapter 17.

Flying Over Water

30. It is very difficult to judge height when flying over calm, glassy water, particularly in hazy conditions where there is no well-defined horizon. However, a radio altimeter is particularly accurate as a height reference in such circumstances.

31. Low flying over the sea requires particular care. A pressure altimeter, set to the appropriate regional pressure setting, will give a useable height reference. In turns, ample height margin must be allowed for safety, and frequent, quick references should be made to the instruments. Drift is difficult to estimate and there is likely to be only an indefinite horizon. Visibility may be reduced by spray on the windscreen and it may help if the windscreen de-icer is used.

8-19 Fig 2 Turning Performance Nomogram



The variables are related by the equation $V_W = \frac{V}{T} = g \tan\theta$

To use the Nomogram join two known values by a straight line and the intersection of this line on its projection with the other scales give the unknown values

Examples : TAS (V) = 180 Kt
Rate of Turn (W) = 1
Angle of Bank (θ) = 25°
Using the Nomogram (see dotted line)
Resultant Acceleration (g) = 1.1
Radius of Turn (T) = 1 nm

Flying Over Snow

32. Flying over snow is similar in many ways to flying over the sea. Lack of relief and a changed appearance to terrain caused by fresh snow must be allowed for. Drift estimation is difficult and the horizon may be poorly defined. It must be remembered that many of the landmarks normally expected may be obliterated or appear very different when the ground is covered with snow. In certain conditions the snow-covered ground and the sky merge into a single white surface, ie there is no visual horizon. Known as a 'white-out', this is dangerous when flying at low level and, if in doubt as to the exact whereabouts of the ground, the aircraft must be climbed away on instruments.

High Speed Low Flying

33. The special physiological problems associated with high speed low level flying are dealt with in some detail in Volume 6, Chapter 9. The problems of the increased size of the blur zone, the difficulties involved in navigation, the need for precise handling of the aircraft and the overriding requirement to maintain a consistently low altitude in order to penetrate the enemy's defences impose great physical and psychological pressures on the aircraft's crew.

Look-out

34. A sharp look-out must always be maintained when flying at low level. Areas set aside for low flying practice are likely to be used by a number of aircraft at the same time, particularly in the UK. The pilot can afford to look inside the cockpit only very occasionally. He must, therefore, carry out vital checks before low flying, paying special attention to the fuel state, the stowage of loose articles, and harnesses. The utmost vigilance must be observed.

Weather Avoidance at Low Level

35. Despite making intelligent use of the meteorological forecast when planning a low level route, occasions will arise when the weather deteriorates to below the authorized minima. During the planning stage, a mental note should be made of the likelihood of low cloud in areas of high ground and reduced visibility downwind of industrial areas. While flying, a lookout for worsening conditions ahead of the aircraft must be maintained in order to allow the maximum thinking time for planning avoiding action. Avoidance may require a 180º turn, back towards the good weather (other actions which may be taken to avoid weather are covered in Volume 9, Chapter 23). If poor weather cannot be avoided, the crew should make a pre-planned and orderly climb-out and transition to instrument flight.

Emergencies at Low Level

36. If an emergency occurs at low level, there will be less time in which to take remedial action than when flying at normal altitudes. The priority is always to fly the aircraft safely, then initiate a controlled, wings level, gradual climb away from the ground, remaining VMC. The crew should then deal with the emergency. At the same time, good airmanship requires a change of heading towards a diversion airfield, establishing radio contact whilst maintaining safe navigation, and determining a plan for recovery at the new destination.

37. If the aircraft is hit by a bird at low level, the initial actions should be as described in the previous paragraph. An airborne inspection by another aircraft, if available, may be able to give detailed damage assessment. At a safe height, just before arrival at the destination, a low-speed handling check should be carried out (lower the undercarriage, select flaps to landing configuration and then check for low speed controllability). Once selected and successfully achieved, leave the undercarriage and flaps in the required position for landing.

Human Factors and Low Flying

All our senses are hightened when low flying. Heart rate rises and breath quickens, eyes sharpen and physical sensations become more acute. Adrenalin quickens the brain and decision making processes. All of the enhanced senses, physical and mental, will, over time, cause Fatigue. Perceptions can alter and time pressure is always with you. Flying at low level will cause some form of arousal and stress that may affect decision making and therefore Situation Awareness. Beware G forces (they can bite!), remain task focused, beware focussed attention and if in doubt remember that SALT is your friend.

CHAPTER 20 - VTOL/STOL/STOVL

Introduction

1. The terms vertical take-off and landing (VTOL), short take-off and landing (STOL) and short take-off and vertical landing (STOVL) cover several types of aircraft and a greater number of circumstances. However, by convention, the aircraft to be included within these terms comprise helicopters, aircraft specifically designed for the V/STOL role and those conventional fixed-wing aircraft which have high-lift devices, reverse thrust etc, which allow use in the STOL role.

2. The use of helicopters is covered in Volume 12, Chapter 12; high-lift devices are dealt with in Volume 1, Chapter 10 and V/STOL engines are discussed in Volume 3, Chapter 15.

3. The purpose of this chapter is to discuss V/STOL aircraft generally, but with particular reference to the vectored thrust solution (Harrier) and the special STOL techniques which can be applied to conventional fixed-wing aircraft.

4. The capability of vertical and short take-off and landing has revolutionized some aspects of military aviation. The limitations imposed by fixed, complex bases no longer entirely apply and this allows for the best tactical deployment and dispersal of aircraft. Fixed wing V/STOL aircraft are capable of close support, reconnaissance, air interdiction and battlefield air interdiction roles. Although there are some disadvantages, the V/STOL capability opens up a wide range of uses and provides a degree of flexibility which modern conventional fixed-wing aircraft do not possess.

V/STOL AIRCRAFT - GENERAL CONSIDERATIONS

Definition of Terms

5.

a. **Vertical Take-Off and Landing (VTOL)**. A VTOL is a take-off or a landing with no ground roll, made at an all up weight (auw) where all the required lift is derived from the engines.

b. **Rolling Vertical Take-Off and Landing (RVTOL)**. A RVTOL is a take-off or a landing made at an auw where all the lift could be derived from the engine but when a low airspeed and short ground roll is used to prevent debris ingestion by the engine, damage to the ground surface or other undesirable effects.

c. **Short Take-Off and Landing (STOL) and Short Take-Off and Vertical Landing (STOVL)**. A STOL/STOVL is a take-off or a landing at a speed lower than the aircraft stalling speed, using the combined lift of aerodynamic surfaces and engine thrust. It is used when the auw is too high for VTOL or RVTOL.

d. **Hover**. To hover is to remain stationary in flight relative to the ground.

e. **Transition**. Transition is the manoeuvre of changing from non-conventional flight when wholly or partially supported by engine thrust; to flight supported by aerodynamic lift, or vice versa. It is normally specified as an accelerating or a decelerating transition.

f. **Translation**. Any manoeuvre involving movement over the ground in any direction in flight supported by engine thrust alone is termed translation.

g. **Reaction Controls**. Reaction controls are used to control an aircraft in slow or hovering flight when the aerodynamic control surfaces are ineffective. Small jets of high speed air are expelled through variable ports at the extremities of the aircraft to provide a rolling, pitching or yawing moment (see also para 10).

VECTORED THRUST AIRCRAFT

General

6. The following information is based on the Harrier aircraft. The Harrier will be described here as a typical example of a vectored thrust aircraft. Examples such as the YAK 38 and the F35 are illustrated on at the end of this Chapter.

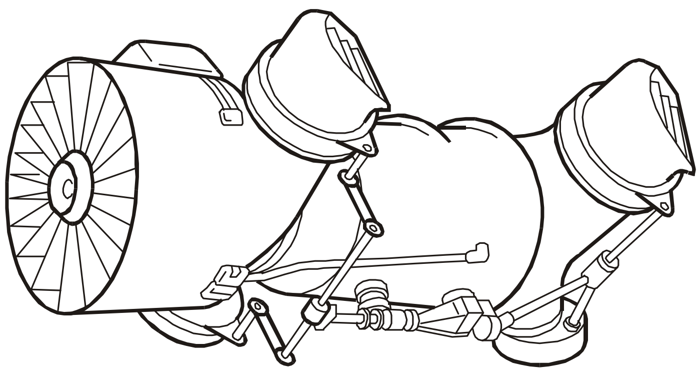
7. The vectored thrust aircraft must always be considered as a perfectly normal aircraft in its operational role, with the added advantage of being able to operate from almost anywhere.

The Engine

8. The engine is a normal by-pass type with two compressor spools. The first, an LP compressor, handles a very large quantity of air, most of which it expels at relatively low velocity through the front, or cold, nozzles. The remainder of the air enters the much smaller HP compressor. After the normal combustion and turbine stages it passes into the jet pipe where it is divided and deflected through the rear, or hot, nozzles at high speed.

9. **The Nozzles**. The four nozzles (see Fig 1) consist of rotating cascades to deflect the exhaust from the jet pipe and plenum chamber. They are mechanically inter-connected to a common drive so that they move in unison to vector the total thrust in the required direction (see also para 13).

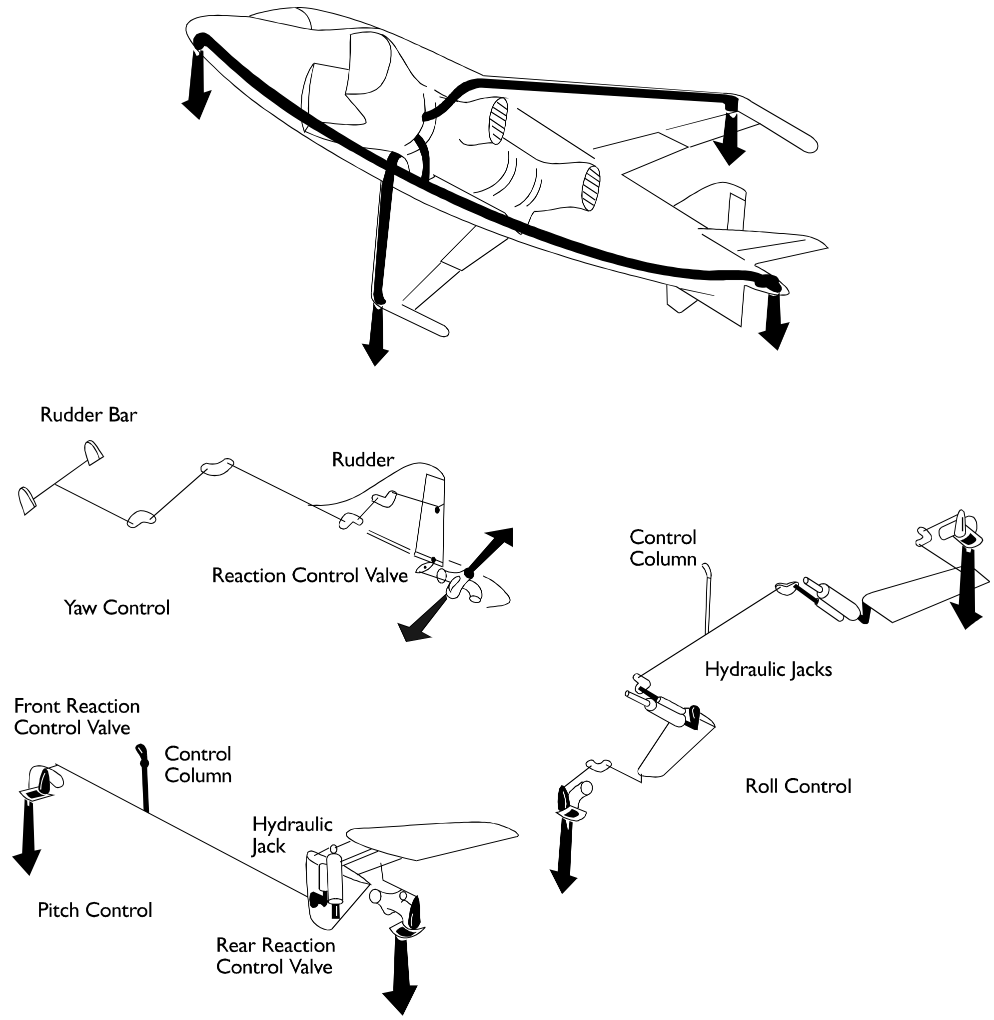
8-20 Fig 1 Nozzle Actuating System



The Flying Controls

10. For conventional flight, normal controls operate conventional aerodynamic surfaces. For slow flight and hovering, where the aerodynamic controls are inadequate, jet reaction controls are provided. These consist of shutter valves located in the front, rear and wing tip extremities of the aircraft, and they are interlinked with the adjacent aerodynamic control surface. They are supplied, via ducting, with high pressure air which is automatically bled from the engine flame tube casing when the nozzles are rotated away from the horizontal (see Fig 2).

8-20 Fig 2 Jet Reaction Control for Slow Flight and Hover



11. Autostabilization is fitted; its incorporation makes handling easier during V/STOL manoeuvres and reduces the demands made on the pilot.

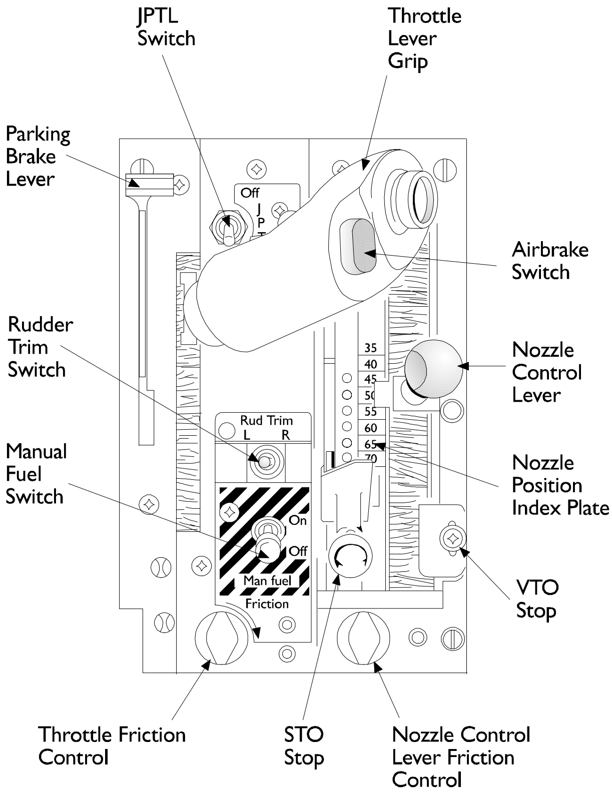
Cockpit Controls and Instruments

12. An additional control in the cockpit is the nozzle lever. Additional instruments are the airstream direction detector (ADD), the nozzle angle gauge and the duct pressure gauge. A yaw vane is located in front of the windscreen.

13. **The Nozzle Lever**. The nozzle lever is mounted inboard of the throttle on the same quadrant pedestal. When the lever is fully forward the nozzles are fully aft. As the lever is moved back so the nozzles are lowered until the lever rests against a stop: this is the hover stop. If the lever is then lifted over the shoulder of the stop, a further inch or so of travel is available: this is the 'braking position' where the nozzles have rotated beyond the vertical to give some degree of reverse thrust.

14. **Adjustable Stop**. In addition there is an adjustable nozzle stop (the STO stop) provided so that the pilot need not look inside the cockpit to select the correct nozzle angle during STO. The quadrant contains a number of holes (starting at 45°), each representing 5° of nozzle movement, and a peg is fitted into the appropriate hole, which prevents the lever moving any further backwards (see Fig 3).

8-20 Fig 3 Throttle and Nozzle Control Lever Pedestal



15. **Airstream Direction Detector (ADD)**. In some conventional aircraft an airstream direction detector is fitted to display the angle of attack to the pilot and thus assist in some stages of flight, notably landing. Whereas in conventional aircraft angle of attack is a function of IAS, aircraft weight and g, in a V/STOL aircraft angle of attack becomes an independent variable and it is vital that a cockpit indicator is provided for use during partially jet-borne flight. This indication is repeated in the Head-Up Display (HUD).

16. **Duct Pressure Gauge**. The duct pressure gauge indicates to the pilot that sufficient air is being bled from the engine to provide reaction control power.

17. **Yaw Vane**. The yaw vane, mounted on a pedestal, is like a small weathercock which takes up the direction of the relative airflow. It helps the pilot to prevent sideslip which is difficult to detect at low speeds.

Characteristics of V/STOL/STOVL Aircraft

18. **Intake Momentum Drag**. Intake momentum drag has a pronounced effect on an aircraft in the hover or in slow flight because, although its value is no greater than that of conventional aircraft, this value remains relatively unchanged, while that of more obvious forms of drag reduce with decreasing speed. Acting parallel to the airflow and through the intake (which is forward of the CG), it tends to yaw the aircraft away from the direction of any sideslip and an aircraft hovering or transitioning, out of wind will tend to yaw further away from the wind direction.

19. **Stability**. A hovering aircraft has no natural stability and very little natural damping, particularly in pitch and roll, and any corrective action necessary is provided by the reaction controls. As speed is increased, the aerodynamic surfaces bring a stabilizing influence to bear; however, certain complications are introduced if the speed increases in any but a forward direction.

a. **Lateral Stability**. If any appreciable sideways or backwards velocity is reached, then aerodynamic rolling moments may exceed the maximum corrective rolling moment obtainable from the reaction controls, and loss of control could result. Intake momentum drag acts to aggravate this condition by increasing the degree of sideslip. The corrective action is to turn the aircraft to face the relative airflow, thus removing the previously induced aerodynamic rolling moments.

b. **Longitudinal Stability**. The aircraft may be unstable in pitch when semi-jet-borne at high angles of attack, the tendency being to pitch-up. Aerodynamic effects produce trim changes which the tailplane may not be able to cope with aerodynamically and which are beyond the power of the reaction controls to counteract on their own. Angles of attack must, therefore, be restricted to a certain maximum value.

20. **Ground Effect**. Ground effect is caused by the jet efflux hitting the ground; the turbulence from it extending to a height of about 15 ft. It is apparent in varying degrees during all V/STOL manoeuvres and Fig 4 shows a velocity contour pattern around a stationary aircraft, at high power, at ground level. Ground effect manifests itself in three ways:

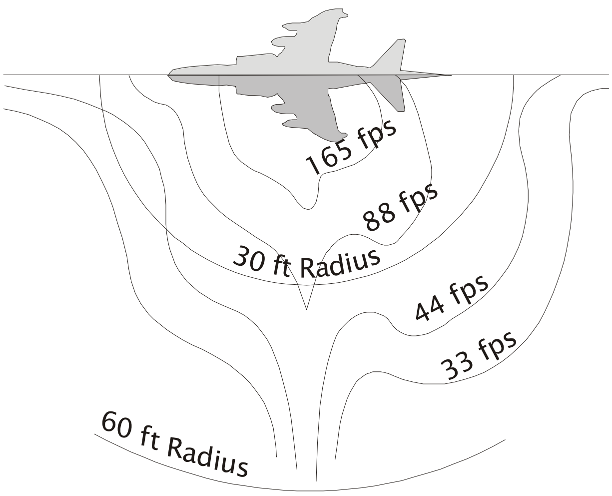
a. A 'cobblestone' effect in the turbulence making it more difficult to hold a steady position.

b. At the same time there is a change of trim.

c. There is also a slight loss of power, caused by the re-ingestion of hot gas.

(With nozzles at 20°, the efflux velocity 200 ft behind the aircraft is 66 fps near the ground).

8-20 Fig 4 Jet Efflux Contour Pattern near the Ground around a Stationary Aircraft at High Power with Nozzles at 81º



Handling Techniques

21. In forward flight the aircraft is handled in the same way as any conventional aircraft. However, after a conventional touchdown, the nozzles can be rotated to the braking position, the reverse thrust aiding deceleration. In common with conventionally powered aircraft, the aerodynamic controls on any V/STOL aircraft become less effective at low airspeed. It is, therefore, necessary to augment the conventional controls with jet reaction controls. The power, and thus the effectiveness, of these controls is directly related to engine RPM (N_F). So, if the reaction controls prove insufficiently powerful

to achieve the desired effect or the control column is reaching the limit of travel, and engine RPM are low, power must be increased to regain control authority. This may be against the natural instincts of a pilot to reduce power if too high or fast.

22. **Use of Nozzles for Manoeuvre**. Deflecting the nozzles during a turn can only produce an acceleration of up to 1g, but the decrease in speed is so marked that a rapid deterioration in the rate of turn results. Unless a very rapid deceleration is required, it is better to use the great reserve of power to sustain the speed and hence the g.

23. **The Short Take-off**. The required speed and nozzle angle for an STO are calculated before take-off taking into account ambient pressure and temperature, and aircraft weight. This calculation ensures that the vertical component of the thrust vector is supplemented by sufficient wing lift to overcome the weight while, at the same time, allowing a generous component of horizontal thrust for acceleration. Details of STO techniques currently taught for particular aircraft marks are described in the appropriate Aircrew Manuals. In all cases, however, once the aircraft leaves the ground, the nozzle angle set must provide an acceleration component as well as a lifting component.

24. **The Vertical Take-off**. Aircrew Manuals for particular aircraft marks describe the techniques to be used for the vertical take-off. However, for all cases, in very light wind conditions and at low thrust/weight ratios, hot gas recirculation through the engine may reduce the power output sufficiently to prevent the aircraft leaving the ground. A 10 kt wind can make an appreciable improvement in VTO performance by clearing exhaust gases from the intake. It follows therefore that it is desirable, although not essential, to line up into wind.

25. **The Rolling Vertical Take-Off**. For an RVTO the actions are similar to those for an STO, and are described fully in the Aircrew Manual. Care must be taken not to attempt to lift off before the engine is developing sufficient RPM to sustain flight.

26. **Accelerating Transition**. The transition to wing-borne flight is the same whatever the type of take-off: the attitude being held constant with the control column while the nozzle lever is moved smoothly forward. The Aircrew Manual describes the technique to be used. The movement of the nozzle lever can be interrupted to retract the undercarriage once the transition is well under way.

27. **Decelerating Transition**. A decelerating transition, is made from a normal final approach thereafter following the advice given in the appropriate Aircrew Manual. In general, a short distance before touchdown, the nozzles are rotated to the braking position. As the aircraft decelerates the power is increased while maintaining attitude. Before the aircraft comes to rest, the hover stop is selected and any further adjustment to position is made by altering the aircraft attitude. During the latter stages, great care must be taken to avoid exceeding the limitations for manoeuvring in jetborne flight.

28. **The Vertical Landing**. Having arrived over a selected point for a vertical landing at the correct height, a controlled descent is made as described in the Aircrew Manual. Position over the point is maintained by using the controls in the natural sense. The aim should be to make a firm landing. Too gentle a landing can result in reduced engine life due to higher JPT because of increased use of reaction controls in the turbulence of ground effect and due to hot air re-ingestion.

29. **The Rolling Vertical Landing (RVL)**. A RVL will normally be executed from a decelerating transition as described in the Aircrew Manual. However, if the approach path has some high obstacles close to the touchdown point, it may be necessary to carry out the RVL from the hover. In such a case,

once past the obstacles, the aircraft should be descended vertically to about 30 ft. Thereafter, the approach should be continued in accordance with the Aircrew Manual to achieve the desired touch-down speed and complete the landing.

30. **The Slow Landing**. The slow landing is the most demanding exercise because corrections are slow to take effect, so that much anticipation is needed. It is started from a conventional final approach at a range of about 1½ miles from touchdown. There are two methods, both of which are described in general below. However, specific techniques are to be found in the appropriate Aircrew Manual for the mark of aircraft being flown.

a. **Fixed Nozzle Approach**.. The nozzles are set at an intermediate angle and the power is slowly increased as the speed falls to the required value while holding a constant attitude; from there on the approach path and the speed are controlled by co-ordinating power and elevators.

b. **Fixed Throttle Approach**. The nozzle lever is moved coarsely to cause a rapid reduction in speed to that equivalent to optimum angle of attack; at the same time the throttle is moved to the required power setting. Thereafter the aim is to keep the attitude constant by co-ordination of nozzle angle and elevators.

31. **Manoeuvring in Confined Spaces**. The normal hover height is 50 to 70 ft to ensure that the aircraft is clear of ground effect and also any debris that may be blown up by the jet blast. The aircraft can be manoeuvred forwards, backwards or sideways by tilting it in the required direction, each degree from the vertical corresponding to about 10 kt once the inertia has been overcome. If much forward movement is required, the nozzle lever can be inched forward in preference to tilting the aircraft nose down. Spot turns with rudder can be made while stationary. If moving, a balanced turn should be performed, using small angles of bank, but the stability limitations (para 19) should always be borne in mind.

32. **Thrust/Weight Margins for VTOL**. A thrust/weight ratio of 1.05:1 is a reasonable minimum for take-off and landing: this gives sufficient margin for the aircraft to clear ground effect fairly quickly and allows for small local temperature variations.

Poor Weather Operations

33. Operationally, V/STOL aircraft are restricted to the same limitations over the target as conventional aircraft of the same role - but they have the advantage, if dispersed sites are available close to the scene of operations, that they can operate over a clear target when conventional aircraft are grounded by bad weather at base. On the same premise, they can also operate effectively in marginal, rapidly changing conditions, e.g. thunderstorms, when remotely based conventional aircraft cannot easily be phased with weather clearances in the target area.

Operating Surfaces

34. **Prepared Surfaces**. Concrete, asphalt or tarmac prepared surfaces on active or disused airfields can be used, e.g. taxiways, dispersals, pans, etc. Roads also provide good surfaces.

35. **Semi-prepared Surfaces**. Small forward airstrips which have been cleared and rolled may be used but their durability depends upon the texture and condition of the top surface.

36. **Natural Surfaces**. Grass provides a suitable surface for STO and RVL operations.

37. **Artificial Surfaces**. A variety of metal or alloy interlocked plates have proved suitable, used as pads or strips over otherwise unsuitable ground; however, they need to be well picketed. Fibre and resin compositions have also been used. If the soil beneath an artificial surface is dusty it may be necessary to lay a thin membrane between the two.

FIXED-WING STOL AIRCRAFT

General Considerations

38. Because well-equipped airfields are not always available, tactical aircraft are specifically designed to have a tactical airstrip capability and the following paragraphs discuss the STOL techniques of conventional fixed-wing aircraft.

Conventional Fixed-wing Aircraft

39. Short-field performance in a fixed-wing aircraft can be achieved by the use of devices such as high camber, high-lift wing section, high aspect ratio and low wing loading, together with “augmented lift” aids, examples of which are slots, slats and Fowler flaps. However, the main disadvantage of such designs is that for high all-up weights, the wing area must be increased to maintain a low wing loading. This in turn requires a greater wing span to maintain a low aspect ratio, with a consequent increase in weight and drag penalties. These requirements impose a comparatively low weight limitation on STOL aircraft.

40. In the case of tactical transport aircraft, where good payload capability and an economical cruising performance is required, and good low speed performance is desirable, some design compromise must be made. To offset the higher landing speeds of the heavier medium range aircraft, the landing ground run can be reduced by using large area flaps, fully fine propeller settings to provide aerodynamic braking, reverse engine thrust and effective wheel braking systems. When operated into tactical airstrips it is probable that the aircraft will be lighter on take-off than on landing, the payload having been off-loaded. In this case the take-off performance might well be compatible with field length. However, weight for weight, the take-off ground run will exceed that of the landing; therefore in operations of this nature it will generally be the take-off auw that is critical.

Marginal Airfields

41. The operation of fixed-wing aircraft into and out of airfields with marginal runway lengths and/or obstacle clearance distances, may require the use of special landing and take-off techniques. The basic principles of these techniques are applicable to all aircraft types.

Tactical Landings

42. A tactical landing is a practised and planned technique employed when it is considered necessary to operate an aircraft to operationally acceptable limits. A tactical landing is achieved by flying the final runway approach at the lowest safe approach speed and then making a positive touchdown as soon as the aircraft has crossed the runway threshold. Maximum use is then made of the aircraft’s deceleration facilities. The basic technique is summarized in the following paragraphs.

43. **Threshold Speed**. The normal threshold speed for the weight of an aircraft may be reduced to operationally acceptable limits by the use of tactical approach techniques. By adopting a high-lift angle

of attack in the landing configuration and using power to counteract the increase in drag, the aircraft can be flown near to the stalling speed for the weight. This configuration is adopted during the final stage of the approach and the air speed is progressively reduced to cross the runway threshold at the appropriate speed for the weight. The approach path angle of the tactical landing is usually the same as for a normal approach; however, where airfields have obstructions within the final approach sector, a steeper flight path may be required in order to achieve the threshold. In extreme cases, the steepest angle of approach for the aircraft type must be flown, since the close proximity of obstacles to the threshold might well deny the use of the beginning of the runway or landing strip. Regardless of the approach angle required, the basic techniques still apply.

44. **Flare-Out and Hold-Off***.* The distance covered from the time an aircraft crosses the threshold until it is placed onto the runway, constitutes a large proportion of the total landing distance. Using tactical landing techniques and speeds this distance will be considerably less than the distance used in a normal landing. To achieve a lower threshold speed, a high angle of attack is adopted during the final stage of the approach; thus the aircraft is already in the landing attitude on crossing the threshold. Use of this technique eliminates the hold-off period and results in a saving of distance covered.

45. **Variations in Technique***.* The flare-out phase can only be eliminated on aircraft stressed to accept a high rate of descent at touchdown. With this type of aircraft the maximum impact rate of descent for weight can be flown to the point of touchdown. On aircraft not designed to accept high impact rates the flight path must be levelled prior to touchdown. On achieving level flight, the abrupt removal of the high power used during the final approach will result in a rapid reduction in air speed, thus enabling the aircraft to be placed firmly on the ground. A reduction in distance from threshold to touchdown can be achieved by the use of the tactical approach and landing technique.

46. **Landing Ground Run***.* The remaining phase of the total landing run is that between touchdown and deceleration to a safe taxiing speed. The difference in technique from that of a normal landing is that all facilities to effect deceleration are used to the maximum. The main deceleration services are wheel braking, reverse thrust and propeller discing. These services will act in conjunction with the retardation caused by the friction of the landing wheels; the wheel brakes being the most effective when the whole weight of the aircraft is on the wheels. Since the factor opposing weight on a moving aircraft is lift, any technique which will reduce lift, especially in the initial high speed stage of the ground run, will be significant. The use of the elevators to force the aircraft more firmly onto the ground is a technique that may therefore apply. In addition, the maximum use of aerodynamic braking, i.e. full flap selection, will augment frictional retardation.

Short Field Take-Off

47. The primary objective of the short field take-off technique is to reduce the normal take-off distance required for a given auw. It should be appreciated that even where runway length is not critical, obstacles in the take-off sector might dictate a short take-off ground run to ensure adequate clearance on the climb-out. A reduction in take-off run can be achieved by reducing the rotation or unstick speed to the lower limit of the performance margins. These margins can be calculated from the Operating Data Manual (ODM) of the aircraft and represent a tactical operating standard as opposed to a normal operating standard. The difference between the two standards being in the application of safety margins. A further reduction can be made by ensuring the maximum acceleration to rotation speed. This is achieved by using take-off power against the wheel brakes to initiate the take-off run. A net climb-out flight path for the short take-off can be calculated from the ODM for the aircraft and equated with the take-off distance available.

Variable Factors

48. The short field performance of a fixed-wing aircraft will be affected by a number of variable factors:

a. Aircraft auw.

b. Runway surface and slope.

c. Airfield elevation or pressure altitude.

d. Ambient temperature.

e. Specific humidity.

f. Runway surface wind component.

Knowing the value of these factors, the take-off and landing performance of an aircraft can be calculated in terms of runway length and take-off distance required which are then compared with the actual distances available. Should the available distances be restrictive, the only factor over which any control is possible is that of auw.

49. When considering the regular operation of fixed-wing aircraft from a tactical airstrip, the most probable adverse values of temperature, pressure and humidity must be assumed, while the airfield criteria will remain constant. Performance calculations based on these factors will then give the maximum auw for landing and take-off and so produce a payload capability for planning purposes.

F35 - Lightning II

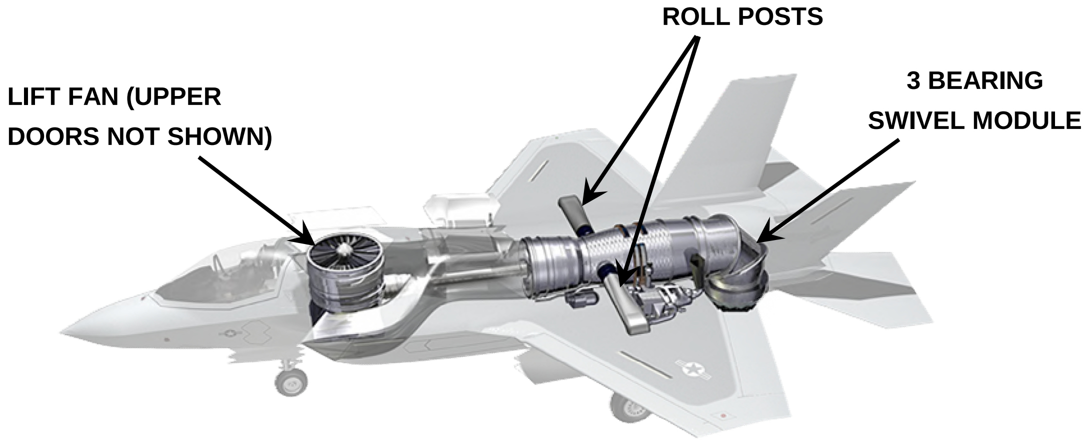
50. The F35B was designed to be a STOVL (short take off and vertical landing) aircraft.

51. The powerplant arrangement for the F35B consists of a main engine, to which the 3 Bearing Swivel Module (3BSM) is fitted, a lift fan driven by the engine through a drive shaft when engaged and two compressor air fed roll posts.

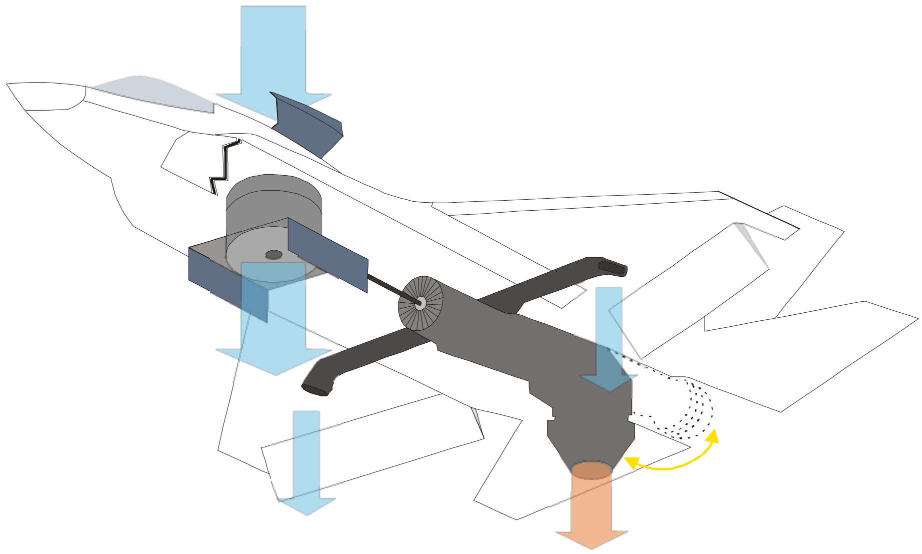
52. While the main engine provided the main thrust for the propulsion system during forward flight, the same engine is used to drive the lift fan through a drive shaft, while it simultaneously generates compressor airflow to the two wing mounted roll posts and manoeuvres the 3BSM to provide vectored thrust for the engine exhaust.

53. During conventional flight the lift fan and roll posts remain protected behind airframe mounted doors. During STOVL operations the airframe doors open which permits the lift system to operate. During operation the lift fan provides vertical thrust for the forward quarter of the aircraft, the 3 Bearing Swivel Module (3BSM) operates to provide vertical thrust for the aft quarter of the aircraft while the two roll posts provide roll control.

8-20 Fig 5 F35 Configuration



8-20 Fig 6 Using Main Engine Driven Vertical Thrust System

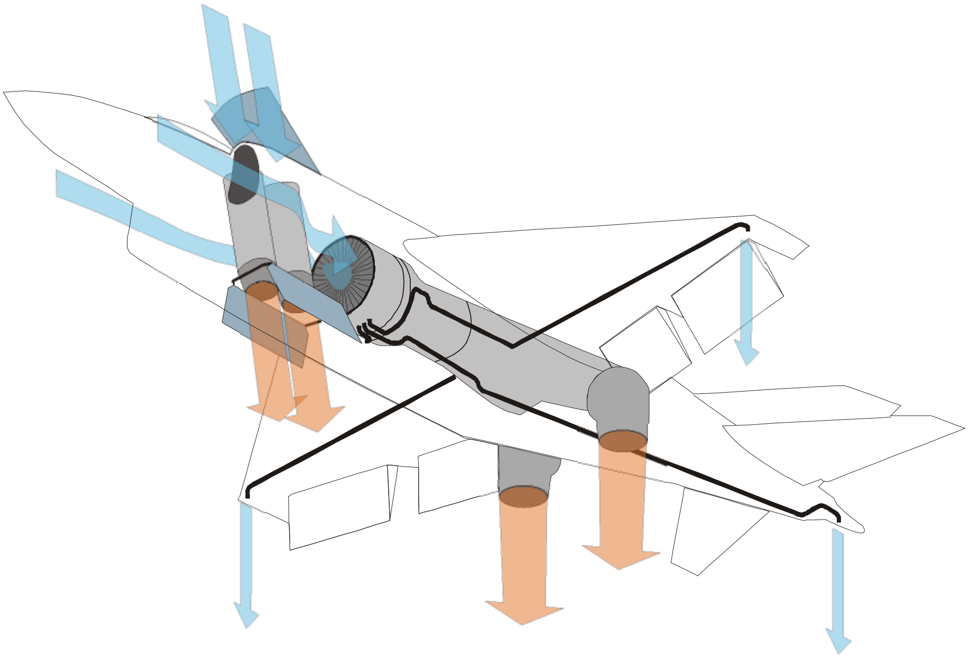


54. At the outlet of the lift fan is the airframe mounted Variable Area Vane Box Nozzle (VAVBN) which controls the thrust from the lift fan and provides in-line thrust vectoring, the 3BSM, which is essentially part of the main engine exhaust, vectors the exhaust gasses to provide in-line and limited lateral thrust vectoring; the roll posts use Low Pressure Compressor air discharged through two wing mounted nozzles to provide roll control. Using a combination of these controls the propulsion system provides fore and aft thrust to permit the aircraft to conduct STOVL.

YAK 38

55. The YAK 38 was outwardly similar to the British Harrier but it followed a different configuration. Together with a vectorable thrust engine in the rear used during flight, two smaller, and less powerful, engines were housed in the front portion of the fuselage and used purely for take-off and landing.

8-20 Fig 7 YAK 38 Using Independent Vertical Thrust System



CHAPTER 21 - FORMATION FLYING

Introduction

1. A formation is defined as an ordered arrangement of two or more aircraft proceeding together as an element. Their movement is controlled by an appointed leader termed No 1. The No 1 is responsible for briefing other members of the formation and for ensuring the safe conduct of the formation throughout the sortie. Detailed considerations of the No 1's responsibilities and leadership are given at paras 4 - 5 of this chapter.

2. There are two categories of formation flying:

a. **Close Formation** - used for:

(1) Take-offs, cloud penetration and landings - used mainly by training and fighter aircraft.

(2) Display and show purposes.

b. **Tactical Formation** - used for all tactical fighter operations. This type of formation is designed to provide all-round search, the best mutual cross-cover and the best mutual fire support.

3. Close formation is discussed in detail in this chapter. In addition, three basic tactical formations and the recommended sequences for changing back into close formation are covered from para 66 onwards. Metric distances are used within this chapter.

Leadership

4. Successful formation is heavily dependent on good leadership. The No 1 commands the formation and is immediately responsible for its security, the tactics and exercises to be flown and for its safe return to base. A thorough briefing before any formation flight is vital, although, in an operational situation, detail is normally covered by reference to Standard Operating Procedures (SOPs). In the case of large formations (e.g. nine aircraft) the briefing must cover positions and procedures for departure, joining, splitting and recovery, in meticulous detail.

5. The No 1 must fly in a position from which he can communicate with all his pilots or, in large formations, with leaders of sub-formations. He must be replaceable by a deputy leader who flies in a pre-arranged position relative to the No 1 and who must at any time be prepared to assume the responsibilities of the No 1. Every member of the formation should know the precise aim of the exercise, the general plan of likely formation changes, the emergency procedures and action to be taken in the event of deterioration in weather and airfield state. Whenever possible, the service-wide standard positions and procedures should be used, and the principle of 'minimum change' put into practice. 'Minimum Change' means the smallest number of aircraft movements for any formation change. The need for explicit briefing, free from ambiguity, when departing from normal procedures, cannot be over-emphasized.

BASIC CLOSE FORMATIONS

The Section

6. The basis of all formations is the section or element, which consists of two or more aircraft all operating under one nominated leader. Larger formations may be formed by the integration of two or

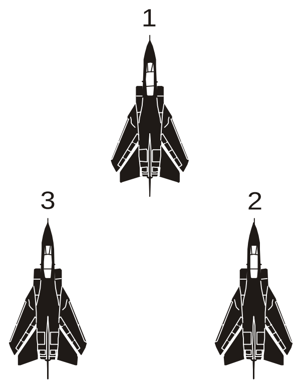
more sections. Each section will have its own leader but a leader of the overall formation must also be nominated; he will normally be the No 1 of the lead section.

Section Formations

7. The standard section formations are:

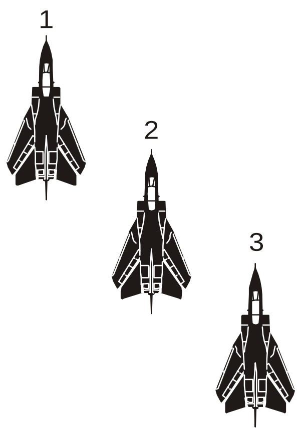
a. **Vic** - three aircraft disposed as shown in Fig 1.

8-21 Fig 1 Vic Formation

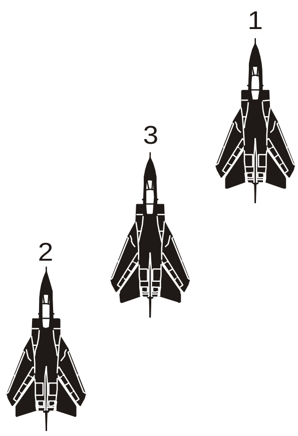


b. **Echelon** - with aircraft disposed as shown in Figs 2 and 3 (3 aircraft).

8-21 Fig 2 Echelon Right from Vic

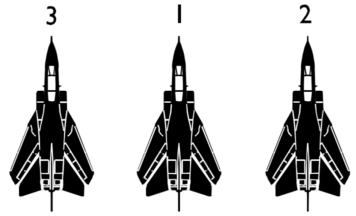


8-21 Fig 3 Echelon Left from Vic



c. **Line Abreast** - with aircraft disposed as shown in Fig 4 (3 aircraft).

8-21 Fig 4 Line Abreast from Vic



d. **Line Astern -** with aircraft disposed as shown in Fig 5 (3 aircraft).

8-21 Fig 5 Line Astern from Vic

Fig 5a Plan View

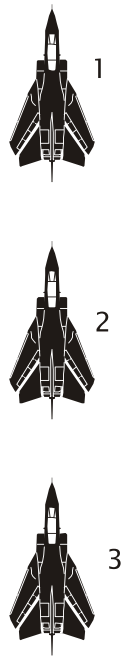
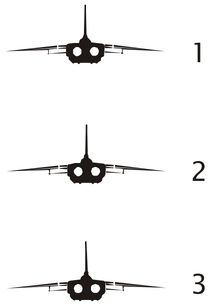


Fig 5b Rear View



e. **Box** - with four aircraft disposed as shown in Fig 6.

8-21 Fig 6 Box Formation

Fig 6a Plan View

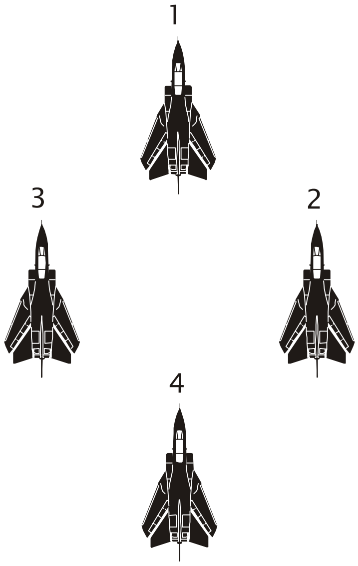
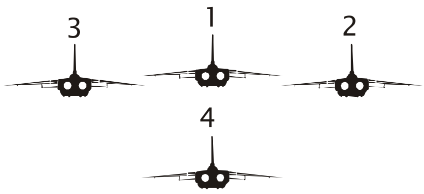


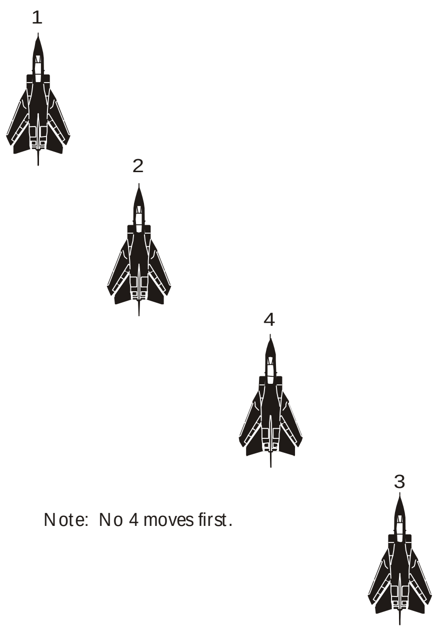
Fig 6b Rear View



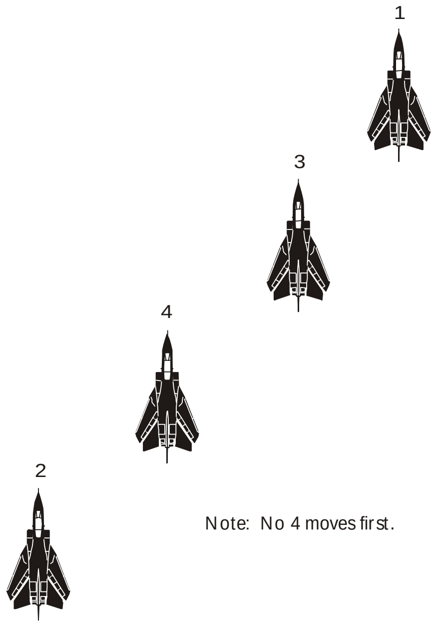
For cloud penetration it is recommended that the maximum size of a close formation should be three aircraft. A three will invariably fly as a Vic, and a pair as an Echelon, as it is essential for the formating pilots to be able to see any hand signals made by the leader (Volume 8, Chapter 22). As the visibility in cloud can be very poor, formation leaders may brief that hand signals will not be used in cloud except in an emergency.

8. Four-ship formations manoeuvred from Box are shown in Figs 7, 8, 9 and 10. The flying of larger formations will be covered in more detail in paras 58 to 65.

8-21 Fig 7 Echelon Right from Box



8-21 Fig 8 Echelon Left from Box



8-21 Fig 9 Line Abreast from Box

Fig 9a Plan View

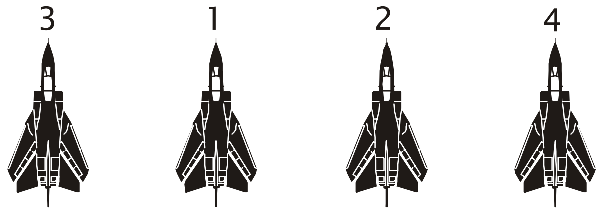
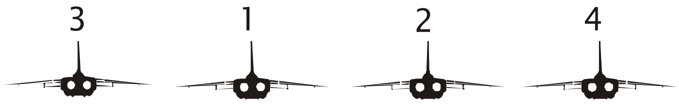


Fig 9b Rear View



8-21 Fig 10 Line Astern from Box

Fig 10a Plan View

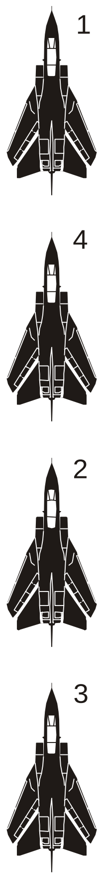
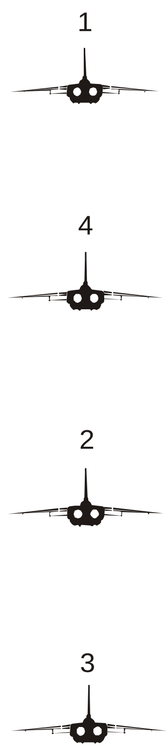


Fig 10b Rear View



CLOSE FORMATION FLYING TECHNIQUE

Relative Speeds

9. The driver of a car subconsciously judges the speed of his vehicle in relation to others against a background of fixed objects - trees, houses, telegraph poles, etc - which border the road. Such a background does not exist in the air and the only way in which relative distances can be judged is by mentally comparing the actual and apparent size of an aircraft.

10. The difference in size of an aircraft viewed from six km range and from three km range is very small, but the difference in size of the same aircraft viewed from one mile and 800 metres is quite noticeable. The effect of this is that when one aircraft is overtaking another, even at a high closing speed, the rate of approach appears very slow at long ranges (five to ten km) and seems to increase almost imperceptibly until a critical range is reached, when the overtaken aircraft appears to grow rapidly in size, and the true speed of approach can be judged.

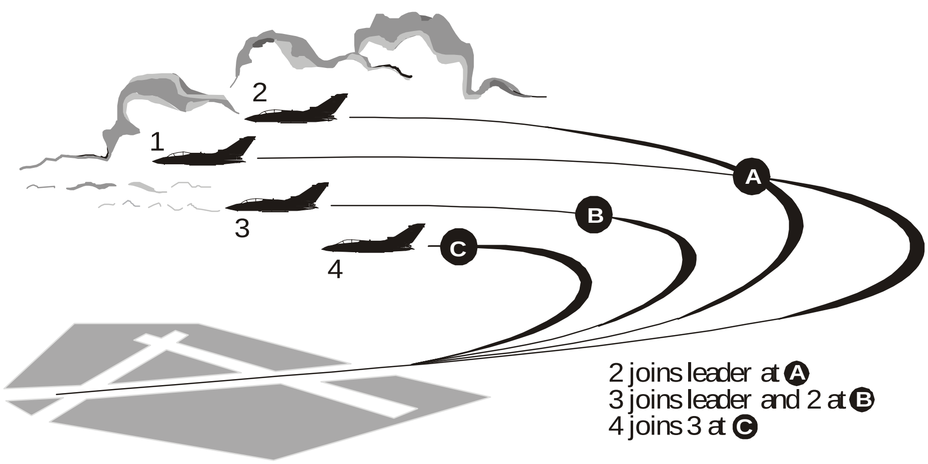
11. Judgement of distance in the air is a matter of experience and practice but pilots can attain proficiency in the art more quickly if they realize that the tendency is to underestimate the rate of approach until the final stages. It is helpful for the initial join-up if the No 1 flies at a constant, known airspeed; a pilot joining the formation can then set his own airspeed to give a reasonable but controllable overtake speed, e.g. 50 knots is a suitable speed advantage when the range to be closed is neither excessively long nor very short, but this will vary for different aircraft types.

Joining Formation

12. The time spent in joining formation serves no useful purpose and the longer the time taken to assemble a formation, the shorter will be the time that the formation can spend on the air exercise. Thus, pilots should join formation with the least possible delay.

13. Fig 11 illustrates the procedure for joining formation after a stream take-off. The leading aircraft should take-off, and fly straight ahead for a distance varying from 800 metres to one mile, according to the type of aircraft, and thereafter commence a gentle turn. The second aircraft - No 2 of the formation, should then turn inside the leading aircraft, so as to intercept it as soon as possible. The third and fourth aircraft should carry out a similar procedure, ensuring that they always keep lower numbered aircraft visual while joining; the final join-up should normally be in numerical sequence.

8-21 Fig 11 Joining Up after Take-off



14. It is important that the leading aircraft should settle down to the agreed cruising speed as soon as possible. The following aircraft may then fly with a small overtake speed (approximately 10 to 20 knots) gaining position by the use of shorter radius turns. In this manner, leeway is rapidly made up and individual aircraft are able to take up their positions without excessive changes in airspeed. If the following aircraft either fly the same flight path as the leading aircraft or make a turn of larger radius outside the leaders flight path, they will have to increase their airspeed in order to overtake and will consequently be obliged to make a large alteration in airspeed before they can take their stations. Moreover, a great deal of time and fuel will be wasted.

15. It can be seen that once the joining aircraft is established in the shorter radius turn, all the pilot needs to do is maintain the interception course until he reaches the point at which he can decelerate and move to the correct formation position. To maintain the interception course the lead aircraft must remain in a constant position in the joining pilot's field of view. If it moves forward the joining pilot must increase his rate of turn and if it moves backwards the rate of turn must be decreased. It must be remembered that, when the lead aircraft is stationary in the windscreen or canopy a collision course is set-up, so positive clearance in the vertical plane must be established in the later closing stages.

Positions in Basic Formation

16. The distances between aircraft in formation are laid down in relevant Command/Group Orders and must be strictly adhered to. No attempt should be made to practise formation flying in manoeuvres until the correct positions for each basic formation pattern have been learned.

17. When flying in Vic or Echelon, a formation pilot will maintain station by reference to agreed features on the adjacent aircraft (e.g. lining up the wing tip and the nose of the aircraft ahead). Obviously these features will vary according to aircraft type and can be varied on a specific type to achieve a particular formation shape for special occasions.

18. In line abreast formation, the correct fore and aft position can best be judged by reference to the cockpit of the next aircraft and the lateral position by reference to its size. The plane of the windscreen arch may assist fore and aft positioning but it is difficult to judge whether one aircraft is truly line abreast with another and the tendency is to formate a little too far back. It is difficult to judge the separation between the wing tips of aircraft with highly swept wings and extra caution is therefore needed.

19. In line astern formation the correct fore and aft position can be judged by the relative size of the aircraft ahead, or a part of this aircraft as seen relative to the windscreen of the formating aircraft. The amount by which each aircraft must be stepped down from the preceding aircraft varies according to the slipstream from each type of aircraft, but generally should be as small as possible. Too large a vertical interval between aircraft results in the last member of the formation flying very much lower than the leader and this may cause some difficulty in turns.

Keeping Station - Straight and Level Flight

20. All pilots should aim to achieve smoothness in their formation flying. This is particularly important when more than a single aircraft is formating in Echelon, line astern or line abreast, since the movement of one aircraft in relation to another is accentuated towards the outside of the formation. If the second aircraft in the formation is flown roughly, the pilot of the aircraft on the outside of the formation will have an extremely difficult task. This may be simplified, however, by keeping station longitudinally and vertically on the lead aircraft instead of the next aircraft, thereby reducing the 'whip' effect.

21. To keep his position constant in relation to the leader of the formation, the formating pilot may be required to adjust his position longitudinally, laterally and/or vertically. A keen sense of anticipation must be developed so that correcting movements are kept to a minimum.

22. **Longitudinal Station Keeping**. Changes of position in the longitudinal direction are made using the throttle to make small speed changes and this in turn may necessitate a small movement of the elevators to maintain position vertically; thus co-ordinated movements of the two controls are made throughout. To maintain a constant position longitudinally the throttle should be moved in the appropriate direction immediately any change is noticed or anticipated. This movement should be smooth and no more than is necessary to correct errors. Large throttle movements will usually result in over-correction, making station-keeping difficult and increasing fuel consumption; the latter may be critical on long sorties. It must be remembered that a clean aircraft usually accelerates quickly and decelerates slowly because of its low drag and due allowance must be made for this. Jet engine aircraft may have poor acceleration, especially at low air speeds, and also decelerate slowly, both effects must be anticipated.

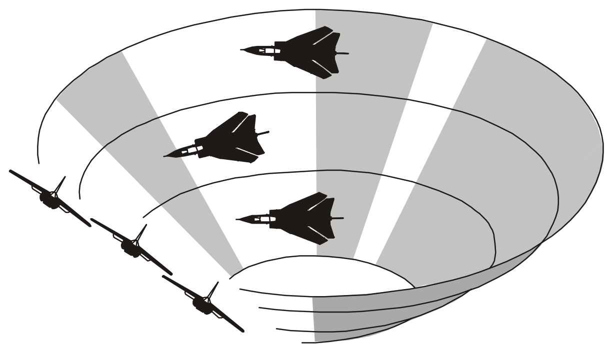
23. **Lateral Station Keeping**. Changes in lateral position are made by gentle movements of aileron, in some aircraft, co-ordinated with use of rudder. Small angles of bank should be used to correct lateral spacing and, when approaching the correct position, opposite bank will be required to return to the leader's heading and so maintain the new position.

24. **Vertical Station Keeping**. Position in the vertical plane is controlled by the elevators. At some stages of flight, notably on an approach, in aircraft with highly-swept wings, even small changes of angle of attack caused by elevator movement will require some throttle movement to maintain longitudinal positioning. Co-ordination of elevator and throttle is important.

Keeping Station - Turns

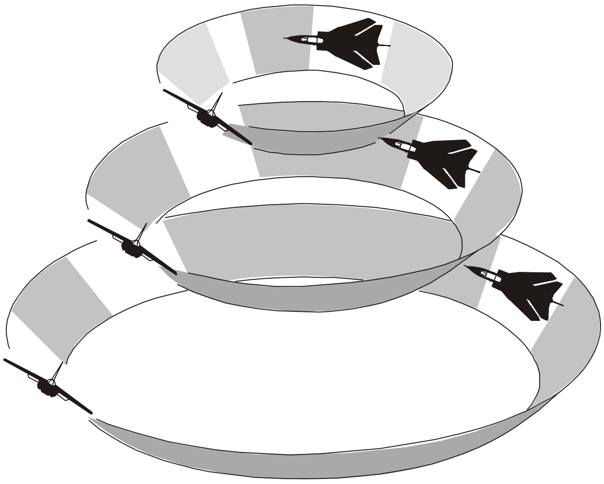
25. Fig 12 shows how, during a turn in Vic formation, the outside aircraft describes a turn of larger radius, and the inside aircraft a turn of smaller radius than the leading aircraft. To maintain the correct position relative to the leader it is necessary therefore for the outside aircraft to increase speed, whilst the inside aircraft must reduce speed. When a turn is initiated, the formating pilot should endeavour to anticipate an alteration in power. The greater the lateral distance between the leader and the formating aircraft, the greater will be necessary speed adjustments. It is this factor which limits the manoeuvrability of large formations.

8-21 Fig 12 Comparison of Turning Paths in Horizontal Formations



26. Fig 13, illustrating three aircraft carrying out a turn in the line astern position, shows that each aircraft flies a longer distance than the aircraft above it. The necessity for stepping down no more than the essential amount, especially when large numbers of aircraft are flying in this type of formation, can be plainly observed.

8-21 Fig 13 Comparison of Turning Paths in Vertical Formations



27. The sensations experienced during turns in Vic formation, especially on the outside of steep turns, may at first be disconcerting, but it will be quickly learned that the outside aircraft is in no danger of slipping down onto the leading aircraft. The control movements required for keeping station, as described in paras 20 to 24, apply during any manoeuvre - even during inverted flight.

28. It is a pre-requisite of good formation flying that the formating pilots should trust their No 1 and concentrate on accurate station keeping without giving too much attention to any particular manoeuvre which may be carried out. Experience enables pilots to fly in formation and at the same time to realize exactly what manoeuvres are being executed; until this experience is gained, any temporary disorientation which they may experience should be ignored. The importance of thorough pre-flight briefing cannot be over-emphasized.

CHANGING CLOSE FORMATION

General

29. Rapid and efficient changes of formation may be required operationally (e.g. for the run-in and break) or for the purpose of display flying. They are an essential part of formation flying and all pilots should aim at the highest standards of promptness and skill in their operation.

Briefing of Close Formation Changes

30. To ensure safe operations, pilots must know precisely which positions they are to occupy in a formation. It follows, therefore, that intended formation positions must be specifically briefed before flight. The guiding principle to be followed in formation changes is that the minimum number of aircraft should move to effect the change. It is not intended to list all possible combinations of formation changes but paras 34 to 41 indicate the general methods employed.

Use of R/T and Hand Signals

31. Formations are allocated code names eg 'Tankard'. This enables the No 1 to pass messages and receive them from any particular sub-unit or individual in the formation. He is termed 'Tankard 1'. A Section is allocated a colour; 'Red', 'Yellow' or 'Blue' with callsign 'Tankard Blue Section' for instance. In each section, aircraft are numbered one, two, three and so on. Within 'Blue Section' the aircraft callsigns are Tankard Blue One, Two or Three.

32. Radio calls and hand signals must be standard, unmistakable and clear of ambiguity:

a. **R/T**. A call is made as follows: "TANKARD BLUE - ECHELON LEFT- ECHELON LEFT - GO". The word "GO" is the executive order. After it is given, those aircraft required to move position must acknowledge with their callsign. A slight pause is observed before starting to carry out the order; this is important where the operation of flaps, airbrakes or undercarriage is called for in close formation.

b. **Hand Signals**. Pilots must be prepared to operate in conditions of radio silence and should become accustomed to working with a minimum of calls; in close formation, visual hand signals usually suffice. A table of the standard formation hand signals used in the Royal Air Force is at Volume 8, Chapter 22.

Look-out During Formation Changing

33. Changes of formation are made on the commands of the formation No 1, as detailed in the following paragraphs. During all changes of formation it is vitally important that each pilot who is changing position should keep the rest of the aircraft in the formation in view. Where this is not possible, e.g. large formations, pilots should not move formation position until aircraft outside their field of view have called clear.

Section Formation Changing

34. **Vic to Echelon Right**. The command is "BLUE SECTION - ECHELON RIGHT - ECHELON RIGHT - GO". After acknowledging, No 3 drops back and down, moves across and then forward and up into position (see Fig 1 and Fig 2).

35. **Vic to Echelon Left**. The command is "BLUE SECTION - ECHELON LEFT - ECHELON LEFT - GO". After acknowledging, No 2 moves back and down, then across, forward and up into position. Note that No 3 holds his position next to No 1 (see Fig 1 and Fig 3).

36. **Vic to Line Abreast**. The command is "BLUE SECTION - LINE ABREAST - LINE ABREAST - GO". After acknowledging, Nos 2 and 3 move forward into position and call 'in' (see Fig 1 and Fig 4).

37. **Vic to Line Astern**. The command is "BLUE SECTION - LINE ASTERN - LINE ASTERN - GO". After acknowledgement by Nos 2 and 3, No 3 moves back and down and calls 'clear'. When No 2 hears that No 3 is clear he moves back, down and across into position. When No 3 sees that No 2 is in position he moves across into position and calls 'in'. No 3 is responsible for avoiding No 2 throughout the formation change (see Fig 1 and Fig 5).

38. **Box to Echelon Right**. The command is "BLUE SECTION - ECHELON RIGHT - ECHELON RIGHT - GO". After acknowledgement by Nos 3 and 4, No 4 moves back and across into position and calls 'clear'. When No 3 hears that it is clear he drops back and down until he can see the other three aircraft, he then moves across and into position on the outside of the section (see Fig 6 and Fig7).

39. **Box to Echelon Left**. The command is "BLUE SECTION - ECHELON LEFT - ECHELON LEFT - GO". After acknowledgement by Nos 2 and 4, No 4 moves back and across into position and calls 'clear'. When No 2 hears that it is clear, he moves back and down until he can see the other three aircraft, and then moves across on the outside of the Echelon (see Fig 6 and Fig 8).

40. **Box to Line Abreast**. The command is "BLUE SECTION - LINE ABREAST - LINE ABREAST - GO". After acknowledgement by Nos 2, 3 and 4, Nos 2 and 3 move forward on No 1. When No 4 sees they are in position he moves across and forward into either the right hand or left hand position as required or briefed (see Fig 6 and Fig 9).

41. **Box to Line Astern**. The command is "BLUE SECTION - LINE ASTERN - LINE ASTERN - GO". After Nos 2 and 3 have acknowledged, No 3 moves back and down and calls 'clear'. When No 2 hears that No 3 is clear, he moves back and down and across into position behind No 4. When No 3 sees that No 2 is in position he moves across into position behind No 2 and calls 'in'. No 3 is responsible for avoiding No 2 throughout the formation change (see Fig 6 and Fig 10).

FORMATION TAKE-OFF

General

42. It is usual for aircraft to take-off in pairs formation but in some circumstances a Vic take-off may be appropriate. At flying training schools, for instance, Vic take-offs are preferred since they provide the opportunity to train two students at a time. For any type of aircraft the choice between Vic and Pairs will also depend upon consideration of wingspan, main-wheel track, runway width and crosswind component.

Taxiing

43. Whilst a formation of aircraft is taxiing, there is a danger of airframe and engine damage to the following aircraft caused by stones and other debris (FOD) thrown up by the jet efflux or slipstream of the preceding one. Therefore, a safe spacing (normally 150 metres minimum) must be maintained when taxiing. The required safe spacing for taxiing will normally be promulgated by the operating authority.

Line-up and Take-off

44. For a Vic formation take-off, the No 1 will line-up on the centre line and the Nos 2 and 3 will position themselves on their respective halves of the runway in the correct fore and aft station and with safe lateral spacing between wing tips. Prior to a pairs take-off, both aircraft may take the middle of their respective halves of the runway with the No 2 positioning himself correctly longitudinally. The No 1 will signal to open up to a briefed power setting against the brakes and on receiving the 'ready' signal from the Nos 2 and 3 (when applicable) will order a 'release brakes', opening up smoothly to the desired take-off power. Wing-men must concentrate on staying with the No 1 whilst making their own take-offs, but the original runway spacing should be held until safely airborne to reduce the risk of collision should directional control problems occur.

Intervals Between Elements

45. The time interval between elements (pairs or singletons) during a stream take-off will vary with aircraft type and prevailing conditions - normally 10-15 seconds will suffice. On aircraft types where runway length may not be important, eg STOVL aircraft, the interval can be achieved by spacing along the runway and rolling together. If the join-up cannot be made below cloud, the interval should be increased (typically to 30 seconds) to allow for either a 'snake' or radar controlled climb.

Slipstream During Take-off

46. To minimize slipstream effects, pairs may be briefed to pull high or hold low immediately after take-off - the low pairs aiming to unstick beyond the point where the preceding one became airborne. This technique, however, is no longer recommended for high performance aircraft. With these, it is better to increase the time interval and use turns to effect a rapid join-up after take-off. The effects of aircraft wakes are discussed in Volume 8, Chapter 17, Para 23.

FORMATION LANDING

General

47. Formation landings are usually carried out in pairs from a circuit or radar approach, with the No 1 landing on the down-wind side of the runway.

48. Only pilots who have attained a high standard of formation flying should progress to formation landings. Absolute confidence in the No 1 is essential.

Technique and Procedure

49. After joining the circuit in the usual manner, the No 1 turns down-wind and reduces to circuit speed as smoothly as possible. At the correct speed, the No 1 gives the signal to lower the landing gear and flaps; formating pilots must anticipate any changes of trim and complete their vital actions. It is important for pilots to resist any temptation to over-control at this stage.

50. The turn onto the final approach should be as gentle as possible so that the formating pilots can keep station comfortably. If a further change in aircraft configuration is required for landing, this should be ordered by the No 1 as early as possible to enable the formation to settle down. At this stage, pilots should appreciate that their aircraft response is more sluggish than at cruising speed. It is vital that wing-men counter any tendency to drop low or fall back on the No 1 on late finals. Flying low might lead to the wing-man landing in the under-shoot and dropping back might place him in the No 1's slipstream or jet wash. Additionally, a formating pilot should beware of over-shooting the No 1 since throttling back too much at this stage might place the engine in the low response region of rpm.

51. The wing-man's aim is to achieve his own individual landing whilst keeping station on the No 1. In this way, the angle of approach and airspeed can be controlled by the No 1 whilst the wing-man is responsible for lining-up and landing on his half of the runway. It follows that the wing-man must split his attention between the No 1 and the runway. Initially all that is required is a glance ahead to assess line-up and drift but, from approximately 500 feet agl, or Decision Height if the formation has been in cloud, progressively higher priority must be given to the runway. On crossing the threshold, the wing-man should make a normal landing promptly whilst the No 1 will delay closing his throttle for two to three seconds to assist the wing-man in initiating nose-to-tail separation.

52. Once formating aircraft are firmly on the ground they should commence braking without delay. The No 1 should delay his own braking slightly until he sees the formating aircraft are safely down and decelerating. The aim is to establish fore and aft aircraft separation as soon as possible in case of directional control problems. Individuals must maintain their lateral position on the runway until cleared to move across by those behind them. The temptation to relax at this stage should be strongly resisted; a formation landing is not complete until all the aircraft are clear of the runway.

THE BREAK AND STREAM LANDING

General

53. If close formation landings are not required or are precluded by the prevailing conditions (e.g. strong crosswind, narrow runway), the break and stream landing procedure is usually used.

54. If the weather is suitable for a visual circuit, the leader of the section should approach on the heading of the runway in use at the briefed height, slightly on the dead side, with his formation in Echelon right (left-hand traffic pattern). On crossing the runway threshold, the leader should bank and pull away firmly to the left, followed in order by the rest of the section at the briefed interval. Each pilot should throttle well back, open the airbrakes, lower partial flap (depending on the aircraft type) and maintain a continuous turn, aiming to roll out in line with, and at the same height as, the aircraft ahead, whether the break was level or climbing. A useful method of judging relative height is by placing the No 1 on the horizon. Individual aircraft should aim to achieve a position 1,000 metres astern of each other, from which point essentially individual landings are carried out. The pre-landing checks should be completed at a suitable point. Caution should be exercised on finals to avoid going too low or using excessive power; the hazard of wake turbulence should be emphasized during the briefing.

55. The No 1 should aim to land on the runway centreline and then move to the exit side of the runway when safely under control. Subsequent aircraft should also touch down on the centreline and move to the exit side of the runway after it is obvious that they can stop within the distance between them and the aircraft ahead. A minimum separation distance will normally be laid down by the operating authority. It is important when large formations are stream landing that, after checking the satisfactory operation of the brakes after touch down, all aircraft keep rolling to the end of the runway. Unnecessarily harsh braking in the landing run should be avoided, or bunching will occur. The runway distance-to-go markers should be used to aid judgement of progressive braking.

56. A landing formation must know of any unusual conditions of runway or crosswinds, and the No 1 should always ascertain these from Air Traffic Control. Controllers should realize that there is much that can be done to help formations. If unusual circumstances are encountered, the No 1 should take them into account, and where necessary, order his formation to increase spacing.

57. It will be noted that a break from the standard Echelon positions described earlier will lead to landings out of numerical sequence. Whilst this is accepted at RAF airfields, it is not at many other NATO airfields. Operational units may overcome this difficulty by forming non-standard sequentially numbered Echelons from tactical formation (described later), or the No 1 may order a sequential renumbering of the Echelon during the run-in. The standard rule is that aircraft will break in numerical order so, if it is intended to break out of sequence, the procedure must be carefully pre-briefed in order to avoid any confusion.

LARGE FORMATIONS

General

58. When formations of more than four aircraft are to be flown, it is essential that all members of the formation are carefully selected and are given sufficient practice in the position in which they are to fly. Practice should be given in separate sections before the main formation is assembled.

Formation Positions

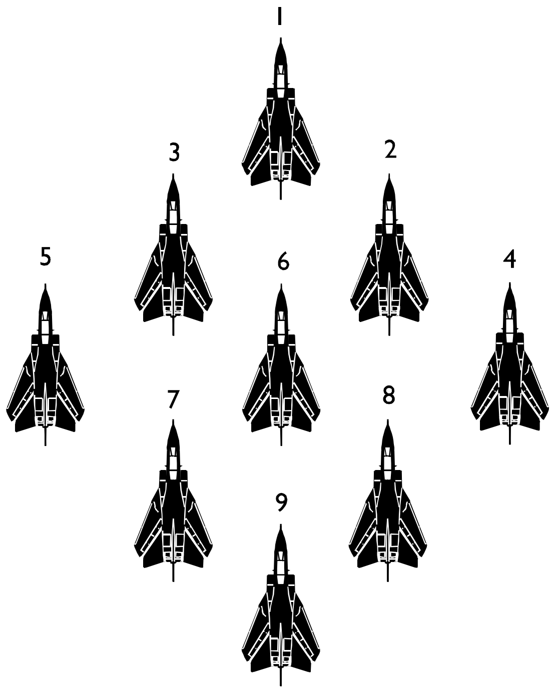
59. Normally, large formations will be formed of several smaller sections and, if the formation is to be a loose one, these sections should remain intact with the section leaders positioning to give the required overall shape. If, however, the formation is to be fully integrated, it is advisable that the second and subsequent line wing-men formate in line astern on the wing-man ahead. This ensures that the pilot has precise formation references and, within his peripheral vision, he should be able to

see the aircraft on the other side of him. The formation No 1 must brief at what stage of the formation join-up, formation wing-men are to transfer their attention to the aircraft ahead; it is suggested that this is when the section leader calls that he is in position.

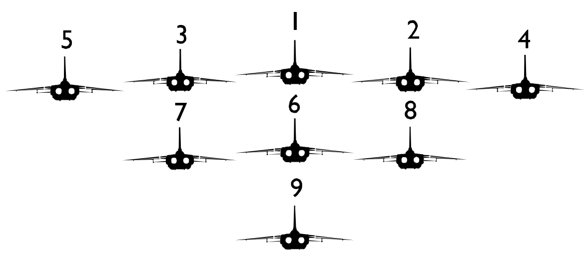
Numbering of Large Formations

60. If, as stated previously, a large formation (eg, a 'Diamond Nine') is to be formed from separate sections, an unambiguous callsign numbering system should be maintained from take-off, through join-up, until landing. The diamond nine in Fig 14 could be formed from a 5-ship plus a 4-ship (BLUE 1 - 5, RED 6 - 9). Alternatively, it could be formed from a 3-ship, a pair and a 4-ship (BLUE 1 - 3, YELLOW 4 - 5, RED 6 - 9). The numbering shown in Figs 14 and 15 follows the general rule that odd numbers are on the left of the formation and even numbers are on the right.

8-21 Fig 14 Diamond Nine Formation



8-21 Fig 15 Diamond Nine Formation - Rear View



Changes of Formation

61. Changes of formation are made in accordance with the principles described earlier, whatever the number of aircraft in the formation. In order to avoid the danger of collision, however, certain additional rules must be observed for larger formations.

62. Changes of close formation within a section will always be called by the section leader and executed on the command "GO". In larger formations, the overall No 1 will often direct the movement of sections with non-executive calls eg "Tankard Formation, form boxes, close trail". Alternatively, the formation leader may wish to order individual section movements when the needs of flight safety so dictate, e.g., "Red section drop back and call clear - GO".

63. Ordering formation changes in large formations can easily lead to confusion. Whatever the occasion and no matter how simple the formation changes might appear, there is no substitute for careful planning, particularly of the joining and splitting-up stages of the mission, where the risk of collision is at its highest. It is impossible to lay down a standard sequence of calls. Each plan must cover all likely eventualities using R/T which is free from ambiguity. On the other hand, every pilot in the formation must understand the No l's intentions and should know precisely the movements required in his section at each significant point in the mission. Through meticulous briefings, the aim should be to reduce R/T calls to the minimum, thus allowing pilots to concentrate on their flying and leave room for any emergency transmissions. Fig 16 shows a possible fly-past formation and suggests the manner in which the No 1 might choose to manoeuvre the three sections to change from Box fours at 200 metres spacing to sections in Echelon right, with 1,000 metres spacing, for a visual run-in and break.

64. It can be seen from the foregoing paragraphs that all formation changes must be carried out with care and the correct methods taught and practised from the earliest days of a pilot's training. However, unfamiliar situations lend themselves readily to misunderstanding and in these cases No 1 must not assume that individuals know the formation manoeuvring required, and should include them in the pre-flight briefing. The following are two common areas of possible confusion:

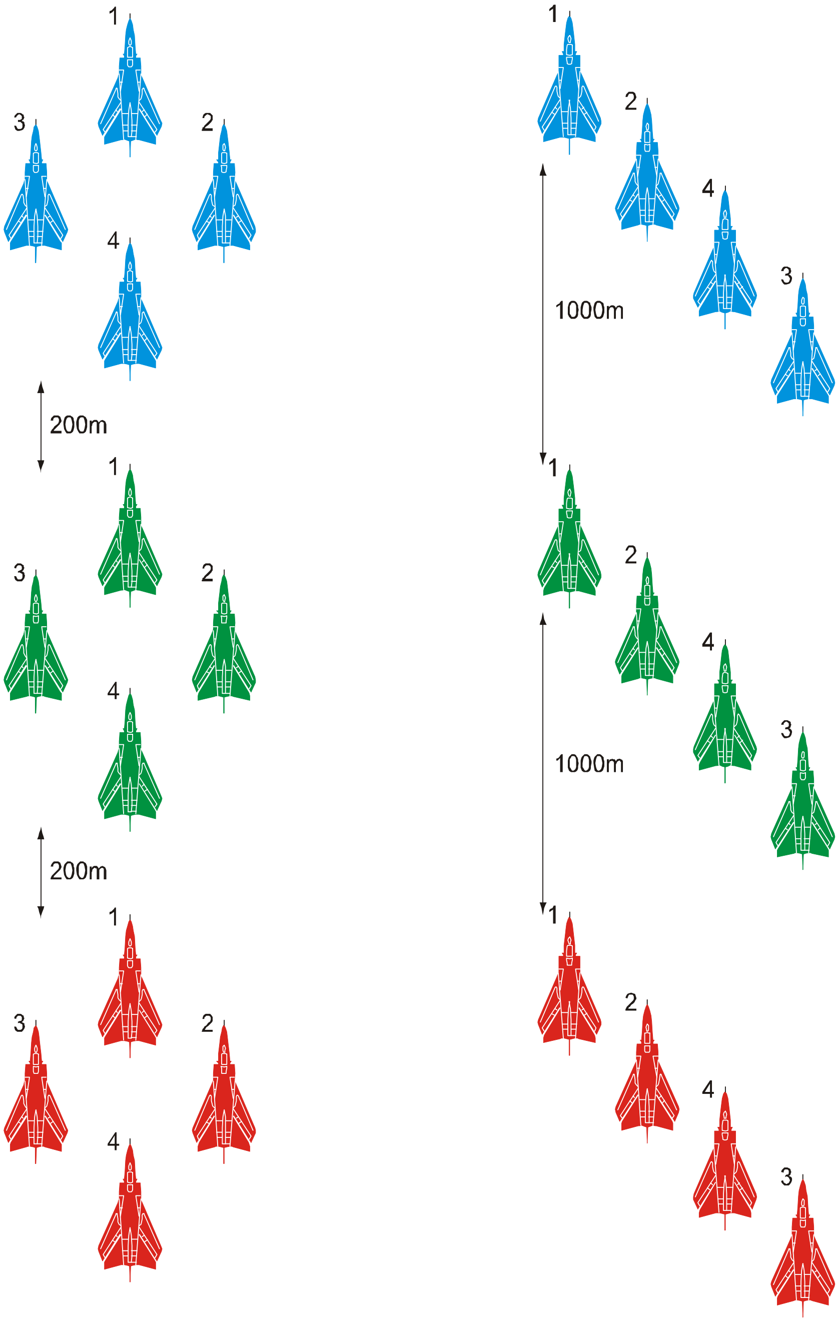
a. **Training Aircraft**. Training aircraft most often operate in sections of three using Vic, Echelon and Line Astern. Pilots are accustomed to the individual positions. Adding an extra aircraft to form a Box 4 will require careful briefing since it cannot be assumed that the same pilots are familiar with the different sequence of formation changes involved.

b. **Operational Fast Jet Aircraft**. Operational fast jets usually fly in tactical formations of two or four aircraft. Pilots are accustomed to completing their missions with a visual run-in and break from a tactical formation e.g. Battle or Arrow (described later). They may not expect to be called into a close Echelon, therefore if the No 1 intends this he should brief accordingly.

Landing a Large Formation

65. It is important that each section of a large formation should spend a minimum of time in the circuit to reduce congestion and minimize delays for following aircraft. Minimum circuit time is achieved by employing the stream-landing technique.

8-21 Fig 16 Large Formation Manoeuvring



TANKARD 1
"Tankard squadron for visual run in and break, sections form echelon right, 1,000m trail."
"Red section fall back and call clear - GO."

RED 1
"Red section clear."

TANKARD 1
"Green section fall back and call clear - GO."

GREEN 1
"Green section clear."

Whilst Tankard No 1 lines the whole squadron up at initials for the run in and break, the section leaders space out on the sections ahead and then put their own sections into echelon on the final run-in.

TANKARD 1
"Blue section echelon right - GO."

GREEN 1
"Green section echelon right - GO."

RED 1
"Red section echelon right - GO."

TACTICAL FORMATIONS

Introduction

66. Tactical formations are planned and flown to achieve as good a defensive posture as possible. Such a posture will depend upon how many aircraft are involved and the profile of the sortie. A 2-aircraft formation in line abreast may achieve good rearwards lookout but is relatively unwieldy in turns. The same 2-aircraft formation in long line astern is easily manoeuvred but cross cover is severely limited. Compromise formations are selected, therefore, to give optimum defensive cover and many are developed as the most appropriate for individual squadrons and for particular aircraft types. The three tactical formations described in this chapter are the more simple manoeuvres, generally taught in flying training schools, from which more advanced tactical formation profiles are developed. They are:

a. Fighting Wing.

b. Defensive Battle.

c. Arrow.

Considerations

67. **Range Estimation**. Range estimation improves with experience. Even so, exact distances tend to be a matter of opinion and cannot be assessed with any degree of accuracy. The correct distances between aircraft will more readily be described as 'a bit too close', or 'rather wide' or the like, and correct spacing will, with practice, become second nature. That said, since this terminology cannot be used in a written description, distances are described more precisely in this chapter.

Airmanship

68. **Lookout**. The purpose of a tactical formation is to take advantage of good lookout. The No 1 is responsible for formation security but relies upon his wingmen to give warning of other aircraft, be they hostile or friendly. Reports to the leader must be quick and accurate giving all the essential information in a dispassionate and unemotional manner.

69. **Slipstream**. Aircraft in formation should take care to avoid the slipstream of other formation aircraft. Apart from dangerous control difficulties, flying into turbulent air might lead to unacceptable rises in turbine gas temperature (TGT).

70. **Terrain and Collision Avoidance**. Each pilot in a tactical formation is responsible for maintaining a safe distance from other aircraft and from the terrain. It is particularly important to be aware of the briefed MSD when at low level and to break off, if necessary, for a safe rejoin.

71. **Sighting Reports**. A thorough lookout for threat aircraft must be maintained. All aircraft, whether believed to be hostile or not, must be reported when on a tactical communications frequency. In training, the briefing will usually require only threats or collision risks to be reported on an ATC frequency. Sighting reports should be given as follows:

a. Callsign of reporting aircraft.

b. Left/Right and clock code (relative to leader).

c. High, low or level.

d. Range.

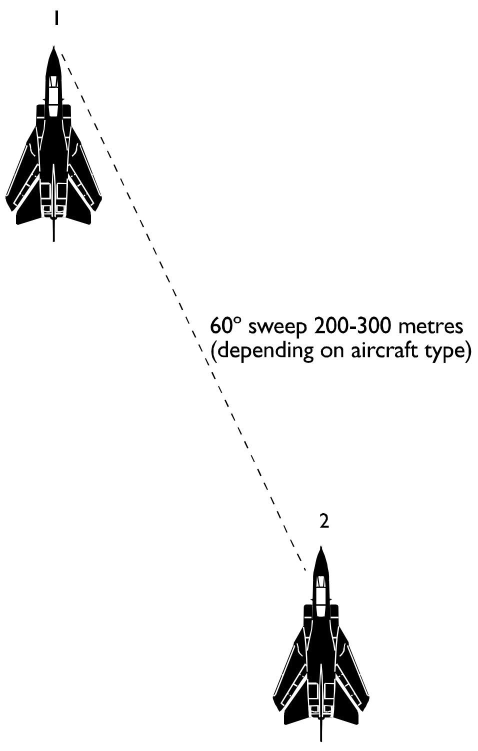
e. Type and number of aircraft.

f. What sighted aircraft are doing.

Fighting Wing Formation

72. **General**. Fighting Wing (Fig 17), in which the No 2 occupies a cone behind the leader of about 60º apex and 200 m to 300 m depth, offers the leader good cross cover and greater manoeuvrability than close formation. Fighting Wing is normally flown as two aircraft. With four aircraft, pairs 'in trail' would normally be flown. The rear pair should maintain the briefed trail separation which will be in the order of 1,500 m to 2,000 m depending upon conditions.

8-21 Fig 17 Fighting Wing Formation

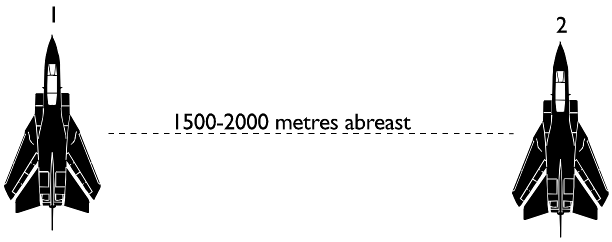


73. **Manoeuvres**. Manoeuvring to remain on station during turns is relatively easy and all-round lookout should be maintained by each pilot. Except when otherwise briefed, the No 2 maintains the altitude of his leader during turns thus limiting the vertical envelope of the formation. This makes transit at low level particularly effective.

Defensive Battle Formation

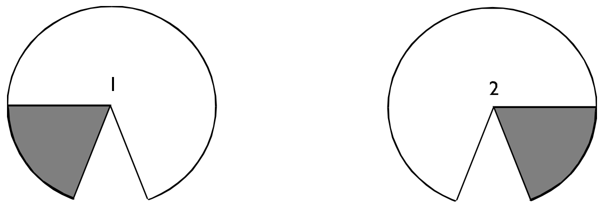
74. **Description**. Despite the relative effectiveness of Fighting Wing formation, Defensive Battle is the basic tactical formation used in the RAF. It is the best compromise between effective lookout, mutual support, manoeuvrability and reduction in vulnerability. The distance apart depends upon visibility and the expected weapon threat and, once the optimum has been decided, convergence and divergence must be countered continuously. The configuration for two aircraft is shown in Fig 18.

8-21 Fig 18 Defensive Battle Line Abreast



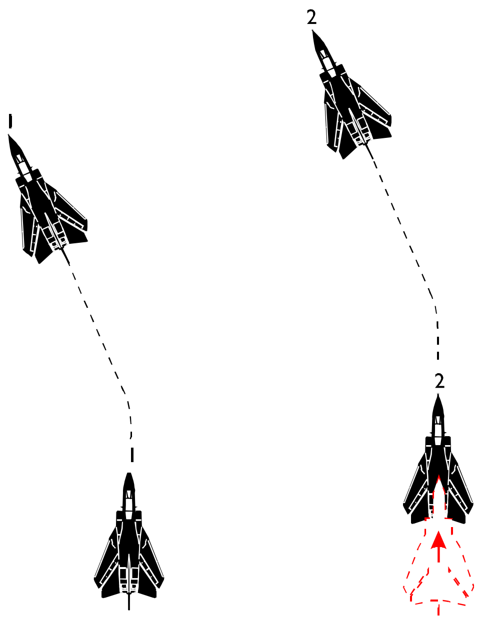
75. **Lookout and Search Areas**. Areas of responsibility for visual search and the lookout sectors are shown in Fig 19. Aircrew should spend about three quarters of their time searching their primary (blank) field and the rest searching the remainder of the sky (shaded). The entire sky, vertically as well as level, must be covered.

8-21 Fig 19 Defensive Battle Formation Lookout Sectors



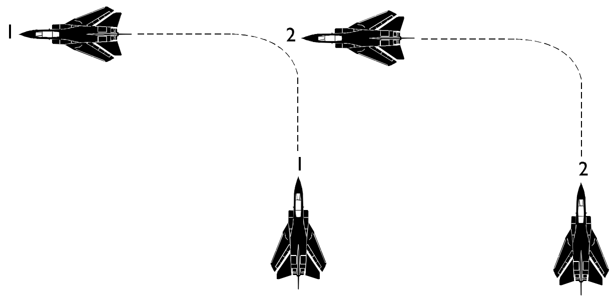
76. **Pre-planned Route Turns**. On a pre-planned route, turns will normally not be called. The leader will fly the briefed route and the other aircraft or elements should anticipate the turns and remain on station. A two-aircraft turn through 25º to the left is shown in Fig 20.

8-21 Fig 20 Pre-planned Route Turn - Left 25º



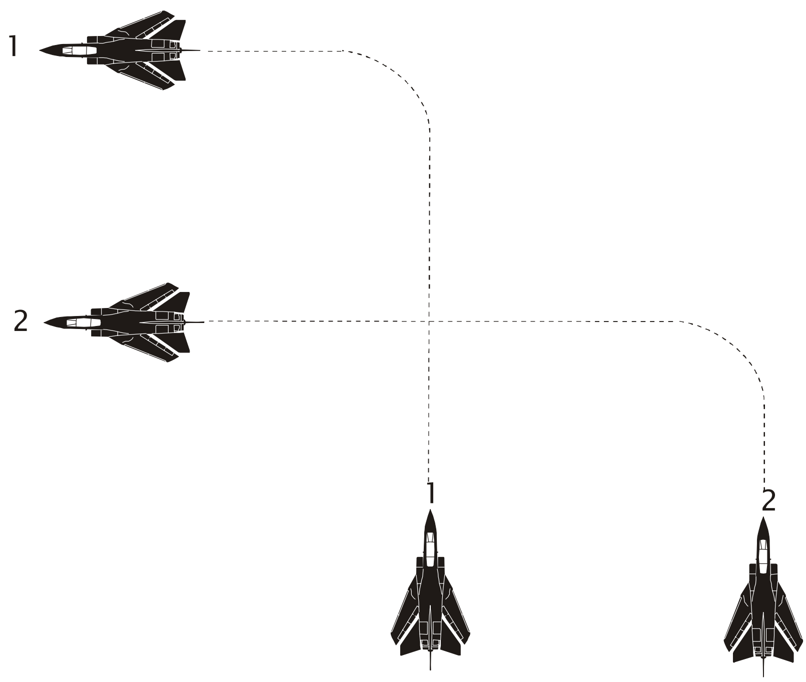
77. **In Place Turns**. 'In Place' turns involve all aircraft turning simultaneously through the appropriate number of degrees. Navigational turns will normally be of 30º or less and will require a small amount of manoeuvring if it is intended to remain in place. Larger turns will have to be well anticipated to remain in place or may be used to regain formation integrity or effect a formation change (90º is illustrated in Fig 21).

8-21 Fig 21 In Place Turn - 90º Left

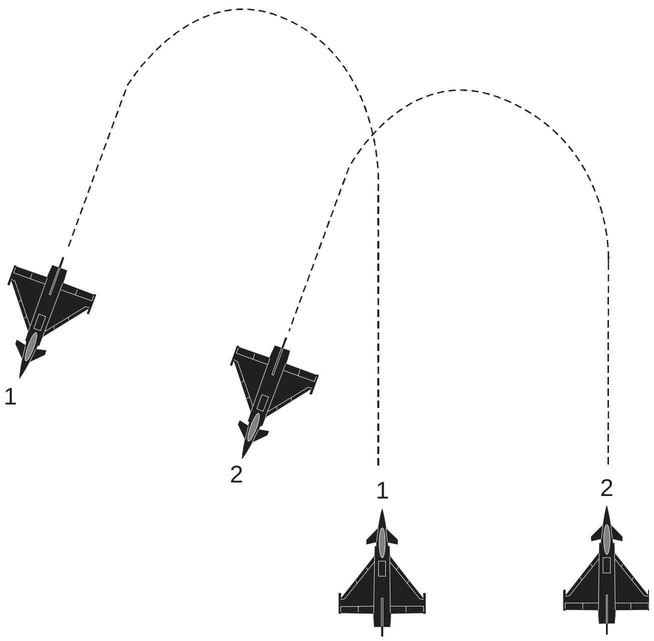


78. **Variable Delay Turns**. When making turns of greater than 60º and up to 180º, a variable delay may be employed as shown in Figs 22 and 23. For a two-aircraft formation, the outside aircraft initiates the turn and is responsible for collision avoidance. The inside aircraft delays, commencing the turn based upon the visual aspect and position of the other aircraft. For a 180º turn (a 'turnabout') no delay is necessary and both aircraft turn at the same rate simultaneously. It follows that the delay becomes progressively greater for turns of less than 180º down to 61º. The 90º delay may be used as a yardstick for judging the time to allow initially but accurate timings will come with increasing experience.

8-21 Fig 22 Variable Delay Turn 90º Left



8-21 Fig 23 Variable Delay Turn 160º Left

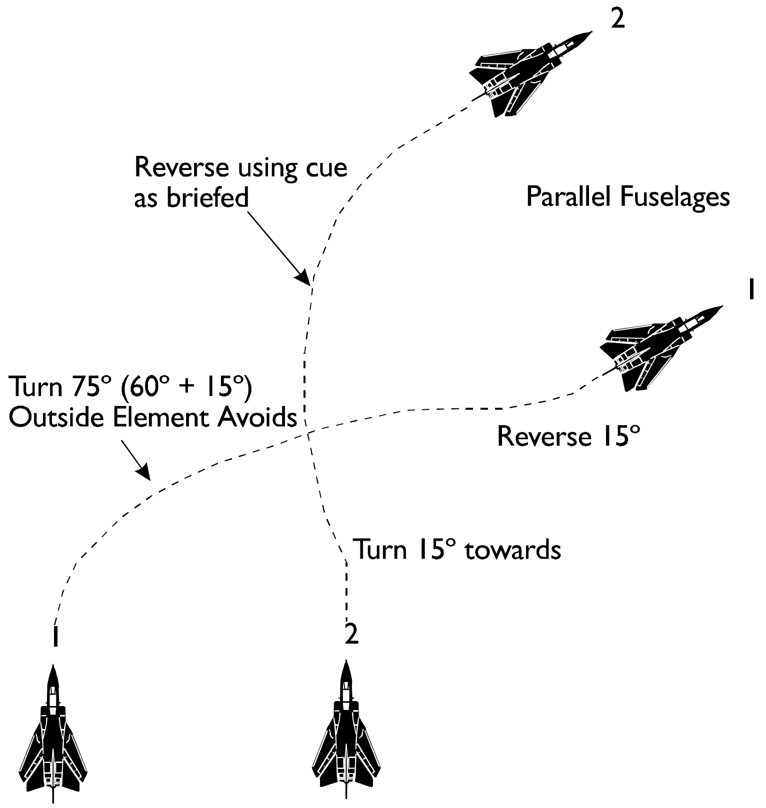


79. **Assisted Turns**. Assisted turns are generally used for turns between 30º and 60º. Assistance, in this context, is defined as an additional compensatory turn to **assist** in final positioning. By applying the right amount of assistance, the length of flightpath is the same for both aircraft and the manoeuvre ensures that both roll out close to the correct spacing. As a rule of thumb, the amount of assistance needed is calculated by halving the difference between the required turn and 90º as shown in Table 1. A 60º right assisted turn is illustrated in Fig 24.

Table 1 Assisted Turns - Calculating Assistance Required

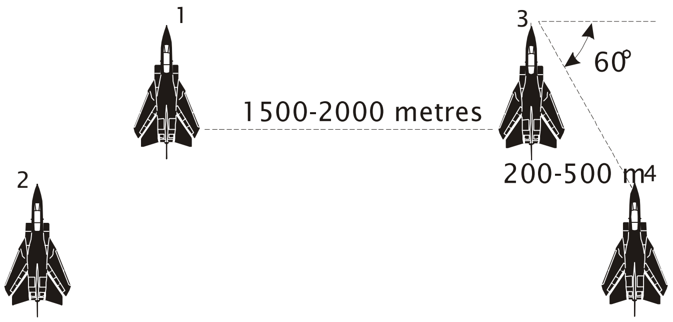
Degrees of Turn	Assistance Required
0	45º
30	30º
45	20º
60	15º
90	0º

8-21 Fig 24 60º Right Assisted Turn

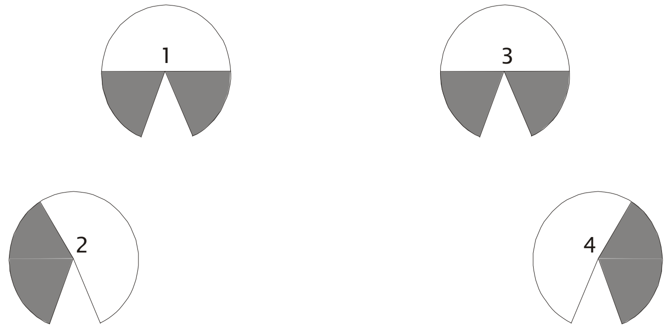


80. **Four Aircraft Profiles**. The four aircraft Battle formation is, essentially, two mirrored elements of Fighting Wing abreast in which the Nos 2 and 4 may assume a slightly longer trail. The profile and lookout areas of responsibility are illustrated in Fig 25. Once again, the illustrated primary (clear) areas should be scanned for about three quarters of the time and the shaded areas for the rest. The whole vertical extent of the sky must be included in the search. Turns of up to 30º may be carried out in place. Larger turns are conducted as for two aircraft Battle but the Nos 2 and 4 change sides for variable delay and assisted turns when their element leaders start to turn, adjusting to resume the lookout regime shown in Fig 25 on roll-out.

8-21 Fig 25 Four Aircraft Defensive Battle



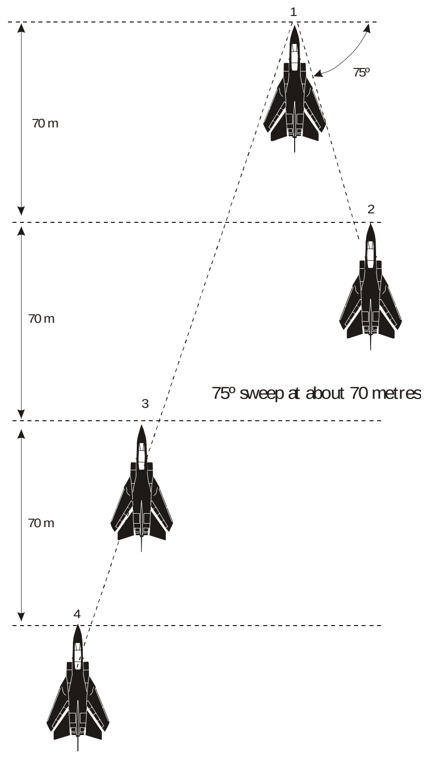
Lookout Areas



Arrow Formation

81. Arrow formation is used for manoeuvring four aircraft in poor weather conditions or restricted airspace and is illustrated in Fig 26. Rearward lookout tends to be restricted but flexibility remains high. The No 2 should position himself at 75º sweep and about 70 metres behind the leader (with small variations depending on aircraft type). The No 3 should be on the other side of the leader, swept 75º and at double the rearward spacing of the No 2. (ie about 140 metres in this example). The No 4 spaces himself outside the No 3 at 75º sweep and again about 70 metres behind.

8-21 Fig 26 Arrow Formation



82. **Turns**. Individual aircraft maintain longitudinal separation, do not normally change sides when turning, and will manoeuvre in plane. This makes Arrow less manoeuvrable than Fighting Wing and the leader must plan turns within the available height to avoid units changing sides.

Recovery

83. **Joining the** Circuit. All the tactical formations previously described will normally maintain position when joining the circuit but may be called to close up to accommodate time and circuit pattern limitations. Procedures are described below (in many training establishments, however, it will be routine to rejoin in close formation).

a. **Fighting Wing Rejoin**. Fighting Wing elements may join the circuit in formation. The No 2 should delay his break for the briefed interval or until the leader has cleared the 12 o'clock position, depending on circuit direction and formation configuration.

b. **Defensive Battle Rejoin**. Defensive Battle formations may maintain position when joining the circuit but will normally close up to not more than 800 metres abreast. The formation breaks in numerical order or as briefed. The No 2 should delay his break for the briefed interval or until the leader has cleared the 12 o'clock position. If on the outside, the No 3 should break at the same time as the No 2; if on the inside, the No 3 should delay until both the Nos 1 and 2 have cleared the 12 o'clock position. The No 4 should delay for the briefed interval or until the No 3 has cleared his 12 o'clock position.

c. **Arrow Rejoin**. The formation may join the circuit in Arrow and break in numerical order. The No 2 breaks after the briefed interval or when the leader has cleared his 12 o'clock. The remaining aircraft break after the briefed intervals.

JOINING CLOSE FORMATION FROM A TACTICAL FORMATION

General

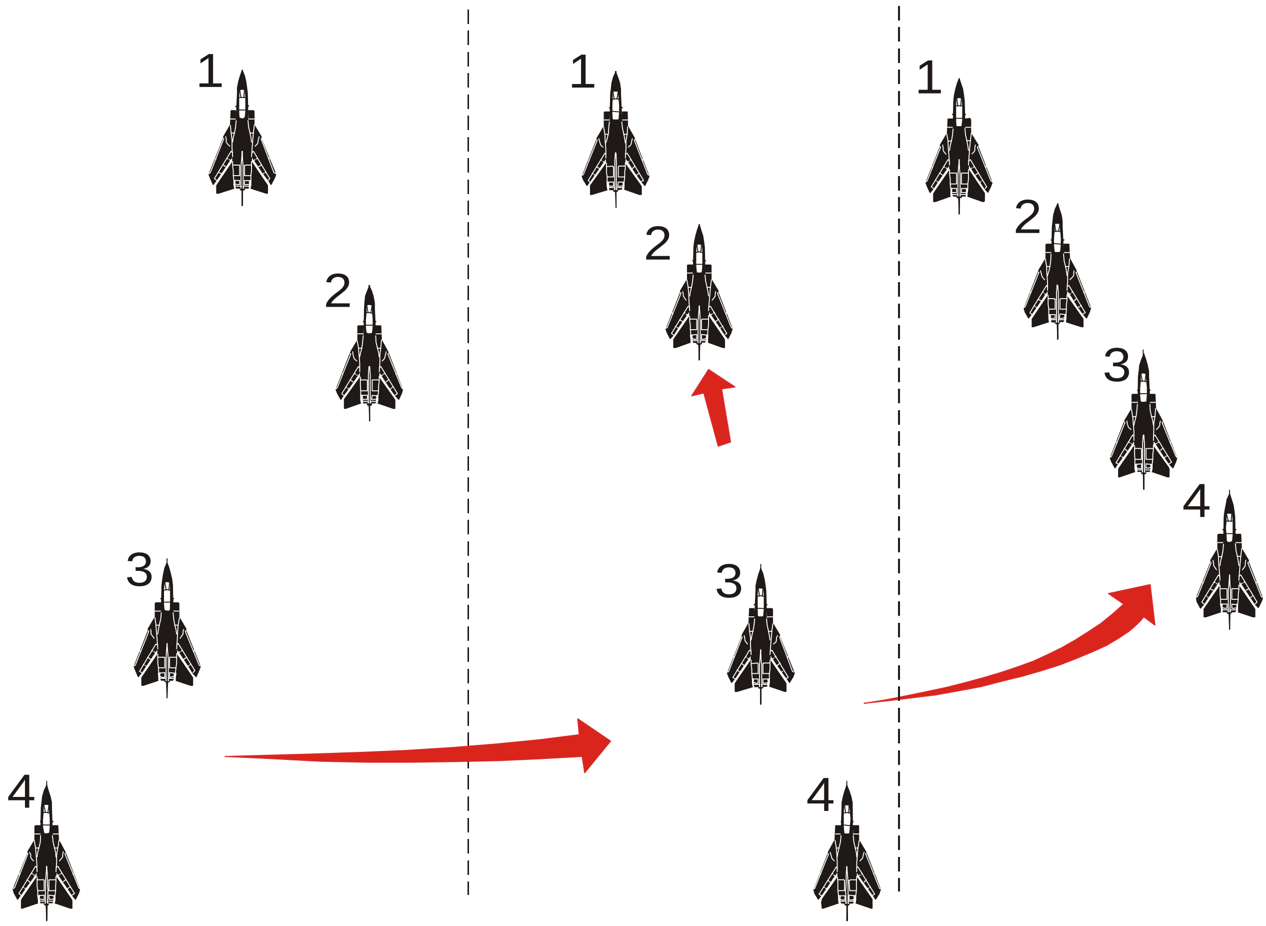
84. Occasions may arise when it is desirable to close up a tactical formation for ease of manoeuvre in difficult terrain (Arrow Formation), cloud penetration (Defensive Battle), or for a set-piece break into the visual circuit. It is not intended to cover joining close formation from all combinations of tactical formations, but a simple technique for changing into close Echelon from four aircraft Defensive Battle and Arrow is shown, the principles of which can be applied to other tactical formations not covered in this chapter. For all tactical formations the guiding principle is that the separate elements always stay together as a fighting unit eg No 2 with No 1 and No 4 with No 3. For this reason, the sequence of aircraft in Echelon will be seen to differ from that produced by manoeuvring a basic close formation into Echelon from Vic or Box. This is not a departure from the principle of 'minimum change', but it produces sequential numbering as a by-product of retaining the integrity of tactical formations.

Arrow and Defensive Battle Formations into Close Echelon

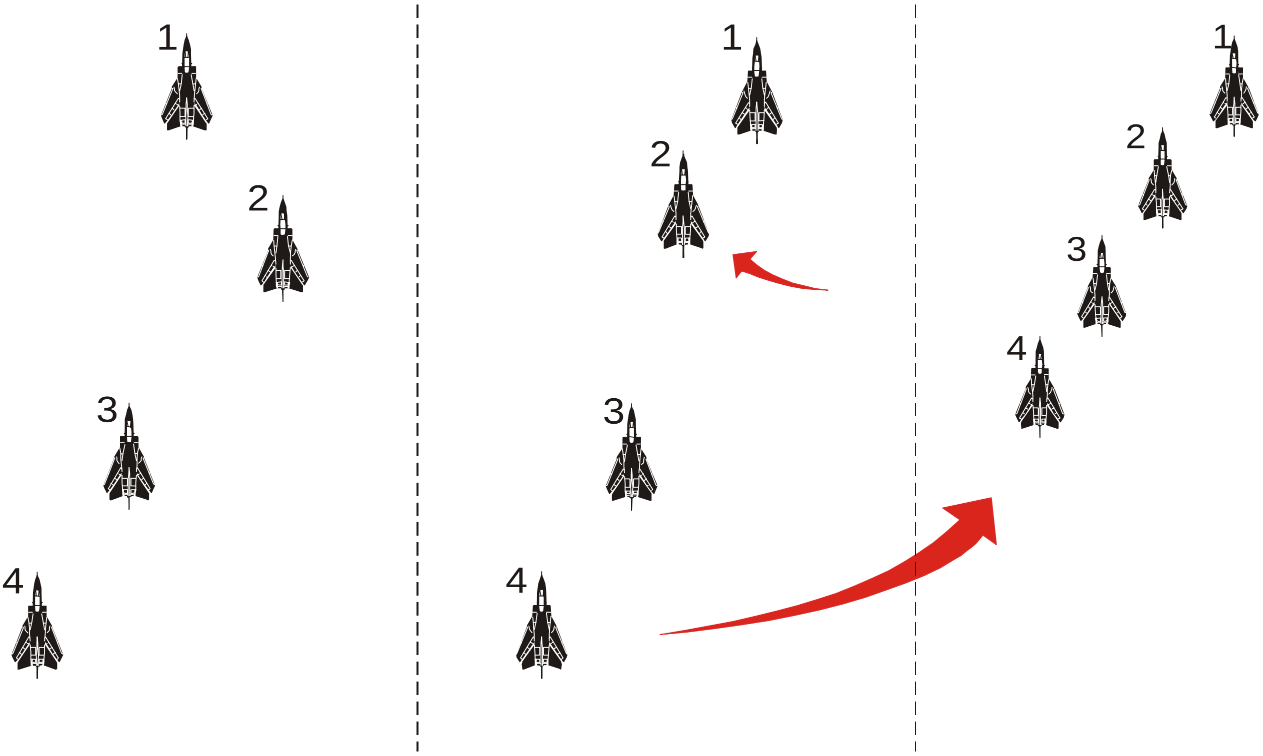
85. Changes into close Echelon from Arrow formation are shown in Figs 27 and 28 and from Defensive Battle in Figs 29 and 30. In all cases, the No 2 and No 4 maintain nose-to-tail clearance on their respective element leaders. Additionally, in the case of Arrow, No 3 keeps nose-to-tail clearance on No 2. From Arrow formation, No 2 may position himself initially on either side of No 1 and thereafter Nos 3 and 4 together move smoothly into their correct Echelon positions with No 4 on the outside of the formation. When a formation is required to change to Echelon from Defensive Battle, No 3's view of the other aircraft is better and his judgement made easier if the move is made through Arrow formation; this is the

recommended technique. Once in Arrow formation, on the command "Tankard formation Echelon Left/Right - GO", Nos 3 and 4 do nothing until No 2 has taken up position in close Echelon on the correct side of No 1. Nos 3 and 4 then move into Echelon as shown in Figs 29 and 30. Should it subsequently be found necessary to change the Echelon from one side to the other, the move should be accomplished by ordering the formation back into Arrow, before calling a change to the opposite Echelon. A direct move from one Echelon to the other is possible but open to confusion and misinterpretation. The good formation No 1 will always put his flight back into a manoeuvrable formation such as Arrow when confronted with a late change of runway or circuit direction. The moves described in this paragraph will place the aircraft in the correct numerical sequence for a run and break. Any requirement for an out-of-order break must be carefully pre-briefed.

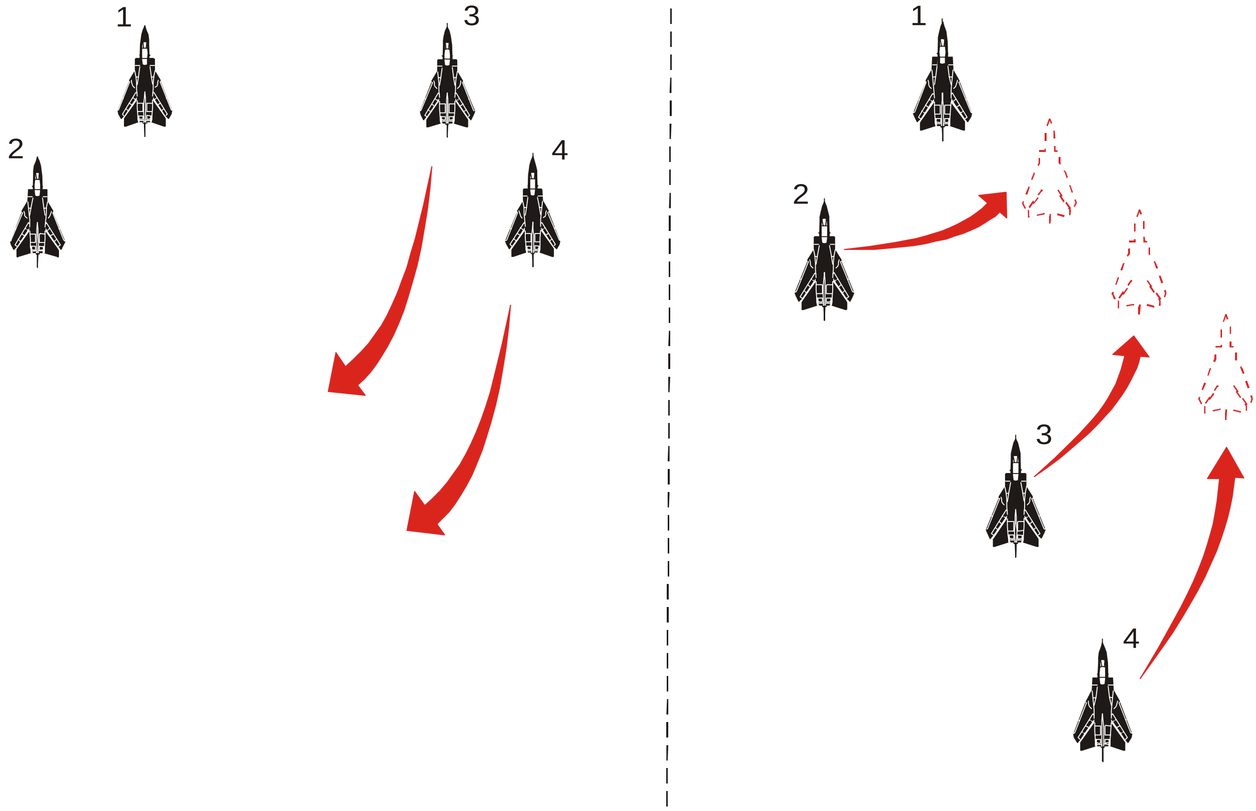
8-21 Fig 27 Arrow to Echelon Right



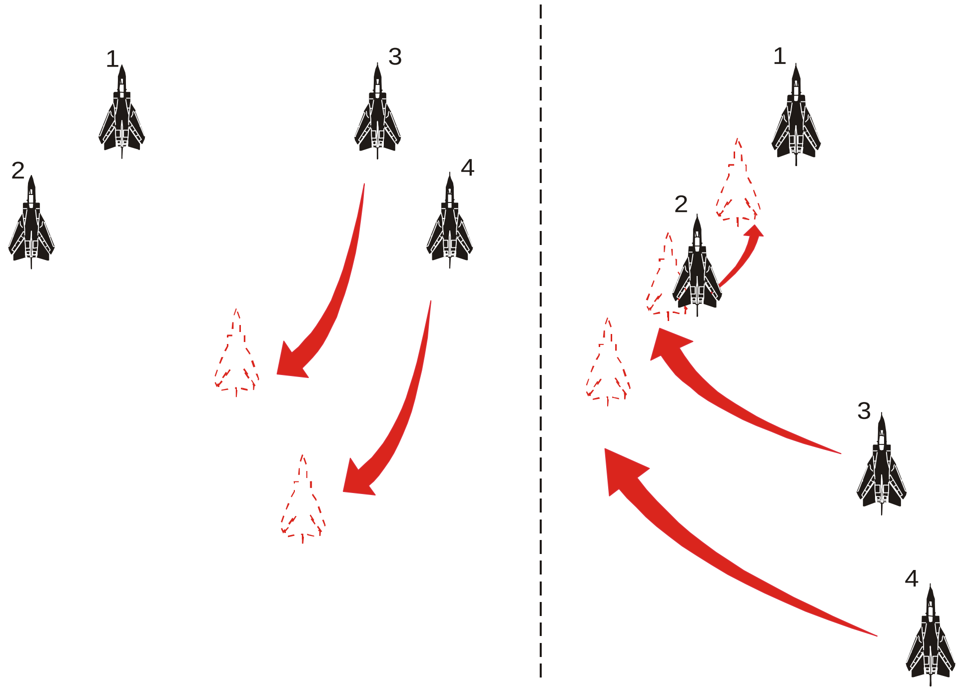
8-21 Fig 28 Arrow to Echelon Left



8-21 Fig 29 Defensive Battle through Arrow to Echelon Right Formation



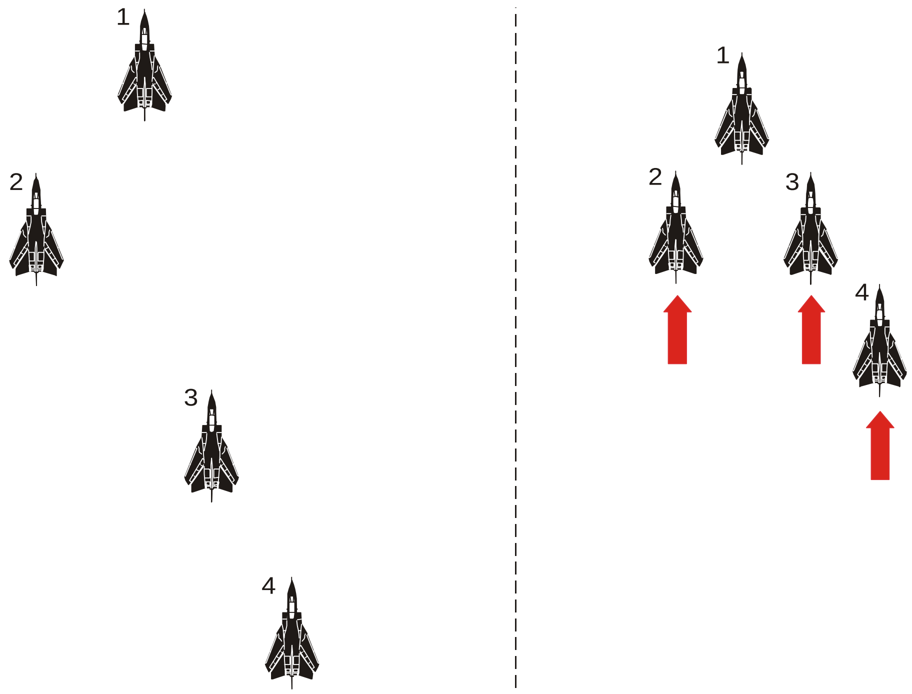
8-21 Fig 30 Defensive Battle through Arrow to Echelon Left Formation



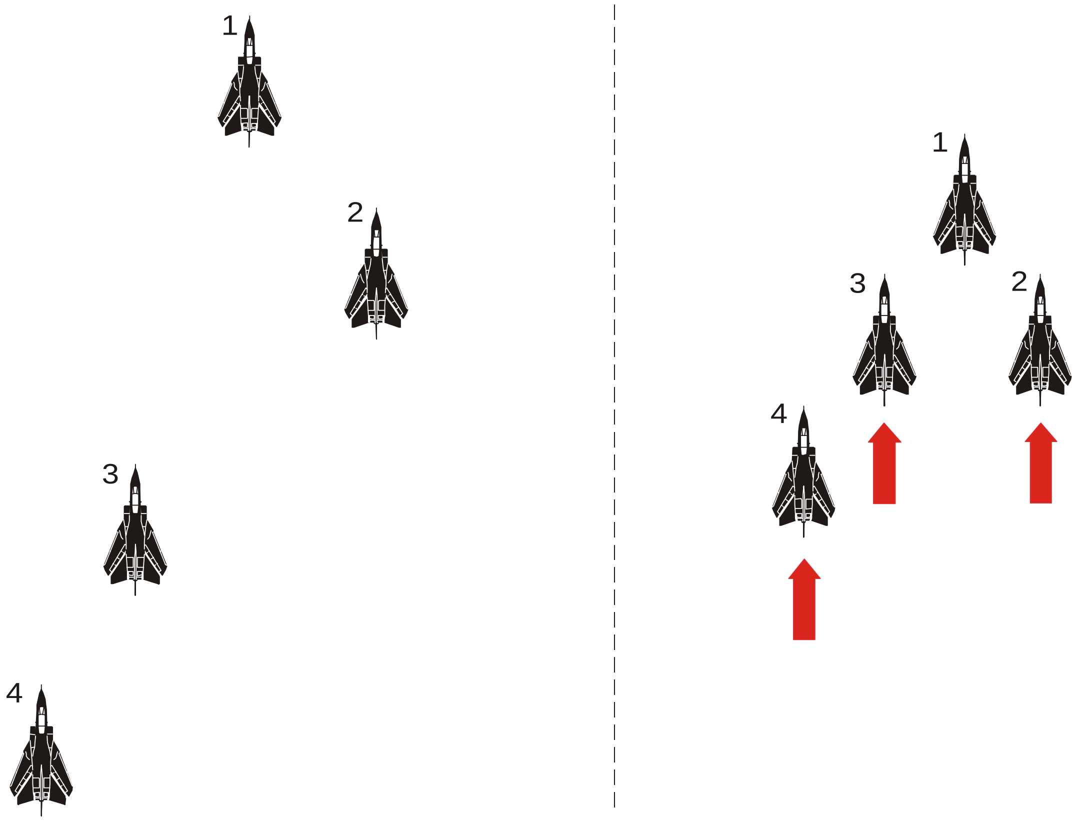
Arrow Formation into Finger Four

86. The Finger Four is a close formation not covered in previous paragraphs. It is occasionally used for recovery when little manoeuvring is required. It is formed from Arrow by Nos 2, 3 and 4 closing up on the No 1 into Echelon positions (Figs 31 and 32). A subsequent change from Finger Four to Echelon is not recommended because it may destroy the integrity of the elements. However, there is no reason why the No 1 should not pre-brief such a change, accomplished by No 2 moving to the end of the Echelon or Nos 3 and 4 moving to the opposite side. For normal operations, it is safer to return the formation to Arrow and then order a change into Echelon Left/Right. Penetration of cloud in Finger Four formation is not recommended, and may be prohibited by some authorities, because if the middle aircraft of the three-aircraft Echelon loses the No 1 in cloud his escape manoeuvre may embarrass the outside aircraft.

8-21 Fig 31 Arrow to Finger Four Right



8-21 Fig 32 Arrow to Finger Four Left



Human Factors and Formation Flying

Formation Flying is not only an integral part of operational flying but also highly satisfying to do well. However, aircraft flying in close proximity is not without it's dangers and can, as proved, be lethal. There is potential for a loss spatial disorientation and Situation Awareness. Formation flying is about sound planning, practice, communications and good leadership.

CHAPTER 22 - STANDARD FORMATION HAND SIGNALS

1. Standard formation hand signals are described in Table 1. The signals are agreed via STANAG 3379 and the standards described in AFSP-4, In-flight Visual Signals. MAA RA2350 – Aircraft Emergencies states that Aviation Duty Holders may issue additional in-flight visual signals, but they should be consistent with STANAG 3379.

Table 1 - Standard Formation Hand Signals

(The signals marked by an asterisk (*) conform to AFSP-4)

EXECUTIVE SIGNALS		
Action	**Description of Signal**	**Action to be Taken at**
1. Running up.	Hand raised, forefinger extended upwards and revolved in horizontal plane.	Commencement of signal.
2. Ready for take-off?	Thumb up.	
3. Commence take off.	Tap on the forehead three times followed by a nod of the head.	Nod of head.
4. a. Increase power. b. Decrease power	a. Positive forward movement of head. b. Positive backward movement of head.	Cessation of signal.
5. Turning.	Forearm vertical, hand flat and parallel with line of flight then moved right or left as necessary.	Cessation of signal.
6. Straightening out.	Chopping motion forwards with edge of flat hand.	Cessation of signal.
7. Airbrakes 'in' or 'out'. *	Hold open hand horizontally at eye level, then move the fingers and thumb to simulate a biting motion.	Nod of head.
8. Flaps 'up' or 'down'. *	Hold open hand horizontally at eye level, with fingers and thumb flat, then tilt hand downward by bending the wrist.	Nod of head.
9. Undercarriage 'up' or 'down'.	Hold a closed hand forward of your head and rotate it in a circular motion in the vertical plane.	Nod of head.
10. Lead Change. *	Point with an index finger to new leader, then hold open hand vertically at eye level, fingers together, and then move it horizontally forward with rotation to finish with hand held horizontally and arm fully extended.	Nod of head and manoeuvre to take the lead
11. Close formation or reform basic formation as briefed.	Lateral rocking of aircraft.	Cessation of signal.
12. Relax close formation.	Hand raised with palm outwards, fingers together, palm against canopy on the appropriate side.	Cessation of signal.
13. Change position. *	Index finger pointed at aircraft/pilot concerned, then pointed to the new position to which this pilot is to move.	Nod of head and manoeuvre to new the position
14. Line astern: a. Close b. Extended	a. Clenched fist, thumb extended to rear, moving back and forth. b. Clenched fist, tapping on the back of head.	Cessation of signal.
15. Climbing.	Forefinger point upwards.	Cessation of signal.
16. Descending.	Forefinger pointing downwards.	Cessation of signal.
17. Levelling out.	Sideways movements of either hand, palm down, fingers extended at face level.	Cessation of signal.

18. Break formation.	Rapid sweeping movement of the open hand, palm forward, fingers upward in front of the face.	Cessation of signal.
19. I am returning/you are to return to base.	Point at self/aircraft concerned, then point downwards.	
INFORMATIVE SIGNALS		
Action	**Description of Signal**	
20. Your aircraft is on fire.	Fly alongside and rock the wings to attract the attention of the pilot, then draw the edge of the hand across the throat in a cutting motion, afterwards pointing to the fire area. Continue this until acknowledged by thumbs up signal.	
21. Fuel state.* To indicate or query the amount of fuel remaining. To indicate or reply.	Make drinking motion with closed hand, thumb extended to touch the oxygen mask. < 10 minutes signal '*Desire to land as soon as possible*' To indicate a greater amount of fuel remaining, hold a closed hand at or above eye level with the appropriate number of fingers extended vertically as follows: 10 - 19 minutes 1 finger (index) 20 – 29 minutes 2 fingers 30 – 39 minutes 3 fingers 40 – 49 minutes 4 fingers 50 minutes or more 5 fingers (open hand)	
22. Receiver failure.*	Tap earphone with open hand and then move hand forward and backward over ear position followed by a thumbs down.	
23. Transmitter failure.*	Tap microphone with an open hand and then move hand up and down in front of face followed by a thumbs down.	
	The pilot with communications failure should attempt to attract attention visually by: a. Rocking the aircraft wings.: b. Flashing landing, taxi or other lights (except navigation lights) during darkness. c. Any other means.	
24. Affirmative/I will comply *	Nod head forward and back or a thumbs up.	
25. Negative/I will not comply *	Turn head left and right or a thumbs down.	
26. Terrorist Attack *	Hold pointed finger to the head with thumb sticking up to simulate a pointed gun to the head.	

DISTRESS SIGNALS (DAY)		
Action	**Description of Signal**	
27. Ejection.*	One or both closed hands pulled downwards from above the head, across the face to simulate pulling ejection blind.	
28. Desire to land.*	Hold an open hand horizontally above the shoulder and then move it forward and downward to shoulder level, finishing with a	

	movement in a simulated round-out.	
29. Systems failure * (HEFOM) **Note**: While HEFOM is in general use in the RAF, AFSP-4 uses the mnemonic HEFOE, where the second E represents *Engine*, vice *Motor*. The signals in both are identical and have the same meaning.	To indicate the nature of the problem or the malfunctioning system, hold a closed hand at or above eye level, and then extend vertically the appropriate number of fingers as follows: **H** Hydraulic one (index) finger. **E** Electrical two fingers. **F** Fuel three fingers. **O** Oxygen four fingers. **M** Motor five fingers (open hand). ***Note**:* 1. The HEFOM signals are to be used only when radio contact is not possible. 2. If either the one finger signal is received, or the intercepting pilot is unable to understand the signals of the pilot requiring assistance, then the intercepting pilot is to assume that the aircraft in distress has one or more systems inoperative, e.g. airbrakes, flaps or undercarriage, and is to proceed with extreme caution.	
30. Receiver failure.*	Tap earphone with open hand and then move hand forward and backward over ear position.	
31. Transmitter failure.*	Tap microphone with an open hand and then move hand up and down in front of face.	
	DISTRESS SIGNAL (NIGHT)	
32. In distress and desire to land.*	Repeated intermittent flashes with a torch, taking care not to dazzle other pilots. (The lead aircraft should assume that the aircraft in distress has one or more inoperative systems and proceed with extreme caution.) ***Note**:* Because night signals will be difficult to understand, only the night signal given above will be used. AFSP-4 gives further details on signals for intercepted and intercepting aircraft at night.	

CHAPTER 23 - AIR-TO-AIR REFUELLING

Introduction

1. Air-to-Air Refuelling (AAR) is accepted as a means of increasing aircraft range without sacrificing other aspects of performance. The adoption of AAR by the RAF is such that almost all aircraft introduced into service today are given a flight refuelling capability. Details of AAR equipments and procedures are promulgated in ATP-3.3.4.2 (ATP 56(C)) - Air to Air Refuelling and ATP-3.3.4.2(C) National SRD-United Kingdom (formerly National Annex Y). These documents are authoritative and users should refer to them for detailed information.

AAR Objectives

2. The objective of AAR operations is to enhance combat effectiveness by extending the range, payload or endurance of receiver aircraft. Successful AAR depends on 3 major factors:

a. **Equipment Compatibility**. It is essential that aircraft requiring AAR are fitted with probes/receptacles and fuel systems compatible with the characteristics of the tanker aircraft employed, e.g. drogue/boom system, fuel surge pressures, fuel type etc.

b. **Performance Compatibility**. It is essential for tanker and receiver aircraft performance to be compatible in terms of AAR speeds and altitudes.

c. **Procedural Compatibility**. It is essential for tankers and receivers to employ pre-planned and compatible procedures for rendezvous, making contact, fuel transfer and departure.

3. The priorities of AAR are:

a. Support of Air Defence Aircraft.

b. Support of Interdictor Strike Aircraft.

c. Tactical Support of Maritime Operations.

d. Overseas support, deployments and exercises.

However, situations occur where the swift deployment of aircraft to counter a distant threat is a vital factor in military operations. Without AAR the speed of response could be seriously affected.

Refuelling Methods

4. There are two main systems for transferring fuel from the tanker to the receiver aircraft; the Boom, and the Probe and Drogue.

5. **The Boom Method**. The tanker is fitted with a flyable, telescopic boom; with the free end terminating in a probe-like fuel nozzle. Receivers are fitted with a reception coupling, or receptacle. The receiver flies a steady formation position whilst the boom operator manoeuvres and extends the boom to make contact with the receptacle. The boom equipped tanker is fitted with Pilot Director Lights (PDLs) to aid receiver positioning. A description of the PDL system is given in the appropriate National SRD.

6. **Boom Drogue Adapter**. The KC-135 and the C135FR boom can be modified to refuel some types of probe equipped aircraft by fitting a Boom Drogue Adapter (BDA) consisting of 3 m (9 ft) of hose attached to the end of the telescoping part of the boom. The hose terminates in a hard non-collapsible drogue. PDLs should not be used with this system. The BDA does not have a hose response system; therefore caution is required during the approach to contact, as excessive closure rates could result in a broken probe or hose. Also, attempts to disconnect which are not made down

the correct withdrawal path, could result in the probe binding in the reception coupling. For this reason, the USAF recommends the use of 'Flexitip' probes with the BDA. Flexitip probes have some internal bracings removed which allows the probe mushroom valve tip some lateral movement within the probe structure, and makes an off-centre disconnect easier. A full description of the BDA is given in the appropriate National SRD. The BDA can only be fitted or removed on the ground.

7. **The Probe and Drogue Method**. From a power-driven hose drum (or reel), the tanker trails a hose which terminates in a reception coupling and a conical shaped drogue. When the hose is at full trail, a winding-in torque (response system) is applied to the drum; this counters the air drag of the drogue. The controlled balance between winding-in torque (response system) and air drag absorbs the impact of the receiver making contact; it also damps any tendency for the hose to whip as contact is made, provided excessive receiver closure rates are avoided. Receiver aircraft are fitted with an AAR probe which terminates in a fuel nozzle.

8. The receiver aircraft is flown to engage the probe into the drogue while maintaining a closing speed of 2 to 5 kt.. When contact is made, the probe engages coupling latches, which grip the probe to make a fuel tight joint; fuel valves in the coupling and probe then open. The receiver continues to move forward, pushing the hose back onto the drum. When sufficient hose has rewound onto the drum, the main fuel valve in the AAR equipment opens and fuel can be pumped to the receiver. After making contact the forward movement required of the receiver to open the fuel valve is typically about 2 m (6 ft); however, the distance varies according to AAR equipment type, details are provided in National SRDs. Most systems afford a considerable range of fore and aft hose movement within which fuel will flow to an in-contact receiver. When AAR is complete, the receiver pilot makes a small power reduction and drops back slowly to stabilize in the astern position. As the hose nears the full trail position, the AAR equipment fuel valve closes. When the hose reaches full trail, the probe begins to pull out of the reception coupling; the coupling and probe fuel valves close, then the coupling latches release the probe.

9. If a Breakaway is commanded, the receiver drops back quickly. A sensor in the AAR equipment detects the high rate of hose movement and the hose drum brake is automatically applied; this achieves a swift, positive disconnect and occurs well before the hose reaches full trail.

Fuel Flow Rates and Pressures

10. Fuel flow rates vary widely according to AAR installation. Generally flow rates will be as described in Table 1, but will be affected by the specific gravity of the fuel and the limitations of the receiver fuel system. Fuel pressure is regulated in most systems not to exceed about 3.5 bars (50 psi) at the reception coupling.

Table 1 AAR System Fuel Flow Rates

Boom System	Up to 3650 kg.min (8000 lb/min)
Integral Hose System	2300 kg/min (5000 lb.min)
Podded Hose System	870 kg/min (2800 lb/min) to 1000 kg/min (3200 lb/min)

Hose Dimensions and Markings

11. Generally pod hoses are shorter, lighter and have a narrower bore than integral system hoses. The lengths of pod hoses vary between 15 m (50 ft) and 27 m (90 ft) whereas 24 m (80 ft) is typical of an integral system hose. Most hoses are marked with coloured bands but there is a wide variety of colours and marking patterns. Most hoses have a series of bands or a block of colour to indicate the

optimum receiver refuelling position; this is achieved when the hose is pushed in so that the markings enter the hose fairing or tunnel. On some hoses, the refuelling position marks are bounded by additional markings indicating the start and stop positions for fuel flow. Usually, there is a series of closely spaced bands at the tanker end of the hose; these provide cues for the receiver pilot to assess rates of fore and aft movement after making contact, or during disconnect. Full details of hose markings and dimensions are contained in National SRDs.

12. To give greater flexibility of operation, the size of the probe nozzle and reception coupling have been standardized throughout NATO countries.

Lighting

13. Adjacent to the refuelling unit and facing aft, the tanker has a panel of coloured lights (red, amber and green) although some equipments may have only amber and green lights. On some systems, the signal lights are duplicated for redundancy. If required, refuellings can be made in radio silence solely by reference to these signal lights. Lighting equipment on the tanker, and probe lighting on some receivers, enable the refuelling to be done at night. The NATO standard light signals are:

Red Light	-	Breakaway, or do not make contact
Amber Light	-	Clear contact
Green Light	-	Fuel is flowing

Variations to the described lighting signals are detailed in the appropriate National SRD.

14. **Drogue Lighting**. Most drogues are illuminated to assist night AAR. Some drogues are lit internally by lights at the coupling; alternatively, the drogue periphery may be highlighted by a series of luminescent tritium light sources. On some tankers, reflective paint is applied to the inside of the drogue.

15. **Probe Lights**. Many receivers have a light which illuminates the probe. These lights should be used with caution, because they can dazzle the refuelling operator in the tanker; furthermore, their use may accentuate a tendency for receiver pilots to chase the drogue and therefore possibly overcontrol.

16. **Drogue Tunnel/Serving Carriage Lights**. The drogue tunnel or the serving carriage of most tanker AAR installations are lit from within. This is particularly useful for gauging the amount of hose pushed back onto the hose drum.

17. ***Boom Tanker Lighting***. Boom tankers are fitted with a rear-mounted floodlight, which illuminates the receiver, to assist the boom operator. The boom is fitted with a boom nozzle light to assist the operator in positioning the nozzle into the receptacle. Some receivers' receptacles are also internally lit; the Universal AAR Receptacle Slipway Installation (UARRSI) is usually lit, or highlighted by marker lights. A UARRSI is a modular AAR unit incorporating an AAR receptacle and slipway to guide the tanker boom nozzle into the receptacle. The UAARSI has a boom interphone capability.

Equipment Currently in Use in the RAF

18. The RAF tanker fleet currently consists of the A330-200 aircraft (see Fig 1), named Voyager K2/K3 in RAF service.

8-23 Fig 1 Refuelling from Underwing Pods

19. The refuelling units are of two types, the Fuselage Refuelling Unit (FRU) and the FRL 905E wing mounted AAR pod. The FRU is mounted at the rear of the fuselage and has a higher rate of flow than the pod. The FRU is primarily intended for use by tanker or transport aircraft but can be used by any type. The refuelling fit of the Voyager depends upon the Mark of aircraft. The fleet will comprise 14 aircraft and all will be fitted with 2 wing mounted pods, with 7 of the fleet also fitted with an FRU. Those aircraft which are only equipped with wing pods are designated Voyager KC Mk2 and those capable of being equipped with a FRU are designated Voyager KC Mk3. The refuelling equipment is operated by a Mission System Operator (MSO).

AIRCRAFT	FRU	POD
Voyager K2		2 x FRL 905E
Voyager K3	1	2 x FRL 905E

20. Specific details of the FRU and FRL 950E pod can be found in the National SRD (see paragraph 1). Brief details of the Voyager capabilities are as follows:

a. At the discretion of the Tanker Commander, receiver aircraft may be cleared to make simultaneous contacts on the wing pods.

b. The Voyager has an extensive array of lights, which are adjustable for brilliance. Formation keeping lights and I/R illuminators are also provided. For conducting night AAR, IR cameras and lighting sources are used.

c. The UK National SRD gives heights and speeds for AAR for the Voyager as Sea level to 35000 ft and the speed range as 180 to 325 kt, whereas the Release to Service Document (at the time of publication) limits the height band to 10000 to 25000 ft and the speed range as 260 to 300 kt. The discrepancy, due to the aircraft using an interim basket fit, will be resolved in the future.

d. The Voyager total fuel load is 109 000 kg (240,000 lb) and transferable fuel is dependent on sortie duration. About 75 000 kg (165,000 lb) is available for transfer during a 4 hour refuelling mission, assuming a fuel burn rate of 6 000 kg/hr (13,220 lb/hr).

e. Fuel is delivered to the receiver at the regulated pressure of 3.5 ± 0.35 bars (50 ± 5 psi).

f. The primary/usual type of fuel is F34 (JP8). Alternate fuels depend upon the airfield where it is uploaded. The Voyager can also accept F35, F40, F43 and F44.

g. The VOYAGER has the following radio, navigation, and RV aids:

i. VHF, UHF and HF radios and Satcom.

ii. VOR, TACAN, ADF, INS, GPS, and weather radar.

iii. UDF, A/A TACAN (bearing and DME), ETCAS, IFF and Link 16.

21. The Voyager wing pod markings and lighting signals are detailed in the National SRD (see paragraph 1).

FLYING TECHNIQUES

Flying Procedures

22. AAR procedures are described in detail in ATP-3.3.4.2 (ATP 56(C)) - Air to Air Refuelling (see paragraph 1).

Tanker Aircraft

23. As the receiver is approaching the drogue, the tanker aircraft should be flown as smoothly as possible because any movement of the aircraft will cause the drogue to oscillate and reduce the chances of a successful contact. It is incumbent upon the tanker captain, therefore, to find the best possible flying conditions conducive to a receiver making contact, i.e. air space relatively free from cloud or clear air turbulence. When a receiver is in contact, it is usually possible to hold position in all but the most turbulent conditions. At all times however, the tanker should be as stable as possible; turns may be made but they should be made smoothly and at such a rate as to allow the receiver to remain in contact easily.

24. Once a receiver has joined, the tanker captain assumes executive control of both aircraft. On large formations during accompanied flights the lead tanker captain is responsible for the safety aspects of the formation. In the event of a receiver emergency the course of action to be taken by the receivers is determined by the receiver leader.

Receiver Aircraft

25. The techniques for successful receiver flying are not difficult to acquire and are well within the capability of the average pilot. Techniques vary slightly but accurate and smooth flying is the basis for success for all types of receiver aircraft. The drogue is approached from behind and slightly below at an overtaking speed of 2 to 5 kt, care being taken in the final stage of the approach not to overcorrect on the controls. If the receiver makes contact too slowly the probe will not engage correctly in the coupling; this is termed a “soft” contact. If an approach is made too fast the drum will not be able to take up the hose quickly enough, the hose will bow and the resulting whip will probably break off the probe nozzle.

Terminology used includes a 'spokes contact', defined as the receiver probe penetrating the ribs or canopy of the drogue, causing damage which can cause FOD and may cause the drogue to lose aerodynamic stability; further attempts to make contact are then not permitted. A 'rim contact' is made when the probe makes a hard contact on the rim of the drogue but does no damage

26. When at the end of an approach and the receiver is sure of making contact, a small amount of power is applied to counteract the drag from the drogue and to maintain the correct closing speed. Immediately a successful contact has been made and the probe is observed to be positively locked in the drogue, a definite reduction in closing speed should be made by slightly closing the throttles before moving up the refuelling position. The normal refuelling position, and one giving the largest refuelling flight envelope, is when the hose is lying at its normal trail angle with the forward edge of the orange band marked on the hose just entering the mouth of the pod, or the serving carriage of the FRU. In all types of receiver aircraft it is essential that pilots are capable of close formation flying for periods of ten minutes of more.

27. To break contact, the throttles are closed slightly and the receiver allowed to drop gently back along the line of the hose, with the aim of breaking contact with the drogue in the normal full trail position. In an emergency the throttles are fully closed and, because of the hose drum braking system, contact will be broken almost immediately with the hose partially wound on the drum.

Night Refuelling

28. Apart from requiring greater concentration, the techniques for night refuelling are identical to those used by day. Any additional difficulties are due mainly to the inability to judge final closing speeds and the distance of the probe from the drogue owing to lack of outside references.

OPERATIONAL USE OF AAR

Methods of Employment

29. **Tactical Applications***.* Extending the radius of action, and/or endurance, of aircraft on operational sorties are possibly the most important applications of AAR. The developing range of operational requirements means a continuing process in evolving the tactical procedures necessary to make the best use of the available effort. For instance, the role of the air defence tanker (ADT), in support of the fighter on a CAP has increased in importance due to changing fighter tactics and the need to provide air defence over maritime areas. The method of close support of strike aircraft will vary with each particular attack sortie due to the variety and location of targets. Inevitably, such wide variations in operational requirements make flexibility paramount for an efficient Tanker Force. Similarly, detailed tanker Standard Operating Procedures (SOPs) are essential to cover every likely operating condition.

30. **Overseas Reinforcement***.* There are two ways in which AAR can be used for aircraft deployment: accompanied and unaccompanied flights.

a. **Accompanied Flight***.* On accompanied flights the receivers make a rendezvous with the tanker close to the receivers' airfield of departure. Thereafter the receivers remain in close proximity to the tanker, taking fuel as planned, until they reach their terminal airfield. In normal peace-time operations the refuellings en route are planned so that, if for some reason the receivers are unable to take on fuel, they have sufficient fuel remaining to either return to their departure airfield or divert to a suitable airfield near track. Accompanied flight is usually employed when the receiver aircraft have poor navigation or communications facilities and/or a short ferry range. After the last refuelling the receivers may leave the tanker and continue to their destination independently. In this way, by flying at their own optimum speeds and heights rather than those of the formation, the receivers' range may be increased. This 'departure' by the receivers may also be used when the tanker is required to land at an airfield other than the receivers' destination.

b. **Unaccompanied Flight**. On unaccompanied flights the receiver makes a rendezvous with the tanker at a convenient point along its track to the destination airfield. For maximum benefit the refuelling should take place at a point as far as possible from the airfield of departure commensurate with aircraft safety. After refuelling, the receiver proceeds alone to its destination. Although this method may be used with long range fighters, it is usually restricted to aircraft with good navigation and communications facilities and/or a large internal fuel capacity, e.g. bomber or transport aircraft.

Rendezvous Procedures

31. **Altimeter Settings**. Unless otherwise directed, an altimeter setting of 1013.2 mb (29.92 inches) is to be used for AAR operations at or above transition altitude, or when over water and operating in accordance with ICAO procedures. When not operating on standard pressure settings, tanker crews are to include the altimeter setting in the RV Initial Call. To minimise the chance of dissimilar pressure settings between receivers and tankers, the following terminology is to be used:

Tanker and receiver altimeter set to:	Terminology used:
1013.2 mb (29.92 inches)	Flight Level
QNH or Regional Pressure Setting	Altitude
QFE	Height

32. **Vertical Separation**. Receivers are normally to join from below and are to maintain a minimum of 1000 ft vertical separation, unless otherwise stated at the planning or briefing stage, until visual contact and positive identification have been made. If conditions for AAR are unsuitable, the tanker commander may select an alternate flight level, altitude or height.

33. **Tanker Speed**. The tanker speed for RV is detailed in the National SRD (See also paragraph 20c). This is the speed that the tanker will fly if communication is not established with the receiver. If the tanker's speed differs from that listed, the tanker should advise the receiver in the RV Initial Call.

34. **Receiver**. The receiver should normally fly the speed prescribed in its flight manual and listed in appropriate tanker National SRD.

35. **Visibility**. Receivers will maintain altitude separation of at least 1000 ft until 1 nm from the tanker.

36. **Receiver Visual With Tanker**. Once the receiver(s) is visual with the tanker, receivers are clear to join and should initiate a progressive climb towards the tanker.

37. **Receiver Not Visual With Tanker**. If receivers are not visual with the tanker, the subsequent actions will be in accordance with the capability of the receiver.

a. Receivers without radar or with only Weather Radar shall not proceed inside 1 nm unless the tanker is in sight.

b. Where receiver national limitations permit, aircraft with a basic airborne intercept radar (i.e. target search available but lock capability not available) may climb to 500 ft below base AAR altitude, maintain this level and close to ½ nm.

c. If radar contact is lost inside of 1 nm without visual contact with the tanker, the receiver is to descend to 1000 ft below tanker altitude.

d. Where receiver national limitations permit, as long as radar lock is maintained, aircraft equipped with an AI radar may continue closure at no more than 10 kts of overtake inside of ½ nm maintaining 500ft vertical separation to a minimum range of 1500 ft.

e. When visual contact is established with the tanker, a progressive climb may be initiated in order to join the tanker.

f. If visual contact is not established by a range of 1500 ft, closure is to cease.

g. If radar lock is subsequently lost, the receiver shall re-establish at least ½ nm range and maintain a minimum of 500 ft vertical separation.

38. **Visual Contact Not Established**. If visual contact is not achieved at the appropriate minimum closure range, the receiver(s) may stabilise at the appropriate minimum range and maintain it until the tanker manoeuvres into an area of improved visibility. Alternatively, the receiver(s) may descend to 1000 ft below the tanker, drop back to 1 nm and either maintain this position until the tanker manoeuvres into an area of improved visibility or terminate the RV.

39. **Termination of AAR Due to Visibility**. AAR is to be discontinued when in-flight visibility is deemed insufficient for safe AAR operations.

40. There are several methods of effecting a rendezvous (RV) which are described in detail in ATP-3.3.4.2 (ATP 56(C)). A brief description of each RV procedure is given in the following sub-paragraphs.

a. **RV Alpha (Anchor RV)**. This is a procedure directed by a radar control station, whether ground based, seaborne, or airborne (AEW).

b. **RV Bravo**. This is a heading based procedure which utilises air-to-air equipment of both tanker and receiver. The tanker controls the procedure.

c. **RV Charlie**. This is a heading based procedure similar to the RV Bravo which allows receivers with an Airborne Intercept (AI) radar to control the procedure once positive AI radar contact is established.

d. **RV Delta (Point Parallel)**. This procedure requires the receiver to maintain an agreed track and the tanker to maintain the reciprocal track, offset a pre-determined distance.

e. **RV Echo (Timing)**. This procedure is intended for use in support of a combat air patrol (CAP); particularly during periods of EMCON constraints.

f. **RV Foxtrot (Sequenced)**. This procedure is normally used when the tanker and receiver operate from the same base.

g **RV Golf (En-route)**. This procedure facilitates join up on a common track to make good a scheduled time. The receivers may have departed either from the same or different bases. There are a number of enroute RVs.

Meteorological Aspects

41. Weather has an important influence on the conduct of AAR operations. In addition to taking account of the weather conditions at the operating and diversion airfields the following factors have to be considered.

a. **Rendezvous Weather**. Weather conditions in the actual area of the rendezvous can be critical. Although it is not impossible to make a rendezvous in thin cloud, it is much more difficult and hazardous than in clear conditions. A visual sighting can be made much more easily if the rendezvous is at a height at which contrails are found.

b. **En Route Weather**. During accompanied flights IMC can make visual station keeping in large formations very difficult. Although the internal radar of the tankers and receivers can be used to assist station keeping in cloud, such conditions are avoided as far as possible by small deviations in route and/or height. Contacts may be made in cloud but flight in heavy cumulo-nimbus formations or clear air turbulence can result in drogue oscillation and difficulties in making contact.

Planning

42. Before a deployment may be undertaken, it must be established that it is feasible. The purpose of the feasibility study is two-fold: to establish that the receiver is capable of undertaking the deployment format and to establish the tanker/receiver ratio required. Many factors are taken into account: the relative performance of the tanker and receiver aircraft, the availability of diversion airfields along the selected routes, the tanker effort allocated to the deployment, the availability of parking space at the staging airfields, and the climatology of the route and the staging and terminal bases. Receivers can normally be classified as high performance aircraft and in many cases the endurance is, apart from fuel, limited by the consumption of oil and oxygen. The endurance of the receiver frequently dictates the format of the deployment.

43. When the feasibility study has been completed, it is then possible to calculate the movement table which provides details of the daily movements of tankers and receivers. From this the personnel and equipment needed at en route bases for ground support can be determined.

The Refuelling Plan

44. When the tanker movements have been determined, the full refuelling plan is calculated; this plan sets out:

a. The positions where fuel is to be transferred to the receivers.

b. The quantity of fuel to be transferred.

c. The Abort Point (AP) - this is a geographical position on a receiver's track associated with a specific refuelling bracket. Should a receiver reach an AP without the planned transfer for the appropriate bracket having commenced, diversion action must be taken. This will allow the receiver to arrive overhead the planned diversion with the minimum fuel reserve.

d. The nominated diversion airfields to be used if a planned fuel transfer fails for any reason or if diversion is necessary for other contingencies.

e. The fuel remaining in the tanker after each transfer, and overhead the planned destination airfield.

Human Factors and AAR

> AAR is a physical and mental challenge requiring high levels of concentration and dexterity. Fatigue can rapidly set in leading to stress to a lesser or greater degree. Good training and plenty of practice will remove 'gremlins' from the mind! Beware of visual distortion and closure speeds (the tanker will appear very small…..until the last moments when it 'blosoms' into the cockpit!!)

CHAPTER 24 - ASYMMETRIC FLIGHT AND ENGINE-OUT PERFORMANCE

Introduction

1. Asymmetric flight is generally accepted to mean the condition applying to multi-engined aircraft, following loss of power from an engine(s). Unusual configurations are not considered in the discussion on handling, although the degradation of performance obviously applies. The term 'multi-engined' in this chapter means more than one power plant mounted laterally either side of the centre line.

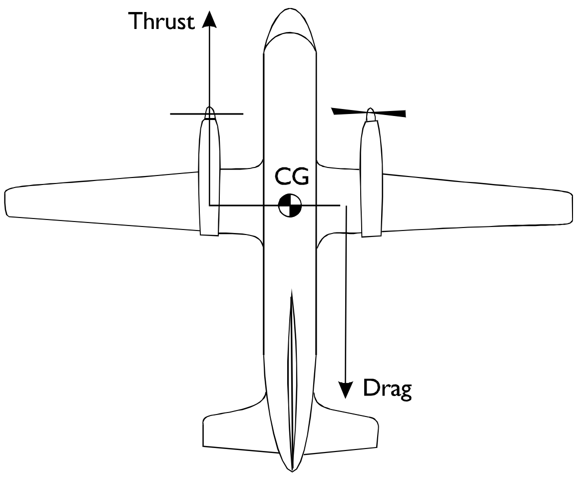
2. Aircrew Manuals give details of the technique and speeds required when using asymmetric power, the information in this chapter being of a general nature. The relevant documents and orders should be studied before practising the use of asymmetric power.

Basic Conditions

3. If a multi-engined aircraft suffers engine failure when airborne, there are two immediate effects:

a. The initial one is the yawing moment that occurs due to the asymmetry of the thrust line (Fig 1). The size of this initial yawing moment depends upon the engine thrust, the distance between the thrust line and CG, and the aircraft's directional stability, which tends to oppose the asymmetric yawing moment. The yawing moment is also affected by the rate of thrust decay of the 'dead' engine and possibly by its drag. On propeller-driven aircraft, the yaw is aggravated by the drag effect of the windmilling propeller. The total moment can be very large, particularly when at high power and low speed.

8-24 Fig 1 Asymmetry of Thrust Line



b. The initial yawing moment results in a subsequent rolling moment which can be very marked. On propeller-driven aircraft, the yaw-induced roll is increased by the reduction in slipstream velocity, and hence lift, over the wing behind the failed engine. Although this effect can be very pronounced, it should be within the capacity of the ailerons to counter it in all but abnormal cases outside design limits.

4. If corrective action is not taken, the aircraft yaws and rolls towards the failed engine resulting in a spiral towards the failed engine.

5. It is important to understand that although the yawing moment is the root cause of the problem, due to the pronounced rolling effects outlined above, it is imperative to control the roll with aileron as well as controlling the yaw with the application of rudder. On older, non-Performance Group certificated

types, a combination of rudder and power reduction on the live engine(s) may be required to maintain control, especially immediately after take-off.

Forces Acting on the Aircraft

6. An aircraft can maintain a constant heading under asymmetric power with an infinite number of bank and sideslip combinations.

7. The forces acting on the aircraft, in the plane of the wings are:

   a. The sideforce on the body and fin, due to sideslip

   b. The sideforce caused by rudder deflection, pivoting the aircraft about the CG.

   c. Any horizontal component of lift, produced by banking.

   d. Thrust from the live engine(s).

   e. Total drag.

8. In addition to these major factors, in the case of propeller-driven aircraft, there are the minor, but appreciable, effects of:

   a. **Torque**. Propeller torque, which increases with power, tends to roll the aircraft in the opposite direction to that of propeller rotation. Torque has a slight effect on control while using asymmetric power; if the torque reaction tends to lift the dead engine, then its effect is beneficial.

   b. **Failure of the Critical Engine**. Asymmetric Blade Effect, as discussed in Volume1 Chapter 23, effectively displaces the thrust lines towards the downgoing blade on each propeller. For example, if the propellers rotate clockwise when viewed from the rear the thrust line is displaced to the right. This displacement results in a greater yawing moment when the critical engine fails due to the longer thrust moment arm. The critical engine is the No1 engine in this example.

   c. **Slipstream Effect**. Each engine will have a different effect on the yawing characteristics of the aircraft due to its slipstream. The spiral path of the slipstream may impact the fin and rudder producing a side force.

   d. **Drag of Failed Propeller**. The amount of drag will depend on many factors including whether the failed propeller has been feathered. A windmilling propeller gives more drag than a feathered one and therefore increases the yawing moment towards the failed engine.

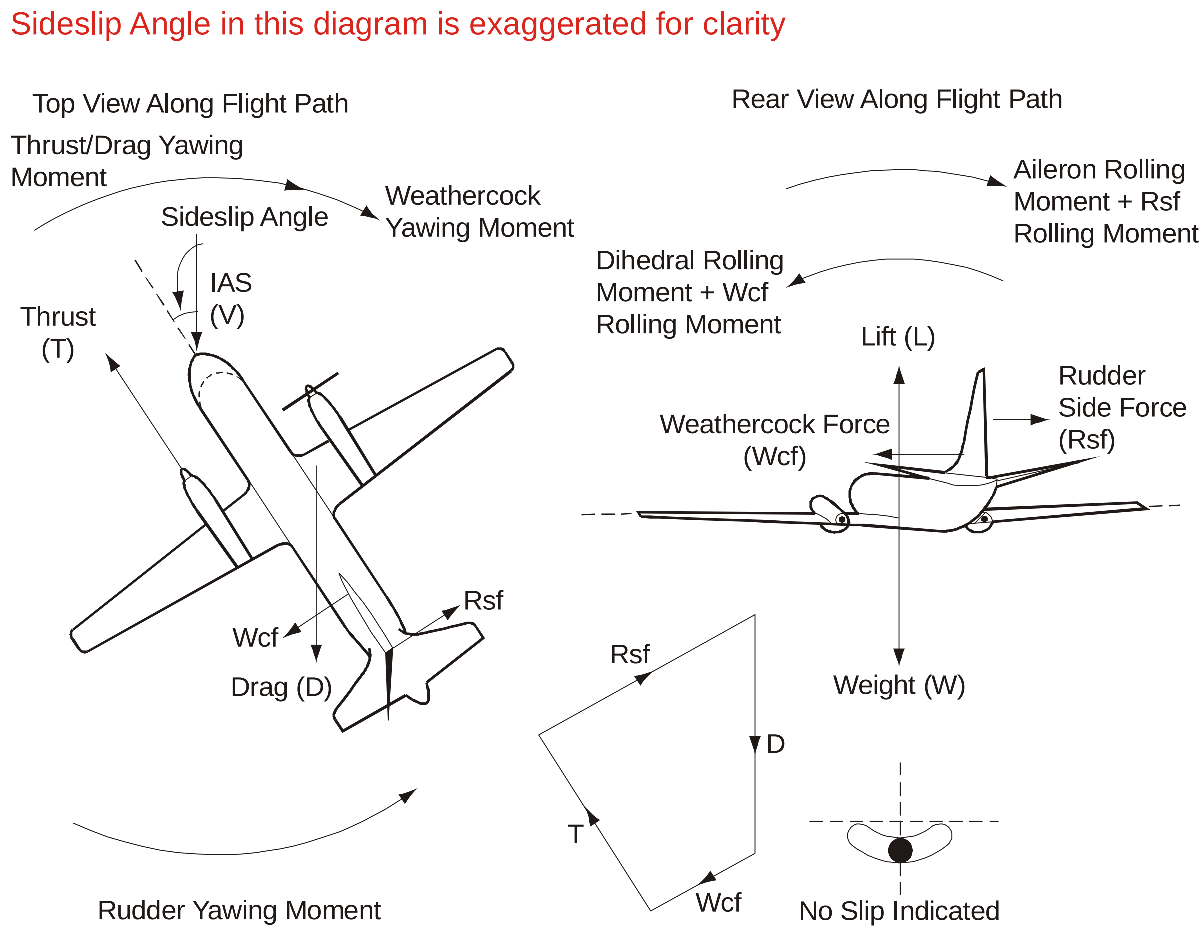
Balanced Flight

9. In straight and level, unaccelerated flight all forces acting on the aircraft, in all 3 axes, are balanced and the moments in equilibrium. The forces are shown to be balanced when their vectors form a closed polygon. An imbalance of forces will cause the aircraft to change its flightpath, ie climb, descend or turn. When the moments are balanced, the aircraft's attitude remains unchanged. When discussing the forces involved in asymmetric flight only the forces and moments acting in the normal (yawing) and longitudinal (rolling) planes are considered. This is because the initial reaction of an aircraft suffering the effects of asymmetric power is to yaw and then roll. All the inputs are to counter the initial yaw and the further or subsequent effects.

10. **Wings Level Steady Flight (Fig 2)**. The initial effects of yaw and roll are controlled by levelling the wings, stopping the yaw with rudder and centring the slip ball. The aircraft will sideslip towards the failed

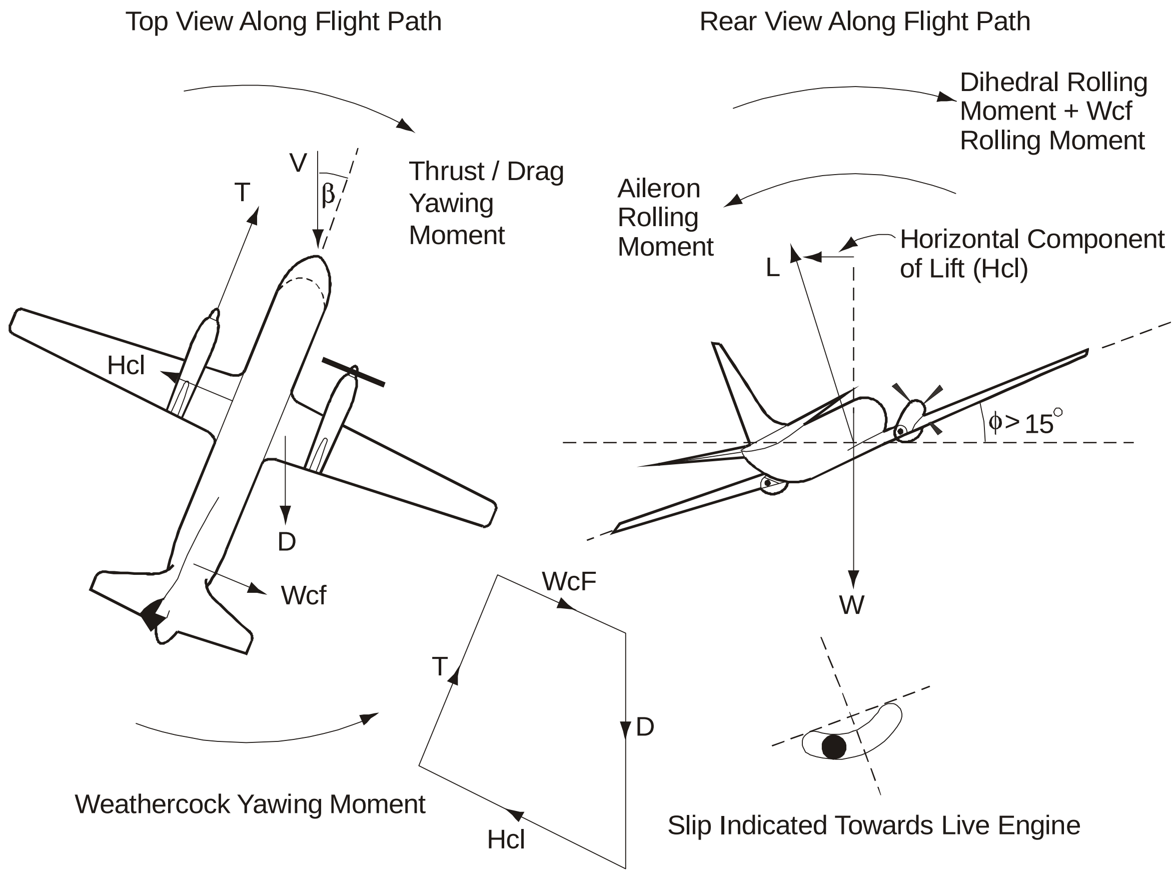
engine. Whilst this sideslip angle is small and its effects imperceptible to the pilot, it will generate a weathercock force requiring a greater rudder sideforce to balance. To maintain a constant heading the rudder moment is opposing the combined effect of the thrust, drag and weathercock moments. As the aircraft is sidesliping towards the failed engine, dihedral effect will roll the aircraft away from the failed engine. The weathercock force also provides a rolling moment away from the failed engine. The rudder side force acts above the centre of gravity and therefore provides an opposing rolling moment towards the failed engine. Fig 2 shows how the opposing forces interact. Passengers should not notice any discomfort and the freight will not be subjected to extra lateral strains. It is for this reason, together with the fact that wings level and slip central are easily definable states, that this is the preferred technique for controlling the aircraft in the event of an engine failure.

8-24 Fig 2 Wings Level Steady Flight



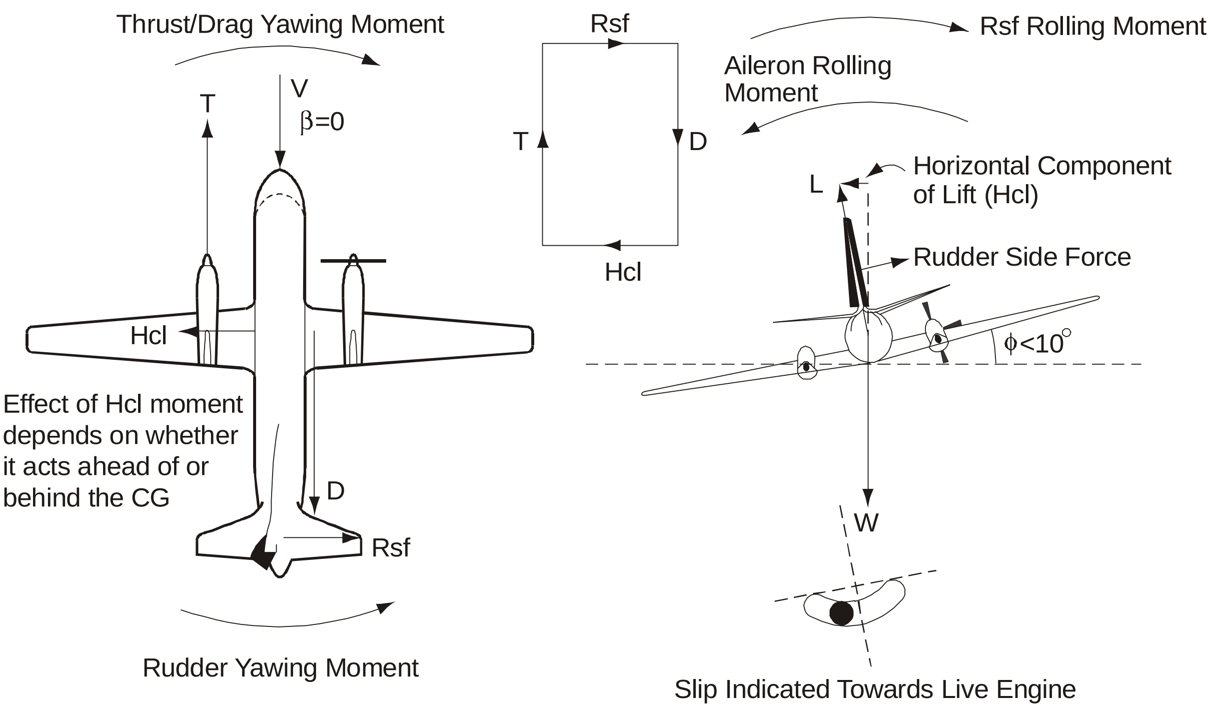
11. **Rudder fixed or Free (Fig 3)**. If the rudder is not available, more bank is needed to provide a larger horizontal component of lift to compensate for the loss of rudder side force. This additional bank will cause the aircraft to sideslip away from the failed engine creating a weathercock force towards the live engine. The weathercock moment and the horizontal component of lift combine to counter the thrust and drag moments. The dihedral effect and weathercock rolling moment both act towards the failed engine balanced by aileron deflection. Although this method is aerodynamically sound, it is uncomfortable for passengers and will provide the maximum strain on the freight. Furthermore, it is difficult to fly accurately, especially on instruments, as the wings are not level and the slip ball is displaced towards the live engine.

8-24 Fig 3 Rudder Fixed or Free



12. **Combination of Bank and Rudder (Fig 4)**. Between the two extremes of control methods detailed above –one using all rudder to control the yaw with wings level and one using all bank to control yaw with rudder fixed or free – there is an infinite number of combinations of rudder and aileron inputs. One such combination occurs when flying at or close to V_{mca} following the loss of an engine. It is unlikely that rudder alone will achieve directional control and therefore must be augmented by an amount of bank – usually up to 5 deg AoB towards the live engine. Use of this combination of bank and rudder will reduce the sideslip angle compared to the use of bank or rudder alone. Fig 4 shows a special case using a combination of bank and rudder where the sideslip angle is reduced to zero, thus eliminating the weathercock force and the dihedral effect. The pilot will have no way of knowing whether he has achieved this configuration, and in most cases using bank and rudder directional control will be maintained with a balance of all the available forces – thrust, drag, horizontal component of lift, rudder side force and weathercock force.

8-24 Fig 4 Combination of Bank and Rudder



IDENTIFICATION OF FAILED ENGINE

Jet

13. On jet aircraft, simple failures (e.g. flame-outs) are always shown by falling rpm and TGT. Internal mechanical engine failures are sometimes masked by apparently normal engine indications, and engine vibrations may be the only clue to a possible mechanical failure. In this case, it may be necessary to throttle back each engine in turn in an attempt to isolate the source of vibration. When the vibrating engine has been identified, it should normally be closed down and not left at idling rpm.

Turboprop

14. Loss of power will be shown on the torque meter, confirmed by falling turbine inlet temperature. The drag from a windmilling propeller can be very large and some installations feather, or partially feather the propeller automatically if the torque loss exceeds a certain figure.

SAFETY SPEED, V_{MCG} and V_{MCA}

Factors Affecting Controllability

15. The factors affecting controllability are:

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

b. **Critical Engine**. The critical engine is usually the engine which, when failed, gives the greatest asymmetric effect. However, on certain types it may be defined by the loss of critical aircraft systems, this will be documented in the Aircrew Manual/Handling Notes. On 4 engine aircraft an outboard engine will usually be the critical engine due to the increase in the yawing moment arm.

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

d. **Temperature**. Temperature affects density and therefore the thrust from all engines is affected although this is more marked on a jet engine.

e. **Weather Conditions**. On a day with rough and gusty conditions the margin of control is reduced. If a control surface is almost fully deflected to control the asymmetric effect, a limited amount of movement is available for further correction necessitated by air turbulence.

f. **Loading (CG Position)**. An aircraft with the CG at the aft limit is less directionally stable due to the reduction in the control moment arm (see Volume 1, Chapter 17, Para 12). Conversely with the CG at the forward limit the aircraft is more directionally stable. . Provided the CG is within the trim envelope no insurmountable handling difficulties should be encountered.

g. **Flap Setting**. The position of the flaps may have a marked effect on the airflow over the control surfaces dependant on aircraft type. If it is significant it is mentioned in the Aircrew Manual.

h. **Asymmetric Drag**. Asymmetric drag may be produced by a windmilling propeller or seized engine. This drag may be reduced by feathering the propeller of the failed engine.

i. **Strength and Skill of the Pilot**. On many aircraft, when high thrust is being used at low speed, the foot loads may be considerable…These forces should be controllable as V_{MCG} and V_{MCA} limit the maximum rudder pedal force to 150 lb and do not assume exceptional skill or strength.

Safety Speed (V_2)

16. Safety speed is the speed to which the aeroplane should be accelerated after take-off. It is a speed which provides a safe margin above the stalling speed for the purposes of manoeuvre before the flap retraction height is reached and which also provides a safe margin above V_{MCA}. It increases with all up weight. The ability to accelerate on asymmetric power depends on the amount of power that can be used while control is retained and the reduction that can be made in drag. Engine failure in the most adverse configuration and at the highest weight, makes it essential that the drag be reduced to a minimum so that the aircraft can accelerate to a safe speed on the power available. The undercarriage and flaps should therefore be raised and jettisonable stores released as soon as possible (as recommended in the Aircrew Manual/Handling Notes).

V_{MCG} (Minimum Control Speed - Ground)

17. V_{MCG} is the minimum speed, under take-off power conditions, at which in the event of a sudden and complete failure of the critical engine, it is possible to recover control with the use of rudder alone and without reducing power on the live engines. It will then be possible to maintain a path parallel to the runway centreline, not more than 30 ft displaced from the centre-line. The effect of nosewheel steering has been disregarded in the derivation of this speed, although the nosewheel is assumed to be in contact with the ground.

V_{MCA} (Minimum Control Speed - Air)

18. V_{MCA} is the minimum speed at which, in the event of sudden and complete failure of the most critical engine in the take-off configuration, it is possible to maintain directional control using full rudder deflection and a maximum of 5º of bank to the live engine.

ENGINE FAILURE DURING TAKE-OFF (COMBAT AIRCRAFT)

Considerations

19. On transport aircraft, full control can be maintained after engine failure at any stage and the take-off continued if the failure occurs after V_1 (see Volume 2, Chapter 9). The considerations of this part of the chapter concerns aircraft on which control can be lost, or which have marginal climb performance, after an engine failure. This latter category includes most modern fast twin-jets. Engine failure during take-off, on such an aircraft, can be considered under four main headings:

a. Engine failure below go speed (V_{go}). (V_{go} is defined at para 20).

b. Engine failure below stop speed (V_{stop}). (V_{stop} is defined at para 21).

c. Engine failure above stop speed but below safety speed:

(1) On the ground.

(2) In the air.

d. Engine failure above safety speed.

Go Speed (V_{go})

20. Go speed is the lowest IAS during take-off from which, after recognition of the failure of the critical engine, take-off can be safely continued and the appropriate speeds and heights can be achieved. Reference must be made to the aircraft ODM to determine whether a V_{go} capability exists.

Stop Speed (V_{stop})

21. Stop speed is the highest IAS during take-off from which, after the failure of the critical engine, an aircraft can be safely stopped within the ASDA using all normal methods of retardation.

V_{stop}/RHAG

22. V_{stop}/RHAG is the highest IAS during take-off from which, after the failure of the critical engine, an aircraft can be safely decelerated to maximum cable entry speed if the aircraft is fitted with a hook and the runway with a compatible cable arresting gear.

23. **Engine Failure Below V_{go}.** Normally V_{stop} is greater than V_{go}; therefore, only V_{stop} needs to be considered for take-off planning. However, if V_{go} exceeds V_{stop} a speed band exists in which an engine failure will result in the aircraft engaging an arrester cable or barrier, or entering the overshoot area. Some aircraft which do not have a V_{go} capability use V_{stop} in isolation.

24. **Engine Failure Below V_{stop}.** If engine failure occurs below V_{stop}, the take-off should be abandoned. If for some reason it becomes apparent that the aircraft cannot be stopped or obstacles avoided, the undercarriage may have to be raised on runways without barriers or cables. The decision to deliberately swing the aircraft with the wheels down is seldom justified in view of the more extensive damage incurred when the undercarriage structure collapses under a side load.

Engine Failure Above V_{stop} but Below Safety Speed or V_{go}

25. **On the Ground**. If engine failure occurs below V_{go}, the take-off should be abandoned and the arrester cable or barrier engaged. On some types it may be prudent to raise the wheels. On other types, such as those not cleared for barrier engagement, it may be necessary to eject.

26. **In the Air**. On some heavily-laden aircraft an engine failure below safety speed may mean a forced landing straight ahead, or ejection. The live engine(s) should be used, within the limits of directional control, to select the best landing area. However, if the critical speed has been attained, and if the overall conditions allow power to be reduced on the live engine(s), then the immediate corrective use of rudder, assisted if necessary by a slight amount of bank towards the live engine, may enable the aircraft to maintain heading. The undercarriage should be raised and all jettisonable external stores should be dropped, and, on propeller-driven aircraft, feathering action should be taken. The pilot should never apply more power than he can hold with rudder, and if a yaw commences with full control applied, the pilot must throttle back until the yaw ceases.

Engine Failure Above Safety Speed

27. An engine failure above safety speed should raise few problems on a modern aircraft since directional control and climb performance are guaranteed.

ASYMMETRIC POWER PROBLEMS AT HIGH SPEED

Directional Control

28. For high-performance, multi-engined aircraft, the failure of an engine or engines at high speeds may have more serious consequences than engine failure at low air speeds. Asymmetric engine failure at high air speeds may generate sideslip excursions large enough to exceed sideslip limitations and cause structural damage or catastrophic component failures. The asymmetric power problems may be compounded by reduced directional stability at high supersonic Mach numbers and high altitude. These problems may result in a maximum air speed or Mach number (as functions of engine thrust settings) being imposed on the aircraft.

CHAPTER 25- INSTRUMENT FLYING

Introduction

1. With the advent of automatic landing systems and the wide everyday use of pilot-interpreted aids, the present-day RAF possesses a complete all-weather capability. Moreover, increasing congestion in and around regulated and controlled airspace means that a pilot must spend a good deal of time referring to instruments, flying controlled procedures and communicating with ground stations. Furthermore, when flying at night, external visual references may be limited. Therefore, it is essential that every military pilot should possess a sound basic skill in instrument flying.

2. During visual flight, emphasis is placed on attitude flying; however, no matter how well an attitude is maintained visually, at least one instrument must be checked to confirm that the attitude is known to be correct. If a correction is necessary, the attitude change is made with reference to the visual horizon. However, during instrument flying, the real horizon is no longer visible, so an artificial horizon is used instead. Thus, there is no basic change in technique: the artificial horizon is used instead of the real horizon and becomes the master instrument.

3. This master instrument can be an artificial horizon (AH) or an attitude indicator (AI). For ease of presentation throughout this chapter, the master instrument will be referred to as the AI.

4. **The Control Instruments**. The combination of attitude and power is fundamental to aircraft performance and determines IAS and the flight path. For example, if an attitude is selected to give an IAS, as in a climb, the power determines the flight path. Similarly, if power is used to adjust the IAS, as in straight and level flight, then the selected attitude determines the flight path. Thus, because aircraft performance is controlled by attitude and power, the AI and the instruments indicating power are called the control instruments.

5. **The Performance Instruments**. The remainder of the flying instruments show what effect the power/attitude combination is having on the aircraft performance. They are known, therefore, as the performance instruments.

6. **Analogue/Digital Instrument Displays**. The text for this chapter refers solely to the techniques used for instrument flying using a standard instrument panel with analogue instrumentation. It is possible however, in modern aircraft, to convey instrument information digitally to the pilot by means of a TV screen and/or by a head-up display unit. A brief explanation of these alternative methods of display is given at paragraphs 50 and 51.

Power Control

7. Most instrument flying procedures are flown using the recommended power settings given in Aircrew Manuals. When flying manoeuvres such as steep turns, which are not part of normal instrument flying procedures, the same power settings as used in visual flight should be used. To make power selections promptly and accurately, without unduly disrupting the concentration on instruments, the following procedure should be followed:

a. First, make an estimated throttle movement.

b. At the next suitable opportunity, check the result on the power gauges.

c. After this initial change, re-adjust the throttle in small stages, monitoring each against the power gauges, until the desired power setting is achieved.

8. A useful method of measuring small power changes is to use some characteristic of the throttle lever or quadrant design against which these small adjustments of the lever can be felt.

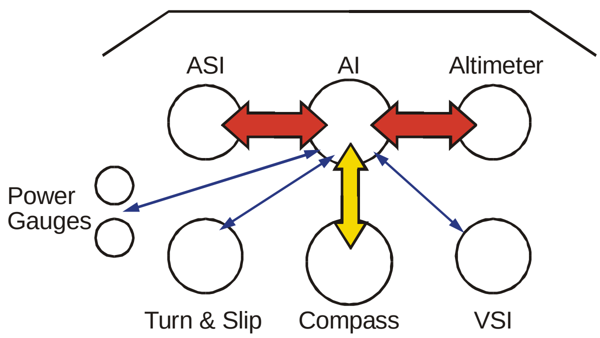
Attitude Control

9. To fly accurately, a pilot must be able to select and trim the correct attitude for a given stage of flight. The AI will give an indication of the magnitude of any attitude change made, but the pilot should confirm the result of any attitude change by monitoring the performance instruments. If they show that the desired flight path is not being achieved, the power/attitude combination should be adjusted again, and the aircraft re-trimmed. Thus, attitude control changes are achieved by reference to the AI and power gauges, with the results of any change appearing on the performance instruments.

Selective Radial Scan

10. In order to take in all the information shown by the instruments, the pilot has to scan them in a methodical manner. An obvious method would be to look at each instrument in turn in a clockwise or anti-clockwise direction. Although no instruments would be omitted from this scan, priority would not be given to the master instrument or to the performance instruments important for any particular manoeuvre, e.g. the compass or directional gyro on rolling out from a turn. The technique therefore is to scan radially out from the AI to the performance instruments and back to the AI. Furthermore, since the performance information required differs for each manoeuvre, the scan is made selective. Thus, each performance instrument will be interrogated according to its importance at any given moment. This method, illustrated in Fig 1, is called the selective radial scan. Note that two performance instruments are never scanned in succession; the route from one to another invariably goes through the master instrument.

8-25 Fig 1 Selective Radial Scan



Note: In all the figures in this chapter:

a. A thick red arrow denotes a constant scan.

b. A medium yellow arrow denotes a less frequent scan ratio of 1: 3.

c. A thin blue arrow denotes 'as required'.

Rates of Scan and Attitude Control

11. The rate at which the instruments should be scanned will vary with manoeuvre and aircraft type. During manoeuvre, the required scan rate is lowest when maintaining a trimmed attitude and highest during power and attitude changes. The rate of scan should also be increased with increased aircraft performance. Consequently, since required attitude changes are perceived only as the scan routes through the AI, the reaction time varies directly with scan rate. However, when the AI is interrogated more frequently, there is a risk of over controlling and perhaps 'chasing' the correct attitude. To reduce this risk during periods of high activity, AI adjustments should be limited to 1º-2º. Periods of low activity should be used to carry out routine airmanship checks, e.g. engine and oxygen checks; these should be broken down into small sections, giving an opportunity to monitor the AI between each section.

Instrument Interpretation

12. The control instruments require no interpretation, since their indications are direct and respond immediately to control changes. On the other hand, the performance instruments give both direct and indirect indications and most are subject to lag of one form or another.

13. An example of a direct indication is airspeed. However, for a given power setting and aircraft configuration, if the airspeed is steady it also means that the pitch angle is constant, thus giving an indirect indication of pitch. Table 1 lists the instruments included in the standard instrument panel and shows the direct and indirect indications available from them.

Table 1 Direct and Indirect Indications from 'Standard' Instruments

Instrument	Direct	Indirect
CSI/ASI	Airspeed	Pitch
Altimeter	Altitude	Pitch
Compass	Heading	Bank or imbalance
VSI	Rate of climb/descent	Pitch
Turn needle	Rate of turn	Bank or imbalance
Ball	Balance	Bank or Yaw

Trimming

14. Instrument flying is made easier by accurate trimming. No change from visual trimming techniques is necessary; control pressures are removed in the same way. However, to ensure a smooth flight (a necessary ingredient of instrument flying) hurried changes and any temptation to fly on the trim should be avoided. The aircraft is properly trimmed if it maintains the selected attitude when the pressure on the controls is relaxed.

Balance

15. The only direct indication that the aircraft is in balance is shown by the ball, usually situated in the turn and slip indicator. The indirect indications of imbalance can be:

a. A slight reduction in airspeed.

b. The presence of an angle of bank.

c. A slow change of heading when the wings are level.

An imbalance situation in single jet operations is unlikely and, if present, is usually caused by cross-controlling. However, imbalance is more likely to occur during propeller-driven and multi-engine operation particularly if the pilot becomes tense or fixated on one instrument, thus stopping the selective radial scan.

16. During propeller-driven and multi-engine operation, if the wings are known to be level, rudder should be used to maintain a constant heading on the compass with the balance ball confirmed central. This is of particular importance during power changes, which would otherwise cause yaw.

BASIC INSTRUMENT FLYING

General

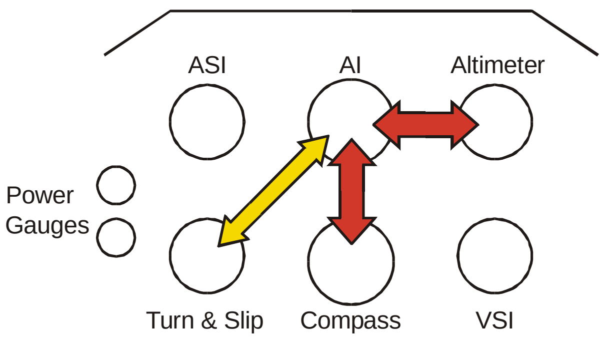
17. The following explanations assume an understanding of the visual flying techniques and procedures relevant to a particular aircraft.

Straight and Level Flight

18. Straight and level flight during instrument flying is best thought of in terms of three separate actions: achieving, maintaining and correcting.

19. **To Achieve Straight and Level Flight**. To achieve straight and level flight, cruising power should be set, the straight and level attitude should be selected on the AI and a coarse trim change made. If the attitude selected is correct, the altimeter and compass will become stationary. Any movement in the altimeter should be stopped by altering the AI pitch indication in a series of small stages. Each stage should be equivalent to a half or whole horizon bar width (the amount varying with aircraft type), with each attitude change being trimmed. If the compass is moving, first confirm that the aircraft is in balance and then apply a small bank correction to the AI to stop the turn, even though the AI may be indicating wings level. A correction of this sort is only necessary when the AI is erected to a false vertical; normally it is not necessary. Thus, straight and level flight is achieved using the AI, altimeter, compass and, on those aircraft prone to imbalance, an occasional glance at the ball (see Fig 2). For the sake of simplicity, airspeed is dealt with later.

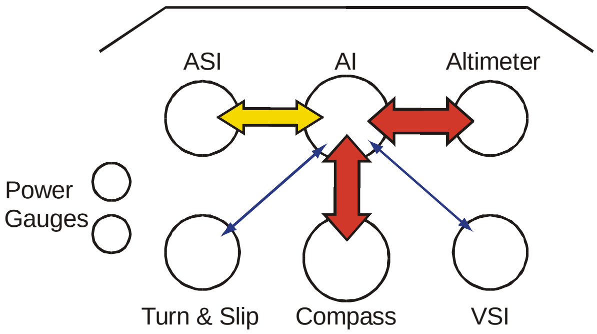
8-25 Fig 2 Achieving Straight and Level Flight



20. **To Maintain Straight and Level Flight**. The scan used to maintain straight and level flight is shown at Fig 3. With the correct attitude selected on the AI and the aircraft trimmed, the compass and altimeter are scanned to maintain the datum height and heading. The correct speed is confirmed from the ASI and the balance ball in the turn and slip indicator is centralized. Occasional checks of the VSI will indicate any small trend of climb or descent. Errors in height will be indicated on the altimeter and

are corrected with reference to the AI by changing the aircraft attitude and re-trimming. When flying in turbulence, the needles on pressure instruments may show fluctuations from the datums being flown. To maintain straight and level flight in turbulence, more emphasis needs to be given to scanning the attitude on the AI (which will confirm that the wings are held level) and ensuring that the balance ball is centralized. The temptation to 'chase' temporary excursions from the datums should be resisted. In conditions of severe turbulence, as well as flying at the recommended turbulence speed, the pilot must continue to monitor the airspeed carefully. In severe updrafts and downdrafts, the speed of the aircraft may increase or decrease markedly, even with the straight and level attitude held steady by reference to the AI. In this case, the airspeed should be held as close as possible to the turbulence speed by throttle movement alone, without changing attitude.

8-25 Fig 3 Maintaining Straight and Level Flight



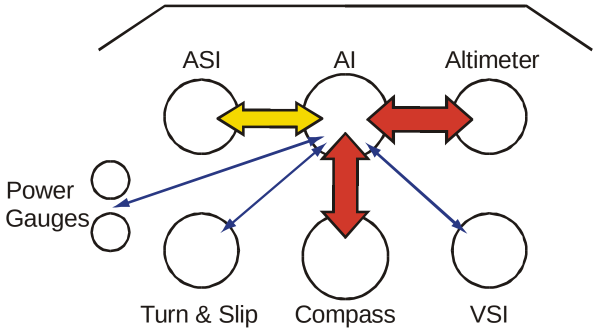
21. **Correcting Back to Straight and Level Flight**. The following sub-paragraphs explain the techniques, should it be necessary to make substantial corrections to recover back to straight and level flight:

a. **To Correct an Altitude Error**. Should it be necessary to correct to an altitude, the amount of attitude correction to be applied will depend upon the aircraft type and the magnitude of the error. On low performance aircraft, a 50 ft error will require an adjustment of 1º to 2º of pitch. For larger height errors, as well as an attitude adjustment of 3º to 4º of pitch, it may be necessary to make a small adjustment to the power. On high-performance aircraft, small corrections, of about 300 ft, can be made by pitch adjustment alone, without a change in power or an appreciable change of trim. Since the rate of closure is determined by the AI adjustment, once a correction is started the VSI should be ignored and reliance placed on the altimeter (using the scan shown in Fig 2). Fractionally before the desired altitude is reached, the straight and level attitude should be adopted with reference to the AI. If necessary, cruising power may once again be set and the 'maintaining straight and level' scan (Fig 3) resumed.

b. **To Correct a Heading**. To correct a heading, bank should be applied on the AI in the appropriate direction, the amount varying according to TAS. At low speeds, an angle of bank equating to half the error may be used, ie for 10º heading error use 5º of bank. At high speeds, an angle of bank equating to the error may be used. If the aircraft has been correctly trimmed in straight and level flight before entering a turn, very little back-pressure will be required on the control column to maintain level flight in the turn. As the heading is regained, the wings should be levelled on the AI and the 'maintaining' scan (Fig 3) continued. On aircraft liable to imbalance, once the wings are levelled on the AI, the ball should be centralized.

c. **Increasing Speed**. To increase speed, the power should be increased as for visual flight and initially the attitude on the AI maintained. On aircraft with a slipstream effect, the heading should be maintained by balancing the aircraft with rudder. As the speed increases, the first indications of a departure from straight and level flight will be a climb indicated on the altimeter, confirmed by the VSI. This climb should be anticipated and, as the speed increases, countered by small progressive nose-down pitch adjustments with reference to the AI, to stop the altimeter moving, and to maintain straight and level flight. In addition, the scan should be extended to include the ASI. During a speed change, the VSI will normally indicate a trend before the altimeter indicates an error. Initially, therefore, the straight and level 'maintaining' scan is used, but as power and speed are increased, the scan should be extended to include the ASI and the power gauges (see Fig 4).

8-25 Fig 4 IAS Control in Straight and Level Flight



d. **Reducing Speed***.* To reduce speed, the IAS attitude should be maintained, and the power reduced to the required setting. If the speed reduction warrants it, the airbrakes should be extended. The 'maintaining' scan should be continued, with the ASI being progressively included. On aircraft with a slipstream effect, the maintaining scan should be continued, with use of the rudder to balance as necessary. As the speed decreases, the first indications of a departure from straight and level flight will be a descent indicated on the altimeter, confirmed by the VSI. This should be anticipated and, as the speed decreases, countered by small progressive nose-up pitch adjustments with reference to the AI to stop the altimeter moving and to maintain straight and level flight. As the new speed is reached, the airbrakes should be retracted and, if necessary, small power adjustments made to achieve an accurate speed.

Level Turning

22. Normally, instrument turns are flown at Rate 1 (i.e. 3º per second) or at 30º of bank, whichever is the lesser, but operational requirements may demand a higher rate. As a means of increasing instrument flying proficiency, steep turns at 45º to 60º of bank are practised. For a small heading change, (i.e. through an angle smaller than the angle of bank used for a Rate 1 turn) the bank should be restricted as follows:

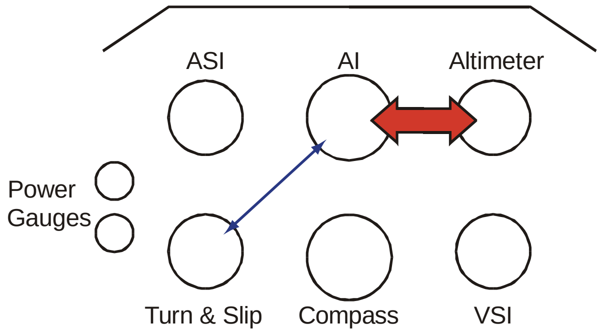
a. At speeds of 100 kt or less, use a bank angle equal to half the numbers of degrees of turn required.

b. At speeds in excess of 100 kt, use a bank angle equal to the number of degrees of turn required.

Medium Turns

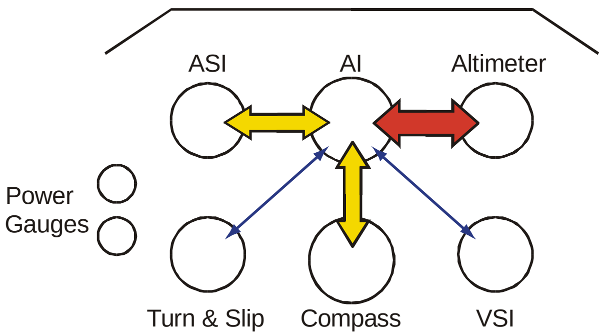
23. **Entry***.* To enter a turn, bank is applied by reference to the AI and the pitch indication is supported by cross-checking the altimeter to maintain level flight (see Fig 5).

8-25 Fig 5 Entering a Medium Turn



24. **Maintaining**. The AI is used to maintain both pitch and bank during turns. Bank is kept constant using the bank scale, and pitch using the pitch scale. When using a mark of instrument not graduated in pitch, only experience can be used to assess the correct indication. The VSI and altimeter should be used to support the AI, in the same manner in which they are used during straight and level flight. The technique for maintaining height is the same, by applying small adjustments with reference to the AI. As the turn proceeds, the compass is progressively included into the scan to monitor the roll-out heading (see Fig 6).

8-25 Fig 6 Maintaining a Medium Turn

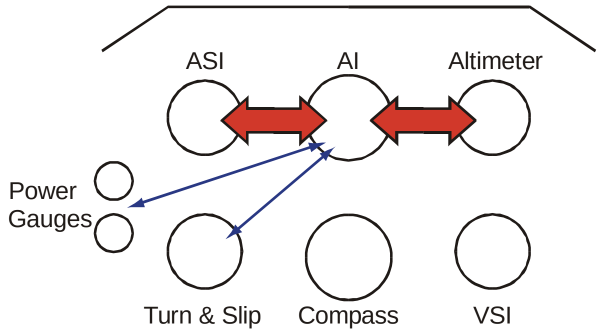


25. **Roll-Out**. To roll out from a medium turn, the heading should be anticipated by the angle used in visual flight. The straight and level attitude should be selected by reference to the AI. However, if the speed has been allowed to reduce during the turn, a slightly higher pitch attitude will be necessary to maintain level flight. As cruising speed is regained, the pitch attitude will have to be progressively lowered using the techniques detailed in para 23.

Steep Turns

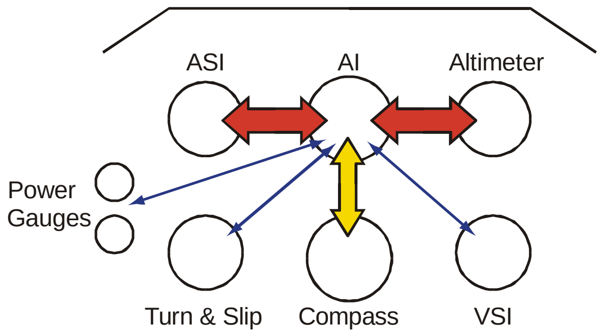
26. **Entry**. To enter a steep turn, bank should be applied by reference to the AI, with back-pressure introduced to adopt a steep-turn attitude. Power should be increased to maintain the entry airspeed. The application of bank, back-pressure and power should be completed simultaneously. The associated scan is shown in Fig 7.

8-25 Fig 7 Entering a Steep Turn



27. **Maintaining**. Whilst maintaining a steep turn, the scan is basically the same as that used during a medium turn except that the ASI is scanned more frequently. This is necessary to confirm that the increase in power selected is holding the required airspeed. Experience and judgement should determine throttle movements. The higher rate of turn makes it necessary to scan the compass more frequently (see Fig 8).

8-25 Fig 8 Maintaining a Steep Turn

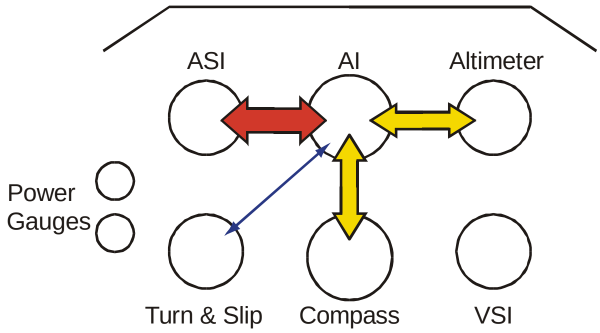


28. **Roll-Out**. To roll out from a steep turn, the heading should be anticipated by the angle used in visual flight. The straight and level attitude should be selected by reference to the AI and, as bank is reduced through 30º, the power should be reset to the entry airspeed setting.

Climbing

29. **Entry to the Climb**. The entry to a climb will vary with aircraft type. If the climbing speed is the same as, or less than, the normal cruising speed, then the power and attitude can be changed simultaneously. If the climbing speed is greater than the straight and level speed, climbing power should be applied and the speed should be increased whilst straight and level, before changing to the climbing attitude. If the aircraft is in balance, heading will be maintained by keeping the wings level. However, on propeller-driven aircraft, in addition to keeping the wings level, rudder will have to be used to maintain balance during the power and attitude changes, prior to re-trimming. The initially-selected attitude should be held constant, by reference to the AI, until the airspeed settles. Attitude adjustments are then made at a constant airspeed. The scan to be used for climbing is shown in Fig 9.

8-25 Fig 9 Climbing



30. **Maintaining the Climb**. The scan used to maintain a climb is the same as that used for entering it (Fig 9). Pitch adjustments to correct the airspeed should not be hurried; at full power the airspeed is relatively slow to react to attitude changes and there may be a temptation to hurry the process by making a larger attitude change than required. To avoid this, only small pitch adjustments should be made, allowing time for any change to take effect before any further adjustment.

31. **Climbing Turns**. No change of scan is necessary when turning during a climb. Bank should be applied by reference to the AI, and the nose lowered fractionally to maintain the airspeed. The roll-out technique is the same as for a level roll-out, except that the ASI is the main support instrument for pitch.

32. **Levelling Off**. To level off at a required height, it is essential to use some anticipation. The attitude change should be initiated at a point prior to the required height, equivalent in vertical distance to 10% of the rate of climb (e.g. for a 2,000 feet per minute rate of climb, use a point 200 feet below the required level). At that point, the pitch should be reduced so that straight and level flight and the required height are achieved simultaneously. The power is then adjusted to reach cruising speed. As the attitude change is commenced, the scan should be changed from 'climbing' to 'achieving straight and level' (see Figs 9 and 2). However, the scan pattern should be extended to include the power gauges and ASI as power is reduced. On propeller-driven aircraft, balance should be maintained during the power change by using rudder. As the altimeter reading becomes steady, the aircraft is flown as for straight and level flight, at a predetermined airspeed.

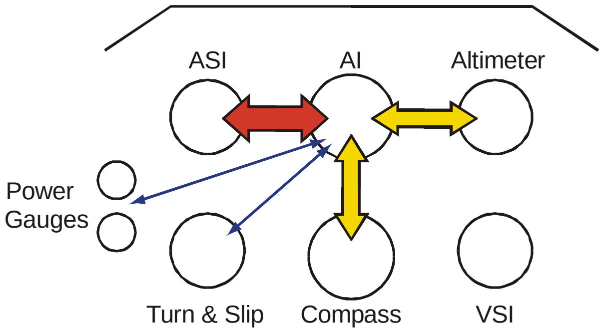
Descending

33. An instrument descent requires no change from the techniques and procedures observed visually. Thus, power and airbrakes (if fitted) should be used in accordance with the appropriate Aircrew Manual. The pilot should be thoroughly conversant with the recommended power settings used for each stage and type of descent. During descents that can be affected by aircraft weight and the wind strength, e.g. when using a runway approach aid, the recommended power settings may require adjustment if an accurate descent path is to be maintained. Usually these adjustments are small and may be made by 'feel', as indicated in paragraphs 7 and 8.

34. **Entry**. The descent should be entered from a level speed that will enable the descending speed to be attained during, or soon after, the power/attitude change. Thus, if the descending speed is less than the level speed, the speed should be reduced before lowering the nose. When entering the descent, the scan should be extended to include the power gauges as and when necessary. On propeller-driven aircraft, it will be necessary to maintain balance with rudder. Once the descending attitude is selected, the AI should be supported by the ASI and compass.

35. **Maintaining**. Airspeed corrections during a descent should be made by small pitch adjustments with reference to the AI, and heading should be maintained by bank adjustments. When it is necessary to maintain a specific power setting, the power gauges should be monitored, and, on propeller-driven aircraft, it is essential to include the ball within the scan. The altimeter should be monitored throughout the descent. The scan used is detailed at Fig 10.

8-25 Fig 10 Maintaining the Descent



36. **Levelling Off**. The level-off should be anticipated by the method described in para 32, this time using 10% of the rate of descent. At that point, the straight and level attitude should be selected by reference to the AI. Power should be reset as appropriate for the aircraft type. Once the attitude change is commenced, the 'achieving straight and level' scan should be used (see Fig 2).

Descending Turns

37. Descending turns are normally made using Rate 1 or a maximum of 30º angle of bank (whichever is the lesser). No change from the 'maintaining the descent' scan (see Fig 10) is required, although during the early stage of the turn, the frequency at which the compass is included can be safely reduced. As the turn proceeds, the compass should be progressively re-included into the scan to monitor the roll-out heading. The roll-out is the same as for a level turn, except that the ASI is the main pitch support instrument.

EXTREME ATTITUDES AND UNUSUAL POSITIONS

Introduction

38. **Extreme Attitudes**. If an aircraft inadvertently enters cloud from a dynamic manoeuvre (such as aerobatics, spinning or tail chasing), it may result in an extreme attitude that can be very difficult to recover from safely on instruments.

39. **Unusual Positions**. The term 'unusual position' (UP) is used to describe any situation when the aircraft is not in the attitude the pilot thinks it is. A UP may be a temporary loss of orientation caused by distraction during normal instrument flying. For a pilot to be in a UP does not necessarily mean that the aircraft is in an extreme attitude.

40. **Attitude Indicators**. Modern electrically-driven AIs are extremely reliable. Power failure is normally clearly indicated by a warning flag, and most AIs can only be toppled with difficulty during extreme manoeuvres. Air-driven AIs, however, are not as stable and are easier to topple. They are also more prone to erection errors. It is essential therefore, with an air-driven AI, to monitor the vacuum gauge whilst flying on instruments. However, a toppled AI may give a steady presentation, and it will only be possible to detect this false indication by cross-reference to the performance instruments.

Recovery Techniques

41. The technique used to recover from an extreme attitude or an unusual position depends upon the reliability of the AI:

a. **Full Panel Recovery**. The technique used when the AI is confirmed as reliable is called a 'Full Panel Recovery' and is detailed in para 43.

b. **Limited Panel Recovery**. If the AI has failed, or is suspected to be unreliable, the 'Limited Panel Recovery' technique must be used (see para 44). The latter case would include any situation where the serviceability of the AI has not been checked for a longer period than normal.

42. Regardless of the type of instrumentation available, the recovery from a UP is made in three distinct stages in the order: power, bank, and pitch.

a. **Use of Power**. The use of power during a recovery from an UP will be determined by the trend indicated on the ASI. If the airspeed is decreasing critically, full power should be applied. Conversely, if the speed is rapidly increasing, the throttle should be fully closed to avoid any unnecessary height loss, and airbrakes, if available, may be extended.

b. **Change of Bank**. A banked attitude will delay, or in the case of an extreme attitude, prevent a safe selection of a level pitch attitude, therefore, the second recovery action must be to level the wings.

c. **Change of Pitch**. Once the speed is under control and the wings are level, the final action is to pitch to level flight. Care must be taken not to exceed the airframe 'g' limitations during this phase of the recovery.

43. **Full Panel Recovery**. A full panel recovery, based on the use of an AI follows the three-stage recovery technique outlined in the previous paragraph:

a. **Power**. First, the airspeed must be checked to ensure it is within acceptable limits. If it is not, action should be taken to bring it under control.

b. **Bank**. The AI should then be checked for power failure. With the horizon bar or pitch markings in view, the aircraft should be rolled until the wings are level. However, even in an extreme attitude with a serviceable AI, the horizon bar should still be readable, but may be partially obscured by the instrument facing.

c. **Pitch**. Finally, to obtain level flight, the aircraft is pitched so that the aircraft datum moves towards the horizon bar in the correct sense.

Scanning of the performance instruments should then be made to confirm the action taken, and to regain balanced straight and level flight. If, having initiated a full panel recovery, the performance instruments do not agree with the AI indications, or disorientation still remains, the limited panel recovery must be implemented without delay.

44. **Limited Panel Recovery**. Following the same three-stage principle, the actions required in a Limited Panel Recovery are:

a. **Power**. The first action in a limited panel recovery is to control the speed in exactly the same way as for a full panel recovery. However, if the aircraft is in an extreme nose-up attitude which results in a very low or rapidly decreasing airspeed, any attempts to manoeuvre the aircraft with large control deflections could worsen the situation. Whenever there is insufficient speed to make a safe controlled recovery, the controls should be held as directed in the Aircrew Manual until the aircraft has settled into a descent of its own accord. The aircraft should then be allowed to accelerate to a safe flying speed before attempting to initiate a recovery.

b. **Bank**. In a limited panel recovery with an unserviceable or unreliable AI, the turn needle has to be used as the master indication of bank to level the wings. Any positive g force above 1g will cause the turn needle to over-read. Therefore, positive g must be reduced to 1g by pitching the aircraft and checking the accelerometer. On propeller-driven aircraft, it will be necessary to reduce any extreme imbalance by centralizing the ball. However, time should not be wasted obtaining accurate balance; once any positive g force has been reduced to 1g, and the aircraft is roughly in balance, a positive aileron movement should be made to centre the turn needle. This corrective roll should be checked before the turn needle is actually centred, the amount of anticipation required varying with airspeed and rate of roll.

c. **Pitch**. The last stage of the recovery should be made using the information displayed on the altimeter - the only instrument that indicates level flight accurately, and almost instantaneously, throughout the entire speed range. Positive elevator should be applied against altimeter movement, ensuring that the ailerons are kept neutral. The control deflection should be maintained until the altimeter slows almost to a standstill, then a check movement made to hold a constant pitch attitude. The aircraft will then be in an approximate straight and level attitude; the power can be adjusted, and the instruments cross-referred to achieve accurate flight and to assess their serviceability. It may also be possible to re-erect the AI at this stage.

EMERGENCIES

General

45. Most modern aircraft have duplicate, or even triplicate, displays for vital instruments, each with associated power supplies. Therefore, a single instrument failure causes few problems. In the majority of cases, an emergency will develop in stages, beginning with an apparently insignificant malfunction that only becomes critical in unforeseen circumstances, or in the event of an additional emergency. Thus, the potential loss of both primary and standby flight instruments must be considered.

46. If, during manoeuvre, apparently ambiguous instrument indications are observed, or the instruments do not respond correctly, the aircraft should be recovered immediately to straight and level flight and the cause investigated. Manoeuvres should not be continued whilst attempting to analyse the problem, since delay could bring about other complicating factors such as pilot disorientation. The procedure for recovery will vary with aircraft type and the attitude obtained. If a master AI is available for use and is not itself suspect, it should be used to select the straight and level attitude. If the master AI is considered unreliable, the standby AI can be used instead or, if no standby attitude instruments are carried, then a limited panel recovery will be necessary.

Loss of Airspeed Indication

47. If all the airspeed indications are lost, the aircraft can still be effectively operated using the basic power/attitude concept provided that an accurate airspeed is not essential. By using the known standard operating power settings and attitudes, it is possible to perform straight and level flight, or manoeuvres such as turning and climbing, without difficulty. Similarly, the initial stages of descent can be performed safely. However, as the aircraft approaches lower heights, and the speed is reduced, it becomes more critical to maintain a safety margin above the stall. Consequently, the safest method of recovering to an airfield is to formate upon, or be shepherded by, another aircraft. When a formation

let-down is not practicable, the continued use of the known power/attitude concept down to Decision Height remains the only option.

Loss of Heading Information

48. In the event of losing all visual and instrument heading information, ground-based direction finding (D/F) and radar facilities provide the only means of obtaining assistance. In these circumstances, the ground controller will request that all turns are flown at Rate 1. On aircraft not fitted with a turn needle, it is desirable that turns are executed at the calculated angle of bank for Rate 1.

Loss of Direct Attitude Indication

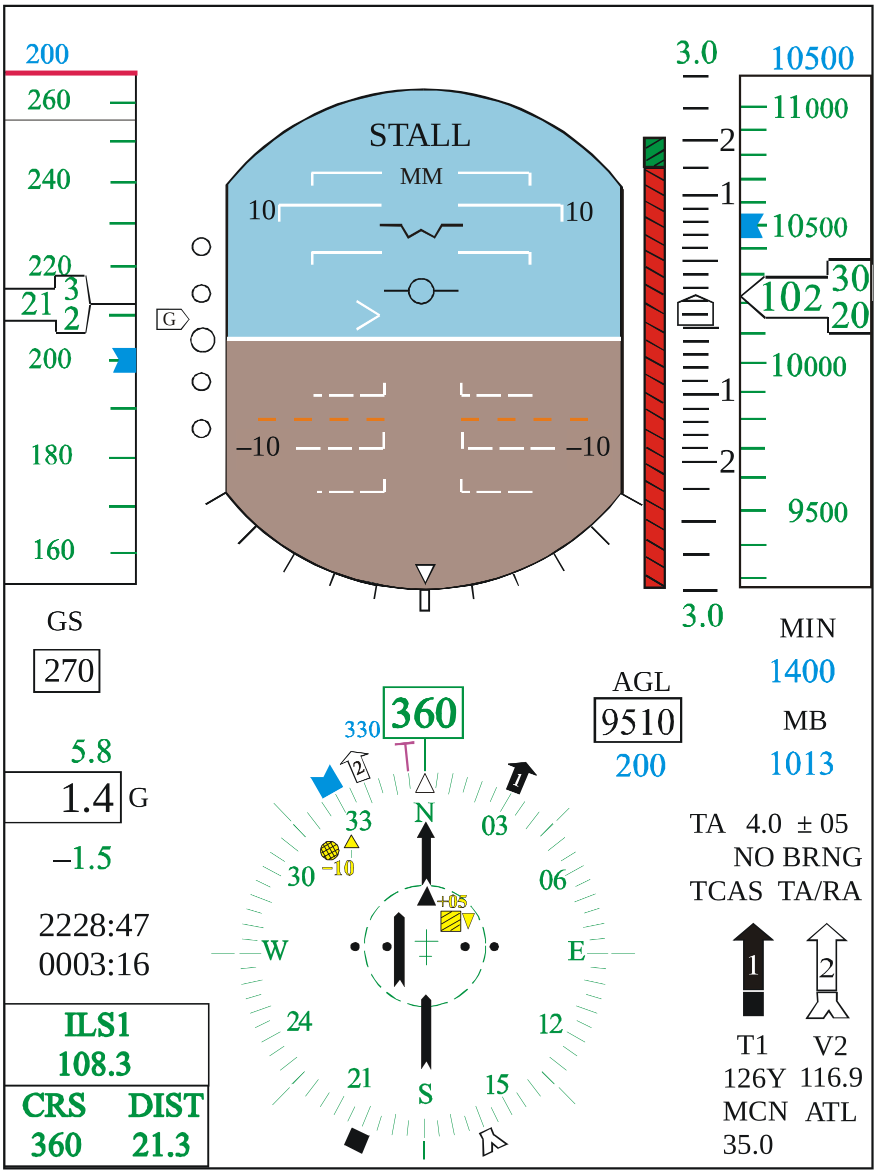
49. The loss of all direct indications of attitude will vary in importance with the type of instrumentation. On aircraft fitted with the standard basic instrument panel, the attitude can be deduced and controlled in all three planes without undue difficulty. On aircraft fitted with instrumentation that does not include a turn needle on which to control bank, control is possible only in pitch, with the wings being kept level by reference to the direct-reading magnetic compass.

ALTERNATIVE INSTRUMENT PRESENTATIONS

Flat Screen Displays

50. Some modern aircraft have the flight instruments presented in digital format on flat screens. A propensity towards such displays within a cockpit is often referred to as a 'glass cockpit' (see Volume 7, Chapter 21). An example of a TV instrument display is at Fig 11. Depending on the complexity and reliability of the digital system, there is sometimes a set of stand-by analogue instruments (ASI, AI and altimeter) available to the pilot. The instrument flying techniques used when flying an aircraft with this type of instrument presentation are exactly the same as for the analogue instruments as explained in this chapter.

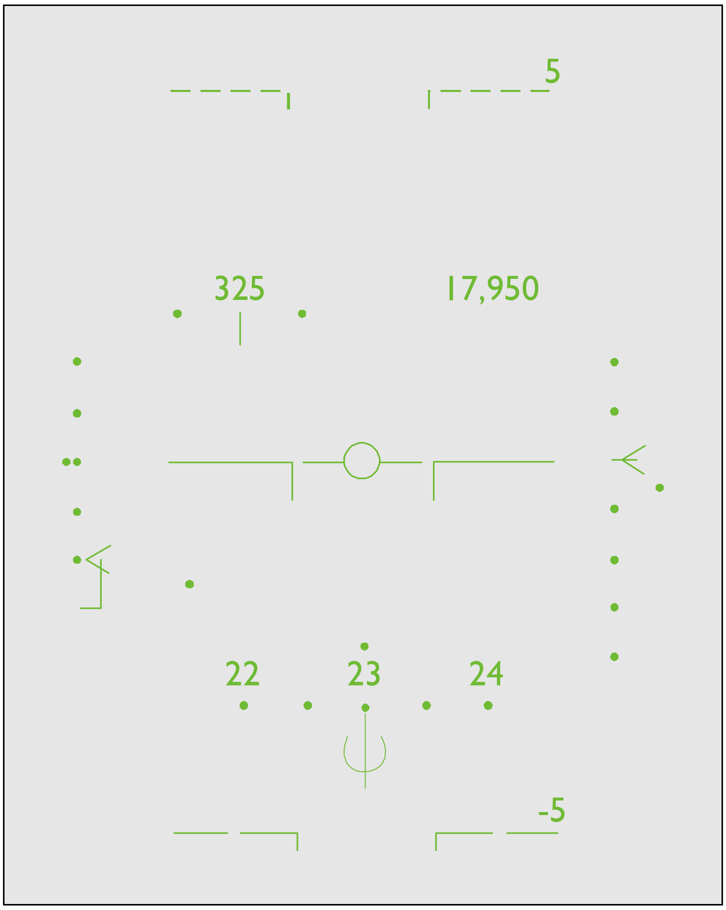
8-25 Fig 11 Flat Screen Display



Head-up Displays

51. It is possible to project flight instrument information onto a flat glass screen in front of the pilot at eye level. The display is collimated and, as well as basic flight instruments, can include extra information such as radar ranging and target information. Such displays are known as 'head-up' displays and are described in detail in Volume 7, Chapter 20. An example of a head-up display used in an aircraft for advanced flying training is illustrated at Fig 12. Where a head-up display is fitted, there will also be a set of conventional instrument displays in the cockpit, to provide the normal 'head-down' information. The instrument flying techniques used with a head-up display will differ slightly from those described within this chapter, depending on how the information is displayed. However, the principle of the selective radial scan can still be used.

8-25 Fig 12 Head-up Display



Human Factors and Instrument Flying

It is very easy to miss the big picture when Instrument Flying as the mind is focussed on 'numbers and dials'. Focussed attention can lead to time distortion and, potentially, loss of Situation Awareness. Follow training regimes and learn from the experienced, get a good scan routine going and if in doubt communicate.

CHAPTER 26 - NIGHT FLYING

Definition

1. For the purpose of flying training and the recording of night flying time, 'night' is defined as the time between the end of civil twilight in the evening and the beginning of civil twilight in the morning. For the purpose of standardization of air traffic control procedures, 'night' is defined in the CAA Air Navigation: The Order and Regulations (CAP 393 – usually referred to as the Air Navigation Order (ANO)), as the time between 30 from after sunset to 30 minutes before sunrise (both times inclusive), at surface level.

Introduction

2. The ability to fly an aircraft as efficiently by night as by day is required of every Service pilot. By day, the aircraft is controlled mainly by reference to ground objects and the visual horizon, supplemented by certain flight instruments. In the absence of external visual references, all of the flight instruments are used. Similarly at night the aircraft is controlled by a combination of external and instrument references, provided that the pattern and perspective of lights on the ground can be interpreted, and sufficient of the natural horizon is discernable. On a dark night, with no external lights visible on the ground, the problem is much the same as flying in cloud. It follows, therefore, that accurate instrument flying is of paramount importance if night flying is to be carried out safely and efficiently. At the same time, it must be emphasized that, although night flying poses additional problems to a similar flight during the day, none of the demands upon the pilot is unusual. With a properly equipped aircraft and the benefit of good pre-flight preparation, the average pilot should find night flying operations well within his capabilities.

Preparation for Night Flying

3. **Knowledge of Control Layout**. Before night flying is carried out, the crew must be thoroughly familiar with the location and function of all controls, cockpit and emergency lighting, crash exits and emergency equipment, so that the correct actions or selections can be carried out under subdued lighting conditions, or even in complete darkness.

4. **Dark Adaptation**. Before night flying, bright lights should be avoided whenever possible to allow the eyes to become adapted to the darkness. Full dark adaptation takes about 30 minutes, but exposure to bright lighting can destroy it in less than a second. Dark adaptation and night vision is significantly affected by a reduction in oxygen level. It follows, therefore, that heavy smoking is detrimental to night vision.

5. **Flight Planning**. Flight planning for a night sortie is similar in most respects to that for a day flight, but consideration should be given to the following factors where applicable:

a. Preparation of maps, charts and logs for ease of reading under low levels of illumination. (Note that markings in red will be illegible under red lighting and some other colour should be used for marking in danger areas, power cables etc.)

b. Possible limited availability of navigational assistance outside airfield normal operating hours (e.g. V/UDF).

c. Limited visibility for identifying ground features.

d. Changing light patterns in urban areas, particularly after the extinction of domestic lighting late at night.

e. Position of moon (visibility reduced down-moon).

f. Changes in accuracy of navigational equipment due to movement of the ionospheric layers. This effect is particularly marked during the dusk/dawn periods.

g. If the sortie is intended to employ astro-navigation, the possibility of upper cloud obscuring the sky.

h. Selection and identification of airfield identification beacons and marine lights.

6. **Night Flying Briefing**. All aircrew engaged on night flying duties should attend a briefing, or carry out self-briefing, to ensure that they are familiar with the following:

a. Airfield layout, dispersal areas, taxi pattern and obstructions.

b. Airfield and approach lighting, and obstruction lighting.

c. Serviceability of navigational aids.

d. Availability of diversion airfields.

e. Forecast weather conditions for period and area of flight.

f. Night flying orders, including marshalling signals to be used and emergency procedures.

g. Standard lamp and pyrotechnic signals.

Pre-flight Checks

7. Prior to night flying, all external and internal lighting should be checked in addition to the carrying out of normal daytime pre-flight checks. Warning and indicator light day/night screens or irises should be set to the required position to avoid undue glare in the cockpit. A torch should be carried to assist with external checks, and to provide an emergency source of cockpit lighting.

Engine Starting and Taxiing

8. **Engine Starting**. The daytime engine starting procedures are supplemented at night by the use of the aircraft external lighting to signal the intentions of the pilot to the groundcrew. On many aircraft servicing platforms (ASP) the level of illumination from floodlights is sufficient for the use of normal daytime signals but, to avoid any possibility or ambiguity or confusion, these signals should always be confirmed by the appropriate light signals as detailed in the unit Flying Order Book. The same principle should be observed when an external intercommunications system is used between the pilot and groundcrew.

9. **Taxiing**. When ready to taxi, the appropriate light signal is given to the groundcrew who will remove the chocks and then commence marshalling with illuminated batons (see AFSP-2 – Aircraft Marshalling Signals). If taxi lamps are used whilst being marshalled, care should be taken not to dazzle the marshaller and thus limit the assistance he can give the pilot. Before leaving the dispersal area, the cockpit lighting should be adjusted if necessary to avoid glare or distracting reflections in the cockpit canopy. The judgement of speed and distance is more difficult at night than in daytime due to the lack of visual cues. Care must be taken, therefore, to keep taxiing down to a safe speed. A good lookout must be kept for aircraft taxiing ahead, as the tail lights can be difficult to distinguish, particularly in the absence of any anti-collision lighting. If the pilot is at any time in doubt about the taxiing clearance available, or suspects the presence of obstructions, the aircraft should be stopped and full use made of landing lamps or hand-signalling lamps to illuminate the suspect area.

Take-off and Climb

10. Before take-off, the cockpit lighting level should be checked and adjusted to an acceptable minimum to reduce the contrast between internal and external references. When flying an unfamiliar aircraft at night, or when out of night flying practice, the aircraft should be held momentarily on the runway while the pilot assesses the perspective of the runway lighting in order to assist in the judgement of a subsequent correct landing attitude. Throughout the take-off run, and immediately after becoming airborne, the direction and attitude of the aircraft should be judged by reference to the runway lighting. When clear of the ground, and before external visual references are lost, attention should be transferred to the flight instruments and the aircraft placed in a steady climb as in normal instrument flying technique. Once the aircraft has reached circuit height, external visual references may again be used, if available, to supplement the instrument indications.

Engine Failure After Take-off

11. For a multi-engine aircraft, loss of an engine at night is no different from a similar emergency during daytime from the point of view of aircraft performance and emergency action to be taken. However, the fact that the aircraft may have to be flown entirely by instruments imposes an additional burden on the pilot. The case of a single-engine aircraft is rather more serious, and, following an engine failure at low level, the recommended course of action will almost invariably be to abandon the aircraft if possible. This presents no problem on aircraft equipped with ejection seats, but the minimum height for successful abandonment without the assistance of an ejection seat will normally preclude any possibility of escape from the aircraft at or below normal circuit heights. In such circumstances, the pilot is faced with no alternative but to attempt a forced landing within some 30° of the aircraft's original heading, aided only by the aircraft landing lights. The chances of success can be considerably enhanced by local knowledge of the terrain in the vicinity of the airfield, and its suitability or otherwise for forced landings. The location of suitable areas should be included in the night flying briefing where applicable.

Circuit Flying

12. The circuit pattern for night flying is normally the same as by day, except that local flying orders may require the aircraft to be climbed straight ahead after take-off until reaching circuit height. With omnidirectional runway lighting, the circuit pattern presents no problems, but with unidirectional lighting it may be advantageous to make use of the compass to assist in flying an accurate downwind leg parallel to the runway. A careful listening watch should be kept on the R/T so that the movements and intentions of other aircraft in the circuit are noted, and the circuit planned accordingly.

Approaching to Land

13. The approach to land is judged by the changing perspective of the runway lighting. On most airfields the pilot is assisted in judging attitude and descent angle by lighting extending out along the approach path from the runway threshold, and also by PAPIs (see Volume 8, Chapter 13).

Landing

14. Most large aircraft have landing lamps of sufficient intensity that the final round-out and touch-down can be judged largely by the use of normal daytime visual cues. On aircraft not so equipped, or in the event of failure of the landing lamps, the landing phase must be judged by looking well ahead and observing the changing perspective of the runway lighting. Peripheral vision plays an important part in this judgement; for most pilots, the runway lighting, as observed by peripheral vision whilst

looking straight ahead, appears to be up around the level of the shoulders or ears when the aircraft is about to touch down. As mentioned in para 10, this effect can best be observed while the aircraft is lined up on the runway prior to initial take-off. During the landing run, care should be taken to reduce speed progressively and, before turning off the runway, a positive check should be made to ensure that the speed is within acceptable taxiing limits.

Overshoot Procedure

15. The procedure for overshooting is the same at night as for a normal instrument overshoot, with the addition of extinguishing the landing lamps, if used, to avoid the possibility of causing distracting reflection from any cloud or mist patches, and to avoid confusion to other aircraft.

Navigation at Night

16. Subject to the considerations discussed in para 5, night navigation is similar in most respects to navigation by day.

17. The amount of map reading that is possible at night depends largely upon the prevailing conditions. On a bright moonlit night, almost as many major features may be seen as during the day. When there is no moon, or when flying under a complete cloud layer, it may be very difficult to see any ground features that are not illuminated. Visibility is better when looking into the moon than down-moon.

18. Coastlines and large water features such as navigable waterways and lakes can often be seen under all but the most adverse conditions, thus forming valuable pinpoints or position lines. Towns are easily visible whilst the street and domestic lighting is on, but it should be remembered that the majority of domestic lights are switched off for the latter part of the night. The apparent shape and size of towns can therefore vary considerably with the time of night. Railways can usually be seen on bright nights and dual carriageways and motorways can often be identified.

19. Flashing/occulting lights from lightships or lighthouses on the coast, and aerodrome identification beacons inland can be seen at fairly long ranges and, because they flash or occult in distinctive groups or in Morse code, give a positive position; civil airfield beacons flash in green and Service airfield beacons flash in red. Distances are deceptive at night and the correct estimation of range from an identified feature requires practice.

20. The use of a red light to illuminate the map should be avoided; under this light all markings in red on the map may be unreadable. Accurate flying and timing becomes even more important at night than by day, because of the reduced number of features that can be seen. Strict adherence to the flight plan is necessary if turning points cannot be seen or identified.

Night Emergencies

21. In addition to engine failure after take-off, the only other emergencies which pose additional problems at night are radio failure and total electrics failure. In both these cases, assuming the absence of a stand-by radio, the emergency can only be communicated to ATC by rejoining the circuit and flying the appropriate emergency pattern as detailed in the local Flying Order Book. Although the procedures may be subject to local amendment, in VMC, those most widely used for these emergencies are for the aircraft to fly a circuit at 500 ft AGL whilst squawking 7600 and monitoring the ILS speech facility. On final approach, a descent is made to 300 ft in front of the caravan or ATC, flashing navigation, taxi and/or landing lights (radio failure), or varying engine noise (total electrics

failure). For the latter, ATC should switch on floodlights to enable a visual check of undercarriage position on a subsequent similar circuit. Undercarriage position will be indicated by three successive pyrotechnics, green for down, red for up. The aircraft should be landed following a further green pyrotechnic (or aldis) signal from ATC.

Human Factors and Night Flying

It is very easy to miss the big picture when Night Flying as the mind is focussed on 'numbers and dials' without a visual reference. Focussed attention can lead to time distortion and loss of Situation Awareness. Normal day time references are not available and perceptions of distance can be corrupted. Cockpit lighting needs to be adjusted accordingly. Keep to a good scan pattern routine and if in doubt communicate.

CHAPTER 27 - SURFACE LIGHTING

Introduction

1. Details and specifications of aerodrome surface lighting can be found in The Manual of Aerodrome Design and Safeguarding, issued by the Military Aviation Authority (MAA) and is authoritative over AP3456. Airfield lighting is also detailed in STANAG 3316.

Aerodrome Identification Beacons

2. An identification beacon (I Bn) should be provided at an aerodrome that is intended for use at night. The beacon should be visible from all directions of approach and will flash a Morse group of one or more letters every 12 sec. The colour of the light is red at military aerodromes and is normally green at civil aerodromes. Not all aerodromes display a beacon.

3. Aerodrome beacons (A Bn) may display alternating white/green or flashing white lights and are normally only located at civil aerodromes.

4. The identification codes are promulgated in the appropriate En Route Supplements within the Nav section of the aerodrome entry in the form:

Airfield	Beacon Type	Morse Ident	Lights
Baldonnel (EIME)	A Bn		Wh Wh Gn
Barkston Heath (EGYE)	I Bn	BA	Red
Akureyri (BIAR)	A Bn		Wh Gn
Cambridge (EGSC)	I Bn	CI	Gn
Details correct Jun 2014			

Aerodrome Obstruction Lighting

5. The marking and/or lighting of obstacles is intended to reduce hazards to aircraft operating at low level under visual flight conditions or moving on the surface by indicating the presence of the obstacles. In areas beyond the obstacle limitation surfaces of an aerodrome, objects that extend to a height of 150m or more above ground elevation are regarded as obstacles. Other objects of a lesser height that are assessed as hazards to aviation are also to be treated as obstacles and should be marked and/or lighted.

6. Low intensity obstacle lights should be used on obstacles less than 45m high. Where this is deemed to be inadequate medium or high intensity lights should be used.

7. Low intensity (10 candela (cds) minimum) lights should be used for obstacles on the movement area where 200 cds lights may cause dazzle.

8. Low intensity (200 cds) lights should be used away from the movement area or in areas on the movement area with high levels of background luminance.

9. Medium intensity steady red obstacle lights should be used, either alone or in combination with other medium or low intensity obstacle lights from 45m up to, but not including 150m in height.

10. Where physically practicable high intensity flashing white obstacle lights should be used to indicate the presence of an obstacle if its height is 150m or more. High intensity obstacle lights are intended for day and night use and care is needed to ensure that they do not create dazzle.

11. Except in the case of a chimney or other substance emitting structure one or more obstacle lights should be located as close as practicable to the top of the object. The top lights should be so arranged as to at least indicate the points or edges of the object highest in relation to the obstacle limitation surface. In the case of a chimney or other substance emitting structure, the top lights should be placed sufficiently below the top so as to minimise contamination by smoke.

12. The number and arrangement of the obstacle lights at each level to be marked should be such that the object is indicated from every angle in azimuth. Where a light is shielded in any direction by another part of the object, or by an adjacent object, additional lights should be provided on that object in such a way as to retain the general definition of the object to be lighted. If the shielded light does not contribute to the definition of the object to be lighted, it may be omitted.

13. All fixed obstacle lighting located on the aerodrome should be under the control of ATC.

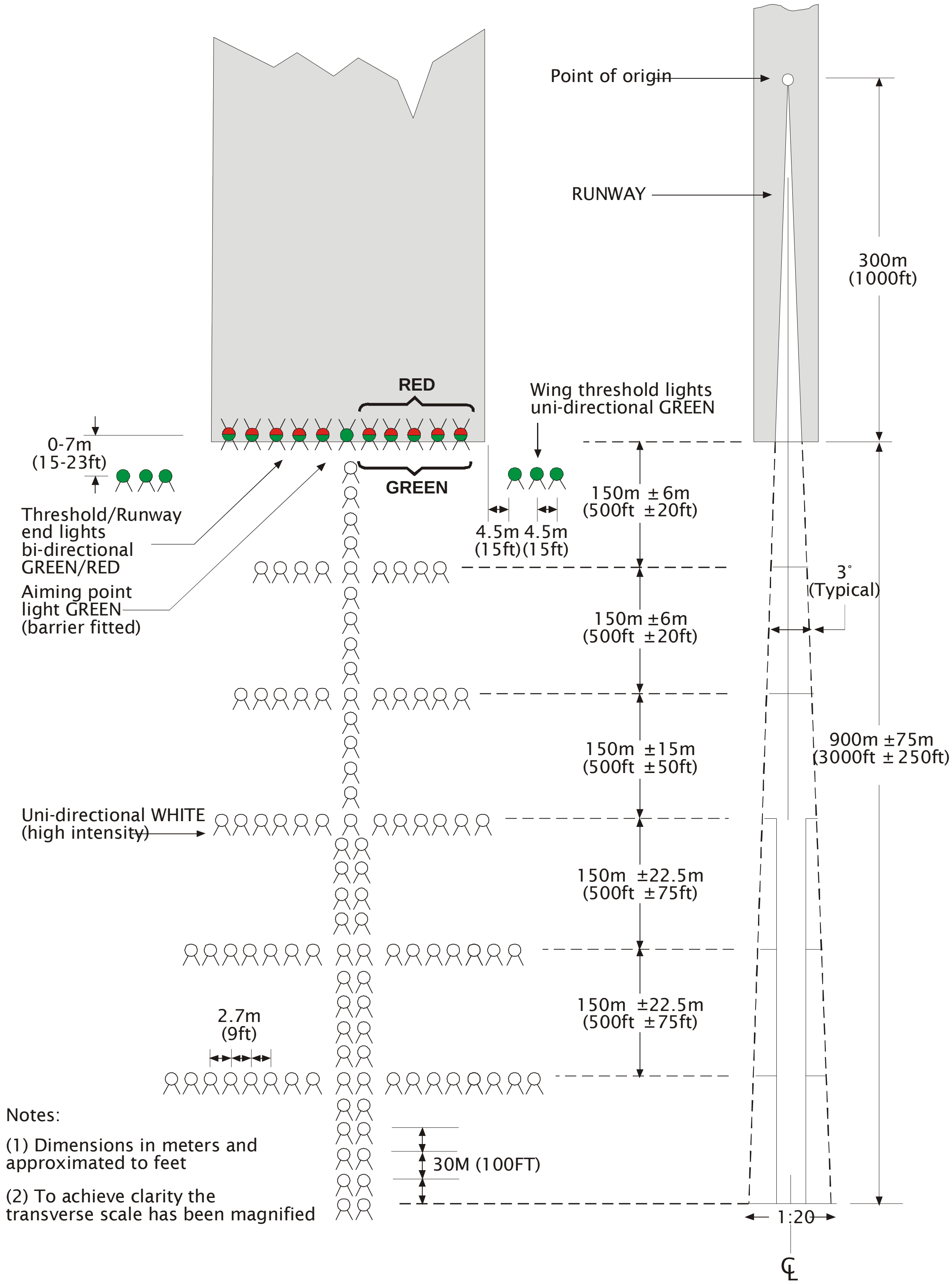
Approach Lighting

14. **Purpose**. The most critical stage of an instrument approach, whether at night or in poor visibility, is the transition from instrument flight to visual flight immediately prior to touchdown. The aim of runway approach lighting is to provide the pilot with visual external references during this transition, and for the remainder of the approach. The presentation of the lighting gives indications of the aircraft's alignment with the runway and, in most cases, the angle of approach, the aircraft's attitude in roll, and the safe touchdown point. The correct approach angle can be maintained, both day and night, by reference to the Precision Approach Path Indicators (PAPI) described in Volume 8, Chapter 13.

15. **Familiarity with Types**. In order to obtain the maximum assistance from the approach lighting, the pilot must be familiar with the type of system installed at his destination. Military aircraft may be required to make use of a wide variety of airfields, military and civil, local and foreign, all employing different standards and types of lighting. Details of the pattern of approach lighting at any particular airfield can be found by consulting the appropriate planning documents. The diagrammatic presentations given in the Terminal Approach Procedure Charts (TAPs) are particularly useful when planning a landing at an unfamiliar airfield at night or in poor visibility.

16. **Main Instrument Runway**. Provided that terrain conditions permit, a centre-line and five cross-bar high intensity white approach system extending to 900 m (3000 ft) from the threshold, with a low-intensity red T superimposed, is installed at the end of the main runway intended for instrument approaches (see Fig 1). Where the installation of the full pattern is impracticable, an abbreviated system is provided.

8-27 Fig 1 Approach Lighting



17. **Main and Subsidiary Runways.** There are prescribed minimum scales for lighting which depend upon the runway and type of approach. The Manual of Aerodrome Design and Safeguarding gives full details of the requirements (Table 6-4), some of which are reproduced in Table 1

Table 1 Minimum Prescribed Scales of Airfield Lighting

	Operating Category			
	CAT II Precision App	**CAT I Precision App/ PAR**	**Non-Precision App**	**Non-Instrument App**
Aerodrome beacon	O	R	R	R
Simple Approach			R	O
HI C/L 5 Bar Approach	R	R		
Supplementary Approach	R	O		
PAPI	R	R	R	R
Runway Edge	R	R	R	O
Threshold	R	R	R	R
Threshold Wing Bar	R	R	R	O
Runway End	R	R	R	O
Runway Centre-Line	R	O		
Touchdown Zone	R			
Stopway	R	R	R	R
Taxiway Centre-Line	R	O[1] R[2]		
Taxiway Edge		R[1]	R	R
Stop Bars	R			
Illuminated Runway Signs	R	R	R	O
Obstacles	R	R	R	R

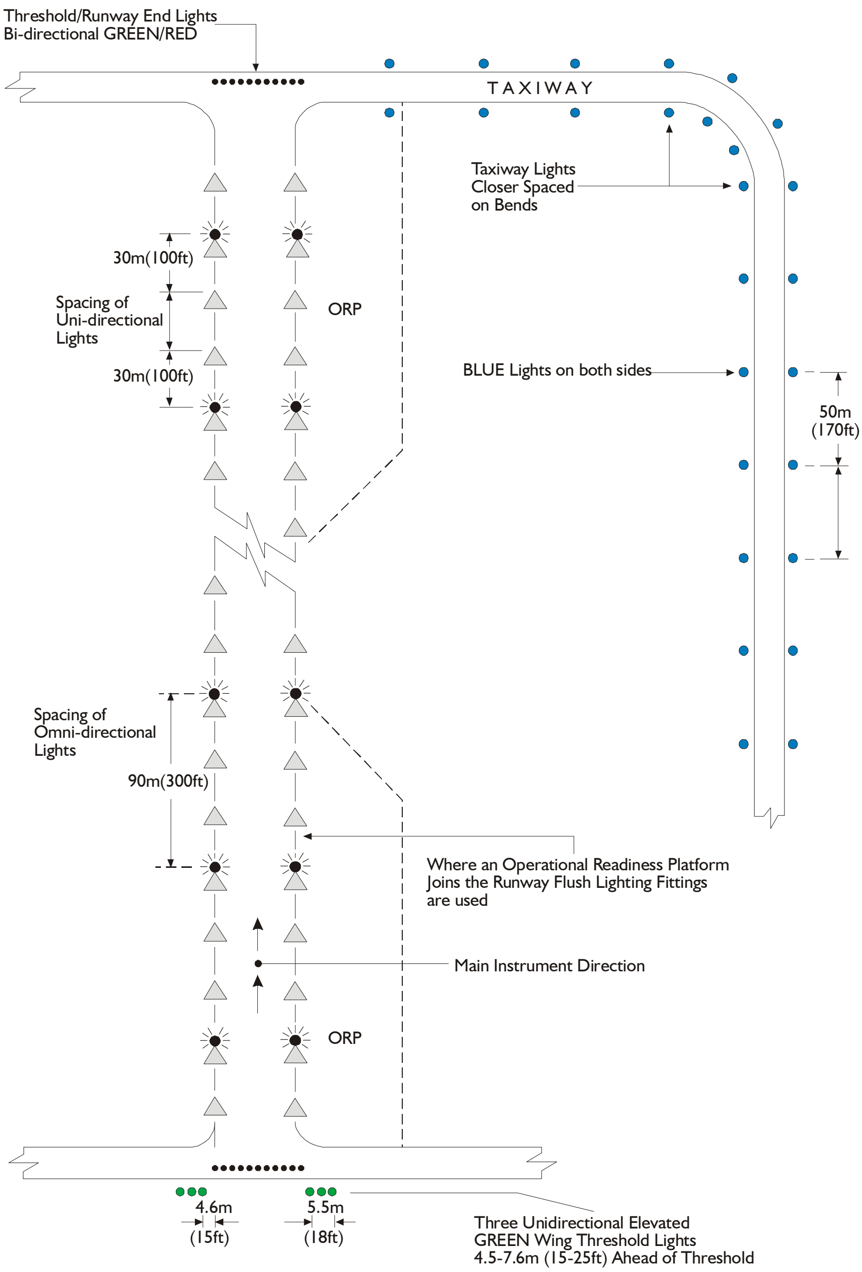
R = Required **O = Operationally Desirable**

1. Taxiway edge lighting may be replaced by taxiway centre-line lighting.
2. Centre-line lighting will be provided on taxiways with a width greater than 18m.

Runway Lighting

18. **Main Runways**. Main runways are equipped with high-intensity unidirectional elevated edge-lights for both directions of landing, and with omnidirectional elevated edge-lights operative for both directions of landing (see Fig 2).

8-27 Fig 2 Runway and Taxiway Lighting



19. **Subsidiary Runways**. Subsidiary runways are equipped with omnidirectional elevated edge-lights if the administrative authority concerned is satisfied that there is a requirement for an officially maintained subsidiary runway which will be used for night flying.

20. **Spacing of Runway Lighting**. The nominal longitudinal spacing of runway lighting is:

a. Unidirectional 30 m (100 ft).

b. Omnidirectional 90 m (300 ft).

Threshold/Runway-end Lighting

21. All runways with a lighting installation have threshold and runway-end lights. Threshold lights show green in the direction of the runway approach. Runway-end lights show red towards the direction of landing. Threshold and runway-end lights are to provide adequate definition of the threshold and runway-end regardless of intensity setting.

22. The minimum requirement for main runways is ten threshold lights at each end to define clearly the commencement of the normal landing area. The minimum requirement for main runways is eight runway-end lights at each end to define clearly the termination of the normal landing area. When the threshold is at the runway-end, bi-directional fittings may be used as a combination of threshold and runway-end lights.

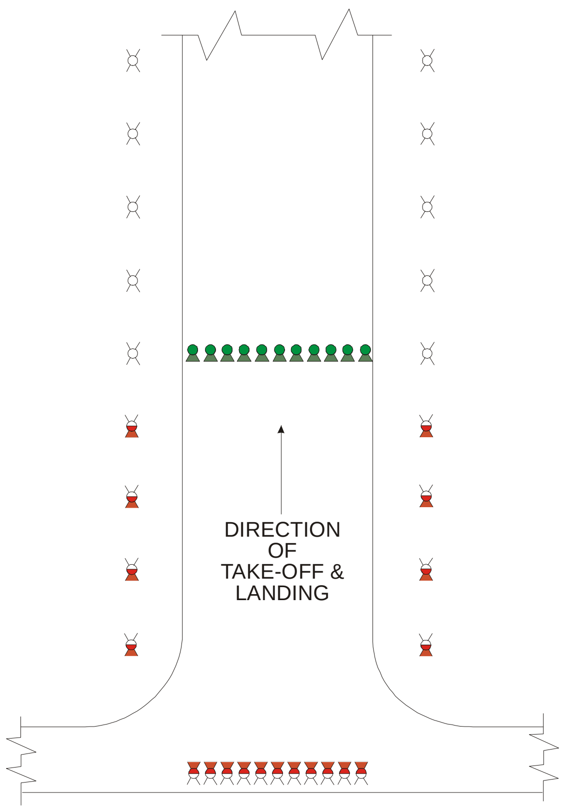
23. Threshold lights may be supplemented by 'wing bars' consisting of three unidirectional elevated high-intensity green lights at each side of the runway. (See Fig 1).

24. Where an arrester barrier is installed, the centre light of the runway-end lighting is fitted with a filter of a distinctive colour from the other end bar lights (e.g. green).

25. *Lighting of Displaced Thresholds.* Where the touchdown point is displaced from the runway end, it is delineated by unidirectional green lights in the approach direction and the displaced portion of the runway by high-intensity unidirectional red edge-lights which are installed and spaced in the same manner as the runway-edge lights (see Fig 3). Where suitable, the displaced portion of the runway may be used for take-off.

Note: In the reciprocal landing direction, the area beyond the displaced threshold (upwind) is deemed to be part of the runway and accordingly is to show high intensity unidirectional white edge lights. The runway end is to be identified by unidirectional red lights.

8-27 Fig 3 Runway Lighting - Displaced Threshold



Zone and Distance Markers

26. **Caution-Zone Lights***.* These lights are provided at certain aerodromes to indicate the amount of runway remaining for either take-off or landing. They are located 700 m (2,400 ft) from the upwind end of the runway at right angles to the runway edge. They are yellow and extend 4.5 m *(*15 ft) inboard of the runway edge.

27. **Illuminated Runway Distance Markers**. Illuminated runway distance markers should be installed on all main runways as follows:

a. The markers are placed on both sides of the main runway on a line parallel and normally equidistant to the centre line of the runway.

b. The unit of distance is 300 m (1,000 ft). The markers indicate the runway distance remaining in thousands of feet (the last three digits being omitted). Where the length of the runway is other than a multiple of 300 m (1,000 ft), then half the odd length is used at each end of the runway for computing the position of the markers.

c. The markers are numbered from the point of origin, increasing towards the beginning of the runway.

d. The colour of the numbers is white on a contrasting background.

Taxiway Lighting

28. Taxiway lighting facilities are governed by the width and purpose of the taxiway (main or access):

a. **Taxiways less than 18 m (60 ft) wide**.

(1) Main routes are lit by blue edge lights 50 m (170 ft) apart with closer spacing on bends.

b. **Taxiways 18 m (60 ft) or wider**.

(1) These taxiways are lit by green centre-line lights only, spaced at a maximum of 30m (100 ft) apart, with close spacing on bends. The last four lights of the taxiways entering a runway are spaced 2 m (6 ft) apart.

Note: At some aerodromes, sections of the main taxiway are fitted with green centre-line lights in addition to normal edge lights.

(2) Warning of the entrance/exit to a hardstanding is given by a bar of five yellow taxiway lights known as a 'taxiway stub bar'. Stub bars are provided where aircraft have a choice of direction, one of which is a right-angled turn giving direct access to a hardstanding. Where entry to a hardstanding is via a secondary route then a stub bar is provided at the entrance/exit to the secondary route. Where a hardstanding exit, or secondary route exit from a hardstanding, joins a main taxiway, the centre of the junction is indicated by a single yellow light to warn pilots of approaching soft ground.

c. **Turning Areas**. At aerodromes where turning facilities for aircraft are provided at the runway ends they are lit as follows:

(1) Taxiway Loops. These are lit in accordance with 'a' above.

(2) Turning Circles. These are lit with blue edge lighting.

29. **Holding Position Sign**. An illuminated red board incorporating the runway designator and the word HOLD in white characters is sited at the holding point on either side of the runway, 22.5 m (75 ft) from the outer edge of the taxiway and visible only from the taxiway side. Holding positions are further identified according to the type of taxiway lighting in use:

a. A taxiway lit by blue lights, has two holding position lights at right angles to the taxiway on its inside edge with relation to the runway.

b. A taxiway lit by green centre-line lights, has two holding position lights in the middle of the taxiway at right angles to the centre line.

30. **Lighting of Hardstanding and Other Areas***:*

a. **Hardstandings***.* Only the entrances to hardstandings are indicated by blue taxi lights.

b. **Aircraft Servicing Platforms and Operational Readiness Platforms***.* Aircraft servicing and operational readiness platforms are outlined by blue taxi lights. To achieve uniformity and minimize the risk of taxiing and other accidents, the following instructions are observed in the illumination of aircraft servicing platforms and dispersals:

(1) Dispersal lighting fittings are not to infringe runway or taxiway criteria.

(2) Illumination is not to interfere with the aerodrome lighting system or lighting aid, either by intensity or siting.

(3) No pattern of lights is to give a false indication to a pilot on the ground or in the air.

(4) All lights are to be screened to prevent dazzle on the ground or in the air.

Aerodrome Lighting During NVG Operations

31. The lighting that can adversely affect the use of NVG includes the airfield lighting that is controlled by ATC, however, other lighting on and adjacent to the airfield including lighting not provided for aviation purposes should be considered. Such lighting will not necessarily be under the control of military authorities and may be legally required to fulfil general safety requirements.

32. Different lighting requirements may be needed for fixed wing NVG (FWNVG) operations than for helicopter NVG (Helo NVG) operations. Simultaneous FWNVG and Helo NVG operations will need to be carefully planned as will simultaneous operations with and without NVG. Airfields which undertake NVG operations should have a NVG Operation Control Plan to ensure, as far as possible, that such measures of lighting control as are necessary to ensure that the performance of NVG is not significantly affected by any light on or adjacent to the airfield.

33. Where NVG operations are to take place, all personnel involved should receive training that includes the light control measures and operational procedures to be used when NVG operations are taking place.

34. Only personnel whose presence is essential for safety and efficiency reasons should be on the manoeuvring area during NVG operations.

35. The Manual of Aerodrome Design and Safeguarding contains further advice on NVG operations. See also STANAG 7134.

CHAPTER 28 - AIRCRAFT EXTERNAL LIGHTING

Navigational Lights

1. **Purpose**. Navigational lights are shown by aircraft at night in order to:

a. Avoid collision.

b. Determine direction of movement of the aircraft.

c. Identify the class of aircraft, (see para 2).

2. **Description**. Navigation lights are displayed by various classes of aircraft as follows:

a. **Powered aircraft** - As shown in Fig 1.

b. **Gliders** - One red light visible from all sides.

c. **Free Balloons** - One red light between 5-10 m (15-30 ft) below the crew basket, and visible from all sides.

d. **Captive balloons** - One white light between 5-10 m (15-30 ft) below the underside of the balloon, and one red light 4 m (12 ft) vertically below, both visible all round. Additional similar groups of red/white lights are shown at 300 m (1,000 ft) intervals down the cable. The ground attachment point is marked by three flashing lights, two red and one green, arranged in a 25 m (80 ft) equilateral triangle, with the attachment point midway between the red lights (Fig 2).

Note: Lights are only shown when the balloon is flown above 60 m (200 ft), or within 2 nm of an airfield or controlled airspace. In a designated danger area lights may not be shown at any height.

e. **Airships** - As for powered aircraft with the addition of a white nose light showing over a horizontal forward sector of 220º.

On aircraft where the arrangement of flying surfaces, etc precludes the placing of lights in the standard position, additional lights of the same colour may be used so that the required sector is covered.

3. **Regulations**. Navigation lights are to be displayed during the period of darkness by aircraft in flight, taxiing, being towed, and when being ground run, (MAA RA2307(1)). Exceptions to this rule include aircraft participating in certain exercises, and also aircraft which have had a failure of navigation lights in flight, and have been authorized to continue the flight by the appropriate ATC unit.

8-28 Fig 1 Powered Aircraft Navigation Lights

Fig 1a Front View

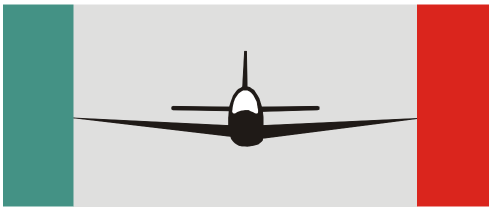


Fig 1b Plan View

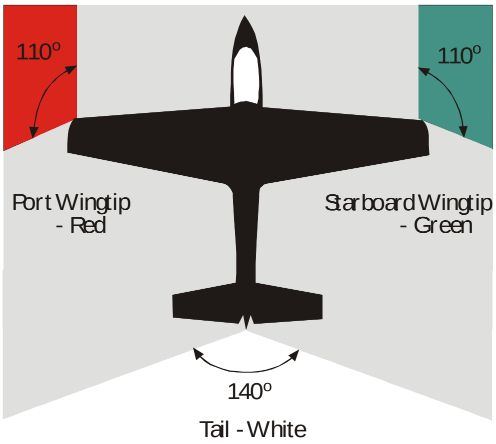
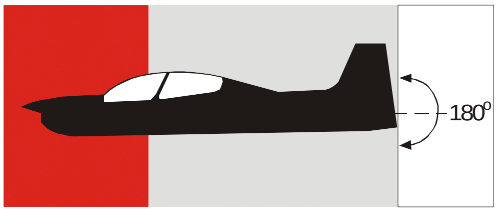
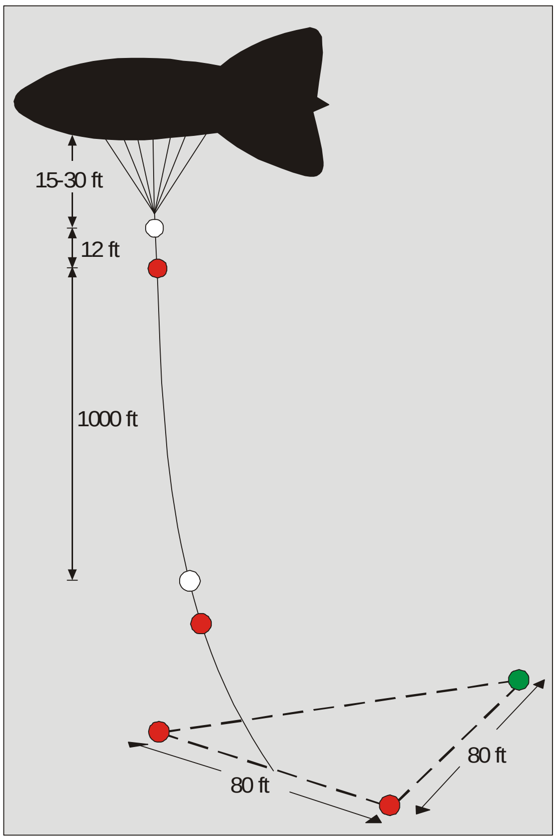


Fig 1c Port Side View



8-28 Fig 2 Captive Balloon Lighting



Anti-collision Lights

4. **Purpose**. Anti-collision lighting increases the range at which visual contact can be made with an aircraft. The flashing characteristic of the lights make them easier to distinguish against a background of other lights or stars.

5. **Description**. The most common form of anti-collision lighting consists of a high intensity rotating red beacon which gives the appearance of 90 flashes per minute. The number of beacons used on an aircraft depends upon that aircraft's size and configuration; the beacons are located so that at least one beacon is visible from any direction. A typical installation would have one beacon on the underside of the fuselage near the nose, and another beacon on the rear top surface of the fuselage or on top of the tail fin. Some installations use a red strobe light in place of the rotating beacon. Civil practice now tends towards the use of white strobe lights at the aircraft extremities in addition to the red anti-collision beacons. Some older installations have high intensity white anti-collision lighting but, in most cases, this is now supplemented by the red beacon. Provision is made in some aircraft for the upper anti-collision lighting to be switched off independently; this avoids interference with the taking of astronomical observations.

6. **Regulations**. Anti-collision lights, when installed, should be used at all times during flights.

Taxi and Landing Lights

7. Aircraft may be equipped with separate or combined taxi and landing lights, and these may be remotely adjusted from the cockpit. Care should be taken to observe any limitations on use as detailed in the appropriate Aircrew Manual.

Miscellaneous External Lighting

8. **Leading Edge Lights**. Leading edge lights are installed on most passenger carrying aircraft, and provide a means of inspecting the leading edge of the wing in flight to assess ice accretion, or checking wing mounted engine installations. On propeller driven aircraft, it is common practice to use this lighting to illuminate the propeller disc while manoeuvring or when stationary on the ground.

9. **Formation Lights**. Formation lights assist in formation station keeping at night. Fixed wing tactical transport aircraft show a cruciform display of white lights extending along the upper surface of the fuselage and wing. Some fighter aircraft display miniature navigation lights on the trailing edge of the wing tips. Helicopters which are required to fly in formation at night have rotor tip lights to define the area of the rotor disc.

10. **Flight Refuelling Lights**. Flight refuelling lights include the FR tanker floodlighting, signal lighting, and drogue lighting, and the receiver aircraft probe lighting (see Volume 8, Chapter 23).

11. **Undercarriage Lights**. Aircraft operated in the pilot training role and having a retractable undercarriage are equipped with an external undercarriage position indicator light which is illuminated whenever the undercarriage is locked down. On some installations the steady white light has been superseded by a flashing light.

12. **Servicing Lights**. A number of aircraft have built in servicing lights to assist with maintenance and servicing at night. Other aircraft have portable servicing lights which can be connected to power sockets provided both inside and outside the aircraft.

CHAPTER 29 - NIGHT FLYING CALCULATIONS

Definitions

1. **Night**. For the purpose of flying training and the recording of night flying time, 'night' is defined as the time between the end of civil twilight in the evening and the beginning of civil twilight in the morning. For the purpose of standardization of air traffic control procedures, 'night' is defined in the CAA Air Navigation: The Order and Regulations (CAP 393 – usually referred to as the Air Navigation Order (ANO)), as the time between 30 from after sunset to 30 minutes before sunrise (both times inclusive), at surface level.

2. **Sunrise and Sunset**. Sunrise and sunset are respectively defined as the point when the upper limb of the Sun just appears above (sunrise) or disappears below (sunset) the observer's visible horizon. At these times, the Sun's centre is 50' of arc below the celestial horizon (see Volume 9, Chapter 9 for further details).

3. **Twilight**. The period of diffused light before sunrise and after sunset is known as twilight. The amount of illumination varies with the Sun's depression and also with atmospheric conditions. Three twilights, each occurring at a particular depression value, are recognized:

a. Civil Twilight

b. Nautical Twilight

c. Astronomical Twilight

For a full explanation of twilight, see Volume 9, Chapter 9. However, only Civil Twilight needs to be considered within this annex.

4. **Civil Twilight**. Civil twilight occurs when the Sun's centre is 6º below the observer's visible horizon. Light conditions are such that everyday tasks are just possible without artificial light.

5. **Local Mean Time**. Local Mean Time (LMT) is explained in Volume 9, Chapter 11. The mean Sun crosses an observer's meridian at 1200 LMT, i.e. local noon.

Calculation of Civil Twilight

6. The times of the beginning of morning civil twilight and the end of evening civil twilight are tabulated in AP 1602, The UK Air Almanac, at three-day intervals for latitudes between 60º S and 72º N. The times given are the UTC of the occurrences at sea level on the Greenwich Meridian, and they may also be regarded as the LMT of the occurrences at other meridians.

7. The calculation process consists of two parts:

a. Extraction of LMT/UTC Greenwich for the occurrence.

b. Adjustment for Arc to Time, for Meridian of Longitude.

8. The Air Almanac includes examples of twilight calculations. However, further explanation of the processes involved is contained here.

Example 1. Calculate the beginning of Morning Civil Twilight, at Cranwell, on 11th January 2005.

Cranwell is at N 53º 02', W 000º 29'. From the Morning Civil Twilight, 2005, Table on page 11, the start of morning civil twilight can be extracted (Fig 1). By interpolation, the LMT of morning civil twilight for 53º 02', on 11 Jan 05, can be taken as 07 h 29 min.

The conversion of 0º 29' of arc, to its equivalent in time, is taken from Page 78 of the Air Almanac (see Fig 2). This gives a correction of 1 min 56 sec (round up to 2 mins). As the longitude of Cranwell is *west*, this time equivalent is *added* to the time previously extracted from the table.

07 h	29 min	LMT
+	02	
07	31	UTC

8-29 Fig 1 Extract from Air Almanac - Morning Civil Twilight Jan 05

	MORNING CIVIL TWILIGHT, 2005					
	Dec	January				
Lat.	30	2	5	8	11	14
	h m	h m	h m	h m	h m	h m
N 72	10 48	10 39	10 29	10 19	10 07	09 55
70	09 52	09 48	09 42	09 36	09 29	09 20
68	09 18	09 16	09 12	09 07	09 02	08 55
66	08 54	08 52	08 49	08 46	08 41	36
64	35	34	31	28	25	20
62	19	18	16	14	08 11	08 07
N60	08 06	08 05	08 04	08 02	07 59	07 56
58	07 55	07 54	07 53	07 51	49	46
56	45	44	43	42	40	38
54	36	35	25	34	32	30
52	28	28	27	26	25	23
N50	07 20	07 20	07 20	07 19	07 18	07 16
45	07 04	07 05	07 05	07 04	07 04	07 02

Note: Where the precise date and latitude is not listed, then dates and locations may be obtained by interpolation.

8-29 Fig 2 Extract from Arc to Time Conversion – Cranwell

CONVERSION OF ARC TO TIME

0° - 59°			60° - 119°			120° - 179°						300° - 359°			0´ - 59´		
°	h	m	°	h	m	°	h	m	°	h	m	°	h	m	°	h	m
0	0	00	**60**	4	00	**120**	8	00				**300**	20	00	**0**	0	00
1	0	04	**61**	4	04	**121**	8	04				**301**	20	04	**1**	0	04
2	0	08	**62**	4	08	**122**	8	08				**302**	20	08	**2**	0	08
3	0	12	**63**	4	12	**123**	8	12				**303**	20	12	**3**	0	12
4	0	16	**64**	4	16	**124**	8	16				**304**	20	16	**4**	0	16
25	1	40	**85**	5	40	**145**	9	40				**325**	21	40	**25**	1	40
26	1	44	**86**	5	44	**146**	9	44				**326**	21	44	**26**	1	44
27	1	48	**87**	5	48	**147**	9	48				**327**	21	48	**27**	1	48
28	1	52	**88**	5	52	**148**	9	52				**328**	21	52	**28**	1	52
29	1	56	**89**	5	56	**149**	9	56				**329**	21	56	**29**	1	56

The above table is for converting expressions in arc to their equivalent in time; its main use in this Almanac is for the conversion of longitude for application to LMT (*added if West, subtracted if East*) to give UT or vice versa.

Example 2. Calculate the end of Evening Civil Twilight, at Valley, on 11th January 2005.

Valley is at N 53º 15', W 004º 32'. From the Evening Civil Twilight, 2005, Table on page 11, the end of evening civil twilight can be extracted (Fig 3). By interpolation, the end of evening civil twilight for 53º 15', on 11 Jan 05, can be taken as 16 h 48 min (LMT).

The conversion of 4º 32' of arc, to its equivalent in time, is taken from Page 78 of the Air Almanac (see Fig 4). This gives a correction of 18 min 08 sec (round down to 18 mins). As the longitude of Valley is *west*, this time equivalent is *added* to the time previously extracted from the table.

16 h	48 min	LMT
+	18	
17	06	UTC

8-29 Fig 3 Extract from Air Almanac - Evening Civil Twilight Jan 05

	Dec	EVENING CIVIL TWILIGHT, 2005 January				
Lat.	**30**	**2**	**5**	**8**	**11**	**14**
	h m	h m	h m	h m	h m	h m
N 72	13 18	13 30	13 42	13 56	14 10	14 28
70	14 14	14 21	14 29	14 38	14 48	14 59
68	14 47	14 53	14 59	15 07	15 15	15 24
66	15 12	15 16	15 22	28	35	43
64	31	35	40	15 46	15 52	15 59
62	15 46	15 50	15 55	16 00	16 06	16 12
N60	16 00	10 03	16 07	16 12	16 17	16 23
58	11	14	18	23	27	33
56	21	24	28	32	36	41
54	30	33	37	40	45	49
52	38	44	44	48	52	16 56
N50	16 45	16 48	16 51	16 55	16 58	17 02
45	17 01	17 04	17 06	17 10	17 13	16

Note: Where the precise date and latitude is not listed, then dates and locations may be obtained by interpolation.

8-29 Fig 4 Extract from Arc to Time Conversion - Valley

CONVERSION OF ARC TO TIME

0° - 59°			60° - 119°			120° - 179°						300° - 359°			0´ - 59´		
°	h	m	°	h	m	°	h	m	°	h	m	°	h	m	°	h	m
0	0	00	**60**	4	00	**120**	8	00				**300**	20	00	**0**	0	00
1	0	04	**61**	4	04	**121**	8	04				**301**	20	04	**1**	0	04
2	0	08	**62**	4	08	**122**	8	08				**302**	20	08	**2**	0	08
3	0	12	**63**	4	12	**123**	8	12				**303**	20	12	**3**	0	12
4	0	16	**64**	4	16	**124**	8	16				**304**	20	16	**4**	0	16
30	2	00	**90**	6	00	**150**	10	00				**330**	22	00	**30**	2	00
31	2	04	**91**	6	04	**151**	10	04				**331**	22	04	**31**	2	04
32	2	-8	**92**	6	-8	**152**	10	-8				**332**	22	-8	**32**	2	08
33	2	12	**93**	6	12	**153**	10	12				**333**	22	12	**33**	2	12
34	2	16	**94**	6	16	**154**	10	16				**334**	22	16	**34**	2	16

The above table is for converting expressions in arc to their equivalent in time; its main use in this Almanac is for the conversion of longitude for application to LMT (*added if West, subtracted if East*) to give UT or vice versa.

Calculation of Sunrise/Sunset

9. The times of sunrise and sunset are tabulated in AP 1602, The UK Air Almanac, at three-day intervals for latitudes between 60º S and 72º N. The times given are the UTC of the occurrences at

sea level on the Greenwich Meridian, and they may also be regarded as the LMT of the occurrences at other meridians.

10. As with the calculation of twilight, the process consists of two parts:

a. Extraction of LMT/UTC Greenwich for the occurrence.

b. Adjustment for Arc to Time, for Meridian of Longitude.

11. The Air Almanac includes examples of sunrise/sunset calculations. However, further examples are illustrated.

Example 1. Calculate sunrise at Cranwell on 11th January 2005.

Cranwell is at N 53º 02', W 000º 29'. From the Sunrise, 2005, Table on page 10, the time of the occurrence can be extracted (Fig 5). By interpolation, the LMT of sunrise for 53º 02', on 11 Jan 05, can be taken as 08 h 09 min LMT.

The conversion of 0º 29' of arc, to its equivalent in time, is taken from Page 78 of the Air Almanac (see Fig 2). This gives a correction of 1 min 56 sec (round up to 2 mins). As the longitude of Cranwell is *west*, this time equivalent is *added* to the time previously extracted from the table.

08 h	09 min	LMT
+	02	
08	11	UTC

8-29 Fig 5 Extract from Air Almanac - Sunrise Jan 05

	SUNRISE, 2005					
	Dec	January				
Lat.	30	2	5	8	11	14
	h m	h m	h m	h m	h m	h m
N 72	—	—	—	—	—	—
70	—	—	—	—	—	—
68	—	—	11 28	11 08	10 52	10 37
66	10 31	10 26	10 20	10 12	10 04	09 56
64	09 51	09 48	09 44	09 40	09 34	28
62	24	22	19	09 16	09 11	09 06
N60	09 03	09 02	09 00	08 57	08 53	08 49
58	08 46	08 45	08 43	41	38	35
56	32	31	30	28	25	22
54	19	19	18	16	14	11
52	08 08	08 08	08 07	08 06	08 04	08 02
N50	07 59	07 58	07 58	07 57	07 55	07 53
45	38	38	38	38	37	37

Note: Where the precise date and latitude is not listed, then dates and locations may be obtained by interpolation.

Example 2. Calculate sunset at Valley, on 11th January 2005.

Valley is at N 53º 15', W 004º 32'. From the Sunset, 2005, Table on page 10, the time of the occurrence can be extracted (Fig 6). By interpolation, sunset at N 53º 15' on 11 Jan 05, can be taken as 16 h 06 min (LMT).

The conversion of 4º 32' of arc, to its equivalent in time, is taken from Page 78 of the Air Almanac (see Fig 4). This gives a correction of 18 min 08 sec (round down to 18 mins). As the longitude of Valley is *west*, this time equivalent is *added* to the time previously extracted from the table.

16 h	06 min	LMT
+	18	
16	24	UTC

8-29 Fig 6 Extract from Air Almanac - Sunset Jan 05

	SUNSET, 2005					
	Dec	**January**				
Lat.	**30**	**2**	**5**	**8**	**11**	**14**
	h m	h m	h m	h m	h m	h m
N 72	—	—	—	—	—	—
70	—	—	—	—	—	—
68	—	—	12 43	13 06	13 24	13 42
66	13 35	13 43	13 52	14 02	14 12	14 23
64	14 15	14 20	14 27	34	14 43	14 51
62	14 42	14 46	14 52	14 58	15 05	15 13
N60	15 03	15 07	15 12	15 17	15 23	15 30
58	20	23	28	33	38	44
56	34	38	42	46	15 51	15 56
54	46	15 50	15 54	15 58	16 02	16 07
52	15 57	16 00	16 04	16 08	12	17
N50	16 07	16 10	16 13	16 17	16 21	16 25
45	27	30	33	36	40	43

Note: Where the precise date and latitude is not listed, then dates and locations may be obtained by interpolation.

Note: These examples calculate the occurrence of sunrise and sunset. If the calculation is required by ATC, in accordance with the definitions used in para 1, then the appropriate adjustment of ± 30 minutes must be made. Applying this factor to the examples shown, gives an end of night time at Cranwell of 0741hrs in Example 1, and a start of night time at Valley of 1654 hrs in Example 2.

Summary

12. In para 1 there are two slightly different definitions of 'night'. The worked examples in this annex show how to calculate the relevant times according to these definitions. Intentionally, the same locations and dates have been used to show that the two methods produce slightly different results. In the case of Cranwell, the twilight method shows that night ceases at 0731 hrs whereas the sunrise

method gives night ending at 0741 hrs. Similarly, for Valley, by twilight calculation, night starts at 1706 hrs, whereas the sunset method gives a result of 1654 hrs. These discrepancies are seasonal, being greatest in June and December (the Summer and Winter Solstices) and least in March and September (the Spring and Autumn Equinoxes).

CHAPTER 30 - AIRWAYS FLYING PROCEDURES

Introduction

1. The Air Traffic Control (ATC) services and provision of relatively accurate navigation aids have made it possible to sustain the all-weather operation of civil and military air traffic. Topics covered by this chapter include the divisions of airspace, the use of radio aids in procedural operations, departures from and arrivals at an airfield, flight in controlled airspace and general considerations when planning an airways flight.

2. This chapter assumes knowledge of the avionics equipment appropriate to aircraft type, knowledge of the appropriate Flight Information Publications (FLIPs), and an ability to fly accurately on instruments. Occasionally, within the chapter, reference is made to authoritative sources where more detailed information may be obtained.

DIVISION OF AIRSPACE

Flight Information Regions

3. The International Civil Aviation Organization (ICAO) has divided the world's airspace into Flight Information Regions (FIRs). An FIR is airspace of defined dimensions, within which flight information and alerting services are provided.

a. ***Flight Information Service (FIS)***. An FIS supplies advice and information for the safe and efficient conduct of flights.

b. **Alerting Service**. An alerting service notifies the appropriate organizations regarding aircraft in need of assistance.

4. An FIR often coincides laterally with national boundaries; larger countries may have several FIRs within their national airspace. In a maritime, or mainly maritime region, an FIR may be known as an Oceanic FIR.

5. An FIR extends vertically from ground level to a specified upper limit. Some nations provide an Upper Flight Information Region (UIR) in upper airspace. Each FIR will have an associated Flight Information Centre (FIC) or Area Control Centre (ACC).

UK Flight and Upper Flight Information Regions (FIRs/UIRs)

6. UK airspace, including that over the surrounding waters, is divided into 2 FIRs. Above each of these FIRs is a UIR. These 4 regions are collectively termed the London and Scottish FIRs/UIRs. The airspace boundaries are detailed in RAF Flight Information Publications (FLIPs).

7. The London and Scottish FIRs/UIRs are divided vertically into the following bands:

a. UIR. Upper Airspace (UAS) from FL245 to unlimited.

b. FIR. Lower Airspace (LAS) from surface level to below FL245.

Operational Air Traffic/General Air Traffic

8. **Operational Air Traffic**. Military pilots frequently conduct routine training flights under the control or authority of the military Air Traffic Services (ATS) organization. Such flights are termed operational

air traffic (OAT). OAT flights can be conducted in free airspace, along TACAN routes or similar military corridors.

9. **General Air Traffic**. General air traffic (GAT) is the term used for flights that are conducted in accordance with the regulations and procedures for flight promulgated by the State Civil Aviation Authorities and operating under the control or authority of the civil ATS organization. Airways flying will normally be conducted as GAT.

10. **GAT/OAT Mixed**. It is permissible to fly one portion of a route as GAT, and then convert to OAT, or vice versa. In such cases, the Flight Plan (see para 37) must indicate the point of change.

11. There are differences between the ATS rules and procedures applicable to OAT and GAT. However, in principle, a flight may be conducted as OAT or GAT irrespective of whether the aircraft operating authority is civil or military. The decision to fly as OAT or GAT will be made by the pilot according to the availability of ATS and the nature of the flight. A military pilot crossing Controlled Airspace (CAS) in the FIR usually proceeds as OAT. Conversely, a military pilot wishing to make use of the CAS route structure and services must proceed as GAT.

12. Access to CAS by pilots of aircraft operating as OAT is permissible provided that the pilot conforms to the associated regulations and procedures concerning ATC clearance and ATS; such details may be found in RAF FLIPs. Aircraft operating under Airspace Surveillance and Control System (ASACS) control, must conduct their flights in accordance with the rules laid down for access to CAS in the instructions issued by parent HQs.

13. Pilots of military aircraft operating as GAT must conduct their flights in accordance with the ATC rules applicable to the airspace. The rules are described in the UK Aeronautical Information Publication (AIP) and RAF FLIPs. However, there are differences between the rules applying to civil GAT and those applying to military GAT. Military pilots are not subject to the speed limit of 250 kts specified for civil flights below FL100 and the VMC criteria applicable to military aircraft are specified in the MAA RA 2307(1).

The UK National Air Traffic Services

14. In the United Kingdom, the National Air Traffic Services (NATS) has the following responsibilities:

a. To provide air traffic services for the safe and expeditious operation of civil and military aircraft in UK national airspace and in airspace for which the UK holds responsibility under international arrangements.

b. To meet the differing operational requirements for both civil and military interests without according preferential treatment to either.

c. To plan airspace arrangements taking into account the requirements for all user interests.

d. To represent the UK on air navigation services matters at specific international meetings.

Air Routes/Airways

15. Air routes are segments of controlled airspace in the form of corridors, known as 'airways', and in many countries, they have an associated structured communication plan. The rules for the use of air routes in the UK are published in the UKAIP. A summary of the rules can be found in the UK Military Aeronautical Planning Document (MAPD) Volumes 1 and 3.

Classes of Airspace

16. Within an FIR airspace is broadly defined as either CAS or uncontrolled airspace. CAS is a generic term and is used to describe airspace which is 'notified' as such in the UK AIP; within this airspace civil pilots are required to comply with ATC and other regulations forming part of the UK Air Navigation Order (ANO) and Rules of the Air Regulations. In essence CAS comprises different types of control zone and control area to which are assigned one of the ICAO Airspace Classifications A to E Classes F and G are reserved for 'uncontrolled' airspace. Although a brief summary of the division of airspace is included here, the UK Aeronautical Information Package (UKAIP) (see paragraph 19) is the authoritative document on this subject and should be consulted for further details.

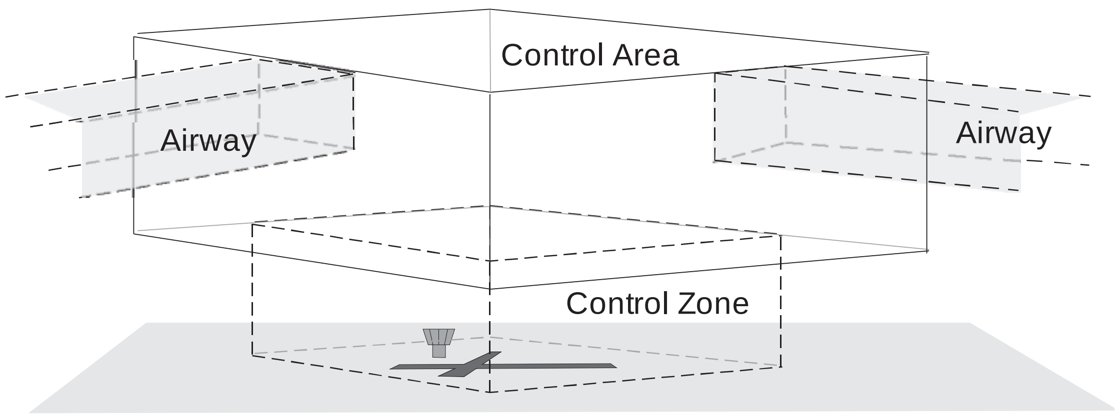
17. **Functional Types of CAS**. CAS is divided into two main functional types; control zones and control areas, but for the purposes of this chapter airways are also considered separately (see Fig 1):

a. **Control Zones (CTZ)**. A Control Zone (generically abbreviated to CTZ but in some cases CTR) is established around an airfield to protect all aircraft flying within it. A CTZ extends vertically from the surface of the earth to a specified upper limit.

b. **Control Areas (CTA)**. A Control Area (CTA) is usually established to cover approaches and departures from a major airport. Many of the control areas over land are classified as terminal control areas (generically abbreviated to TCA or in specific cases TMA). In addition, vast control areas exist over ocean regions. These are called oceanic control areas (OCAs). Control areas extend vertically between promulgated lower and upper limits.

c. **Airways**. An airway is a control area, or portion thereof, established in the form of a corridor equipped with radio navigational aids.

8-30 Fig 1 Illustration of The Relationship between Control Zones, Control Areas and Airways



International Civil Aviation Organization (ICAO)

18. **The International Civil Aviation Organization (ICAO)**. ICAO exists to regulate the purely civilian aspects of international aviation. It promulgates standards and recommended practices which member states agree to observe whenever possible. The Ministry of Defence has no direct link with ICAO but by policy it conforms to ICAO standards and practices provided that they do not conflict with military requirements. Amongst the tasks of ICAO is airspace classification which UK military aircraft recognise.

ICAO Airspace Classifications

19. **Airspace Classification**. Most countries, including the UK, have adopted the ICAO classification system by which airspace is divided into 7 classes (A to G). Of these, classes A to E are controlled airspace, whilst classes F and G are uncontrolled airspace. The ICAO airspace classification scheme is explained in the UK Aeronautical Information Package (UKAIP) which is available via the Civil Aviation Authority (CAA) and also on the AIDU milFLIP site. The classes of airspace are briefly described below but readers should note that **the UKAIP is the authoritative document and should be consulted for the most up to date information and promulgated changes**.

Controlled Airspace – ICAO Definition

Controlled Airspace is defined as airspace of defined dimensions within which air traffic control service is provided to IFR flights and to VFR flights in accordance with the airspace classification. Under ICAO, controlled airspace is defined as:

a. Class A. IFR flights only are permitted. All flights are provided with air traffic control service and are separated from each other.

b. Class B. IFR and VFR flights are permitted. All flights are provided with air traffic control service and are separated from each other. This class of airspace is not designated in the UK.

c. Class C. IFR and VFR flights are permitted, all flights are provided with air traffic control service and IFR flights are separated from other IFR flights and from VFR flights. VFR flights are separated from IFR flights and receive traffic information in respect of other VFR flights.

d. Class D. IFR and VFR flights are permitted, and all flights are provided with air traffic control service, IFR flights are separated from other IFR flights and receive traffic information in respect of VFR flights, VFR flights receive traffic information in respect of all other flights.

e. Class E. IFR and VFR flights are permitted. IFR flights are provided with air traffic control service and are separated from other IFR flights. All flights receive traffic information as far as is practical. Class E shall not be used for control zones.

Uncontrolled Airspace- ICAO Definition

Generally, under ICAO, uncontrolled airspace is as follows:

a. Class F. IFR and VFR flights are permitted, all participating IFR flights receive an air traffic advisory service and all flights receive flight information service if requested. This class of airspace is not designated in the UK.

b. Class G. IFR and VFR flights are permitted and receive flight information service if requested.

Airspace over the UK

20. The structure of the airspace over the UK and surrounding waters, which is subdivided into the seven various ICAO classes, is described in the UKAIP. The following paragraphs contain extracts from the UK AIP and briefly describe the UK airspace structure. Table 1 gives an overview of the different classes of airspace in the UK with more detail being given in subsequent paragraphs. It will be seen from Table 1 that Classes B and F are not currently designated in UK airspace but Tables 3 and 7 are included as users may encounter B and F airspace when flying in other parts of the world.

Table 1 An Overview of UK Airspace Classes

<table>
<tr><th>Class</th><th>Type of Flight</th><th>Separation</th><th>Service Provided</th><th>Radio</th><th>ATC Clearance</th></tr>
<tr><td rowspan="2">A</td><td>IFR</td><td>All IFR by ATC</td><td>ATC</td><td>Yes</td><td>Yes</td></tr>
<tr><td>VFR</td><td colspan="4">VFR flight not permitted</td></tr>
<tr><td>B</td><td colspan="5">This class of airspace is not designated in UK airspace</td></tr>
<tr><td rowspan="2">C</td><td>IFR</td><td>All IFR by ATC</td><td>ATC</td><td>Yes</td><td>Yes</td></tr>
<tr><td>VFR</td><td>VFR from IFR by ATC
Traffic Info on other VFR</td><td>ATC</td><td>Yes</td><td>Yes</td></tr>
<tr><td rowspan="2">D</td><td>IFR</td><td>All IFR by ATC
Traffic info VFR flights and traffic avoidance on request</td><td>ATC</td><td>Yes</td><td>Yes</td></tr>
<tr><td>VFR</td><td>Nil
Traffic info VFR and IFR flights and traffic avoidance on request</td><td>ATC</td><td>Yes</td><td>Yes</td></tr>
<tr><td rowspan="2">E</td><td>IFR</td><td>All flights by ATC
Traffic info on VFR flights as far as practicable</td><td>ATC</td><td>Yes</td><td>Yes</td></tr>
<tr><td>VFR</td><td>Nil
Traffic info as far as practicable</td><td>Traffic info as far as practicable</td><td>Nil
Pilots advised to contact ATC</td><td>No</td></tr>
<tr><td>F</td><td colspan="5">This class of airspace is not designated in UK airspace</td></tr>
<tr><td rowspan="2">G</td><td>IFR</td><td rowspan="2">ATC separation not provided
Traffic advice on acft under Procedural of Deconfliction services</td><td>UK FIS</td><td>No</td><td>No</td></tr>
<tr><td>VFR</td><td>UK FIS</td><td>No</td><td>No</td></tr>
</table>

UK Controlled Airspace (ICAO Classes A to E)

21. **Class A**. The UK airspace designated as Class A is detailed in the UKAIP, ENR 1.4 ATS Airspace Classification section. Class A airspace comprises all Control Areas (Airways) below FL195 with some exceptions listed in the UKAIP, some areas of the Channel Islands TCA and the following Control Areas: Clacton, Cotswold, Daventry, London TCA, Manchester TCA, Portsmouth, Worthing (all below FL 195), the Shanwick Oceanic Control Area and the North Sea Control Area (CTA2 and CTA3 – FL 175 to FL 195). Consult the UKAIP for full details and updates to the above.

Table 2 Class A Controlled Airspace ATC Services Description (ICAO)

	IFR	VFR
Service	Air Traffic Control service	VFR flight not permitted
Separation	Separation provided between all IFR flights by ATC	
ATC Rules	Flight Plan required. ATC Clearance required. Radio Comms required. ATC instructions mandatory.	
VMC Minima	At or above FL 100 (see below) Below FL 100 (see below and note 1)	
Speed Limitation	As published or ATC instruction.	

(1) VMC minima in Class A airspace for; climbs and descents maintaining VMC, powered aircraft crossing Airways or other penetration of Airways are:

	Flight visibility	**Horizontal** (distance from cloud)	**Vertical**
At or above FL 100	8 km	1500 m	1000 ft
Below FL 100	5 km	1500 m	1000 ft

22. **Class B**. No UK airspace is currently designated as Class B.

Table 3 Class B Controlled Airspace ATC Services Description (ICAO)

	IFR	VFR
Service	Air Traffic Control service.	
Separation	Separation provided between all flights by ATC	
ATC Rules	Flight Plan required. ATC Clearance required. Radio Comms required. ATC instructions mandatory.	
VMC Minima	Not applicable	At or above FL 100 8 km flight visibility and clear of cloud. Below FL 100 5 km flight visibility and clear of cloud.
Speed Limitation	As published or ATC instruction.	

23. **Class C**. Within the London and Scottish FIR/UIRs, Class C airspace extends from FL195 to FL660 which includes the Hebrides Upper Control Area (HUTA) and a network of domestic and international routes for use by GAT. See the UKAIP ATS Airspace Classification section for full details of airspace designated as Class C.

Table 4 Class C Controlled Airspace ATC Services Description (ICAO)

	IFR	VFR
Service	Air Traffic Control service.	
Separation	Separation provided from IFR flights by ATC.	Separation provided from IFR flights by ATC. Traffic information provided from other VFR flights and traffic avoidance on request.
ATC Rules	Flight Plan required. ATC Clearance required. Radio Comms required. ATC instructions mandatory.	
VMC Minima	Not applicable	At or above FL 100: 8 km viz; 1500 m horizontal and 1000 ft vertical from cloud. Below FL 100: 5 km viz; 1500 m horizontal and 1000 ft vertical from cloud.
Speed Limitation	As published or ATC instruction.	Below FL 100: 250 kt IAS or As published or ATC instruction.

24. **Class D**. Class D CAS comprises CTAs and/or CTRs surrounding notified aerodromes, including some military aerodromes, together with part of the Scottish TMA and sections of some airways. See the UKAIP ATS Airspace Classification section for full details of airspace designated as Class D and rules to be followed when flying in Class D airspace.

Table 5 Class D Controlled Airspace ATC Services Description (ICAO)

	IFR	VFR
Service	Air Traffic Control service.	
Separation	Separation provided between all IFR flights by ATC. Traffic Information provided on VFR flights and traffic avoidance advice on request.	ATC separation not provided. Traffic information provided on IFR and other VFR flights; traffic avoidance advice on request.
ATC Rules	Flight Plan required. ATC Clearance required. Radio Comms required. ATC instructions mandatory.	
VMC Minima	Not applicable	At or above FL 100: 8 km viz; 1500 m horizontal and 1000 ft vertical from cloud. Below FL 100: 5 km viz; 1500 m horizontal and 1000 ft vertical from cloud.
Speed Limitation	Below FL 100: 250 kt IAS or as published or ATC instruction.	

25. **Class E**. Class E CAS comprises the parts of the Scottish TMA below 6000 ft and parts of some airways. See the UKAIP ATS Airspace Classification section for full details of airspace designated as Class E.

Table 6 Class E Controlled Airspace ATC Services Description (ICAO)

	IFR	VFR
Service	Air Traffic Control service.	Traffic information as far as practicable.
Separation	Separation provided between all flights by ATC. Traffic Information provided on VFR flights as far as practicable.	Separation not provided. Traffic information provided as far as is practicable.
ATC Rules	Flight Plan required. ATC Clearance required. Radio Comms required. ATC instructions mandatory.	None. However, pilots are encouraged to contact ATC and comply with instructions.
VMC Minima	Not applicable	At or above FL 100: 8 km viz; 1500 m horizontal and 1000 ft vertical from cloud. Below FL 100: 5 km viz; 1500 m horizontal and 1000 ft vertical from cloud.
Speed Limitation	Below FL 100: 250 kt IAS or as published or ATC instruction.	

Advisory Airspace (ICAO Classes F and G)

26. **Class F**. No UK airspace is currently designated as Class F.

Table 7 Class F Advisory Airspace (ICAO)

	IFR	VFR
Service	Air Traffic Advisory Service	UK Flight Information Services as required (Basic Service, Traffic Service).
VMC Minima	Not applicable	At or above FL 100: 8 km viz; 1500 m horizontal and 1000 ft vertical from cloud. Below FL 100: 5 km viz; 1500 m horizontal and 1000 ft vertical from cloud. **OR**: At or below 3000 ft amsl: **Aircraft**: 5 km viz and clear of cloud in sight of the surface. **Aircraft**: **140 KIAS or less**; 1500 m viz and clear of cloud in sight of the surface. **Helicopters**: At a speed which, having regard to the visibility, is reasonable: At least 1500 m viz, clear of cloud and in sight of the surface.
Speed Limitation	Below FL 100: 250 kt IAS or as published or ATC instruction.	

27. **Class G**. All UK airspace, including that above FL 660, not included in Classes A to F is designated Class G airspace.

Table 8 Class G Airspace (ICAO)

<table>
<tr><th></th><th>IFR</th><th>VFR</th></tr>
<tr><td>Service</td><td colspan="2">UK Flight Information Services as required (Basic Service, Traffic Service, Deconfliction Service or Procedural Service).</td></tr>
<tr><td>Separation</td><td colspan="2">ATC separation cannot be provided. Deconfliction advice is provided under a Procedural or Deconfliction Service which aims to achieve planned deconfliction minima.</td></tr>
<tr><td>ATC Rules</td><td colspan="2">Instructions issued by Controllers to Pilots are not mandatory, however services rely on pilot compliance.</td></tr>
<tr><td>VMC Minima</td><td>Not applicable</td><td>At or above FL 100:
8 km viz; 1500 m horizontal and 1000 ft vertical from cloud.
Below FL 100:
5 km viz; 1500 m horizontal and 1000 ft vertical from cloud.
OR:
At or below 3000 ft amsl:
Aircraft: 5 km viz and clear of cloud in sight of the surface.
Aircraft: 140 KIAS or less; 1500 m flight visibility and clear of cloud in sight of the surface.
Helicopters: At a speed which, having regard to the visibility, is reasonable:
At least 1500 m flight visibility and clear of cloud in sight of the surface.</td></tr>
<tr><td>Speed Limitation</td><td colspan="2">Below FL 100: 250 kt IAS or as published or ATC instruction.</td></tr>
</table>

28. **ATC Services**. Aircraft flying airways will normally receive one of two types of control:

a. Radar Control where radar surveillance is available.

b. Procedural Control where there is insufficient radar cover. Safe separation is maintained by use of position reports.

29. **Formations of Aircraft**. Procedures for operating formations of aircraft within CAS are set out in the MAA RAs 2307(1) and 3234 and also in the UK Military Aeronautical Information Publication (Mil AIP). Normally, aircraft are treated as one unit, so long as elements are contained within one nm laterally and longitudinally and are at the same level or altitude. Formations should be in order and at the cleared level before entering CAS. In the event of a loss of formation integrity, a clear, unambiguous statement of the situation is to be made to inform ATC.

PREFLIGHT PLANNING

General Study

30. Details of ICAO and national procedures appear in the UK Military AIP and the UK Civilian AIP (see Volume 9, Chapter 13). Information on the associated nav/comms equipments - VOR, ILS, DME, GPS, ADF, transponders and VHF/UHF communications is in Volume 7.

31. The No 1 Aeronautical Information Documents Unit (AIDU) (RAF) Terminal Charts Specification & Legend contains important information including holding procedures, decodes for symbology and a list of abbreviations.

32. **Preferred Routes and Standard Routeing Scheme**. FLIPs and the UKAIP list some 'preferred routes' which ATC require aircraft to use when travelling through busy TCA, or between certain points. Preferred routes usually present efficient transit but are not always the shortest. However, requesting to fly these routes will usually reduce ATC clearance times. In the upper airspace, the Route Availability Document (contained within the En-Route Bulletin) offers a similar facility. If there is a route available, that meets your requirements, it should be used and followed to the exit point.

33. **Use of Magnetic Datum**. Airway centrelines and tracks depicted on arrival and departure procedures are based on the magnetic datum. In addition, headings given by ATC will be magnetic.

34. **Flight Planning**. Planning for airways and overseas flights must be comprehensive.

Instrument Flight Rules

35. Instrument Flight Rules (IFR) are a set of rules governing the conduct of flight under instrument meteorological conditions, although they might be applied under visual meteorological conditions. IFR are set out in the MAA RA 2307(1) and the UK Mil AIP.

36. Aircraft flying within CAS are normally expected to fly under IFR irrespective of the actual meteorological conditions. In some classes of airspace (usually airways and OCAs), IFR is mandatory at all times.

37. The following conditions are to be complied with when the flight is proceeding inside CAS as GAT:

a. A Flight Plan (Form CA48/RAF Form 2919) must be submitted to the appropriate Air Traffic Control Centre (ATCC).

b. Clearance for the flight must be obtained from the appropriate ATCC.

c. A pilot must have a valid instrument rating.

d. The aircraft must carry appropriate radio equipment operating on the notified radio frequencies.

e. The aircraft must carry radio-navigation equipment as specified in FLIPs.

f. The flight must be conducted in accordance with the ATC clearance and instructions received.

Area Navigation (RNAV)

38. Historically, airway routes have been structured around navigation aids to enable aircraft fitted with simple displays to fly direct from one beacon to another. However, use of narrow airway corridors can lead to aerial congestion and delays. The advent of Flight Management Systems (FMS) has enabled aircraft to route direct from point to point (based on latitude and longitude waypoints) under ATC clearance, thus avoiding airways. Area Navigation (RNAV) is the term given to this navigational method, permitting aircraft to operate on any desired flight path, within coverage of ground-based navigation aids or using self-contained navigation aids, or combination of both.

39. **Required Navigation Performance**. ICAO has developed the concept of Required Navigation Performance (RNP) as part of the methods of reducing horizontal separation between aircraft. To be permitted to fly RNAV, an aircraft must have a navigation system meeting a specified RNP. In the European region, Basic Area Navigation (BRNAV) specifies an RNP of ± 5 nm on 95% of occasions (also referred to as RNP5) and Precise Area Navigation (PRNAV) specifies an RNP of ± 1 nm on 95% of occasions (RNP1).

40. **RNAV Certification**. In addition to RNP standards, there is a list of minimum equipment and essential functions that form part of the RNAV certification process. In simple terms, the aircraft must have automatic position determination from one or more navigations systems (VOR/DME, INS, GPS etc) and, additionally, the equipment must have specified displays, including indications of position relative to track, bearing and distance to the active waypoint, display of groundspeed or time to the active waypoint, and failure indications.

41. **RNAV in European Civil Air Conference (ECAC) Airspace***.* The minimum RNP required to fly RNAV in ECAC airspace above FL 95 is presently BRNAV. There will be a progressive mandate for aircraft to carry instrumentation meeting BRNAV criteria as RNAV procedures spread into TCA/TMAs and other areas of the lower airspace.

42. **RNAV Routes**. An RNAV route is an airway defined by latitude and longitude co-ordinates (WGS 84 datum) and which does not necessarily coincide with radio navigation aids. If the aircraft is RNAV capable, crews should plan to fly on RNAV routes. When flying RNAV, aircrew should anticipate possible re-routeing by ATC.

Minimum Navigation and Communications Equipment

43. The national requirements for minimum navigation and communications equipment are listed in the UK MAPD Vol 3, International Planning, Section 2-2. Aircraft that cannot comply with the required minimum must obtain suitable exemption prior to flight.

44. In the UK FIR (except when overruled by the RNAV requirement for RNP5), for flight under IFR within CAS, the minimum combination of radio and navigation equipment is:

a. VHF radio.

b. VOR Receiver, DME and ADF.

c. For landing at certain aerodromes within Control Zones, ILS.

Reduced Vertical Separation Minima

45. Reduced Vertical Separation Minima (RVSM) has been introduced to some CAS in order to increase capacity of traffic by utilizing intermediate Flight Levels previously avoided. As the name implies, a reduced vertical separation is employed between aircraft. This change in procedures has been made possible due to improved accuracy in modern altimeter systems. In order to fly in RVSM airspace, the aircraft must have been awarded the status of 'RVSM compliant' (ie it meets specific requirements for altimeter equipment, engineering practices and crew training), or have been granted exemption from RVSM rules.

Fuel Planning

46. Fuel planning procedures are covered in Volume 9, Chapter 15. When planning to land at civilian airfields, there is a requirement that the captain satisfies himself before take-off that there is sufficient fuel for the intended flight plus a safe margin to allow for contingencies.

47. **Holding Fuel**. Aircrew should plan a reserve of fuel to permit a period of holding time at civilian airfield destinations. Minimum hold times are specified by operating authorities (usually in the order of 30 minutes).

48. **Contingency Fuel**. When route planning for long distances (and overseas) it is advisable to include a small amount of extra fuel (e.g. 5%) to cover slight deviations along route. Contingency fuel may be mandated by operating authorities.

49. **Hold-off/Island Holding Fuel**. Some destinations do not have a diversion airfield nearby (e.g. on remote islands). In such circumstances, it is necessary for the aircraft to carry a reserve of fuel to allow for a period of holding-off, which may be needed to provide an opportunity to land after any inclement weather has moved away. The minimum hold-off time will be specified by operating authorities and may be in the order of 1 or 2 hours.

Communications Failure

50. Communications failure procedures are covered in Volume 8, Chapter 8.

51. Aircrew should study the UK MAPD Vol 3 International Planning, and the Radio Communication Failure - National Procedures handbook to identify procedures specific to areas of operation. In many countries the ICAO procedures will apply, however careful study is still necessary, in order to understand the requirements at different stages of flight.

DEPARTURE PROCEDURES AND TECHNIQUES

Pre-flight Equipment Checks

52. It is normal practice to check flight instruments and nav/comms equipment before take-off in accordance with the relevant Aircrew Manual.

53. **Pre-take-off Selection of Aids**. The appropriate communication and navigation aid frequencies should be selected before or at the holding point. Setting-up will vary with particular ATC procedural requirements or operating authority SOPs. In training, the first en-route VOR is normally selected on NAV 1 and a suitable recovery aid for the departure airfield (e.g. ILS) on NAV 2 (where fitted).

Clearance to Fly Within Controlled Airspace

54. A flight plan must be filed for any flight in CAS, and a clearance must be obtained before joining. ATC clearance for GAT flights in CAS can be given only by the ATC authority operating the relevant CAS.

a. **Pre-flight Clearance**. When the point of entry to CAS is within 10 minutes flying time from the aerodrome of departure, pre-flight clearance should be requested.

b. **In-flight Clearance**. When the point of entry is more than 10 minutes flying time from the aerodrome of departure, in-flight clearance should be requested by the pilot either direct from the controlling authority of the airspace on the appropriate RT frequency or through another air traffic service agency, e.g. ATCC or ATCRU.

Note: During the issue of any pre-flight Clearance, the phrases 'Take off' or 'After Take-off' should not to be used. The Phrase 'After Departure' may be used but the aircraft is not to proceed beyond the Holding Position until ATC has issued the clearance to 'Line up' or 'Take off' as a separate message.

Pre-flight Clearance

55. A pre-flight clearance is passed by RT; at large airfields a dedicated frequency (eg 'Clearance Delivery') may be set aside for this purpose, otherwise the ground control frequency may be used. The tower frequency is only used at airfields where clearance requests are few.

56. The clearance contains the following information in this order:

a. Aircraft callsign.

b. Clearance limit, ie the destination or some specified point en route.

c. Route and flight levels allocated, ie those available and not necessarily those requested on a flight plan or other flight notification.

d. Any further information ie departure instructions, RT frequencies, transponder setting or expiry time of clearance.

57. The clearance must be logged and read back to ATC with the essential items verbatim. Shorthand notes, confirming or amending the pilot's copy of the F2919/CA 48, provide a practical means of checking off the clearance as it is received.

In-flight Clearance

58. Where the departure airfield is more than 10 minutes flying time from the entry point, clearance should be requested in the air. The departure instructions will include any pertinent flight limitations, transponder setting and the frequency on which to contact the airways controller. The initial call to the airways controller should request entry at the chosen point, for example "London Control, ASCOT 3456 request joining clearance ___ (airway) at ___ (position)." ATC may request further flight details including position and heading, level and flight conditions, and estimated time of arrival (ETA) at entry point.

Standard Instrument Departures

59. Some airfields publish outbound routeings from each runway; these provide obstacle clearance, help to optimize the flow of air traffic and keep RT to a minimum. These routeings are known as standard instrument departures (SIDs). A SID is an approved procedure for departing safely from a runway and climbing into the en route or airways structure.

65. As it is possible to be allocated one of a number of SIDs when leaving an airfield on a particular route, it is essential to study all possible relevant SIDs before flight.

66. **Joining Airways**. A SID terminates with the aircraft established in the required airway. Where a SID is not available, crews must plan an alternative joining procedure. This will normally be at a reporting point or beacon, approaching through the minimum amount of CAS (normally at 90º to the airway to be joined). Aircraft must remain clear of CAS until clearance has been received, and the pilot should ensure that the first cleared Flight Level has been attained before entering the airway. The transponder should be set to Mode C well before the entry point. Approximately 2 minutes before the entry point the navigation aids should be set up for the first leg. At the joining point the aircraft should be turned onto the required heading, the time should be checked and, if required, the controller should be advised.

Noise Abatement Procedures

67. Many airfields are situated in sensitive areas where it is essential to keep aircraft noise to a minimum. Noise abatement procedures, designed for this purpose, are published within the SID or in separate Special Procedures for the airfield concerned.

Airborne Submission of Flight Plans

68. It is permitted to file a flight plan whilst airborne. This procedure might be used, for example, when an aircraft has departed VFR, but finds deteriorating weather, and chooses to enter CAS. In such event, the Captain should contact the appropriate civil ATS unit on the Flight Information Service (FIS) frequency, or military ATCRU on the Initial Contact Frequency (ICF); the message starts with the words "I wish to file an airborne flight plan". Aircrew should anticipate re-allocation to a 'quiet' frequency and be ready to transmit the remainder of the flight plan request details in an expeditious manner. At least 10 minutes prior warning of entry to CAS must be given.

EN ROUTE PROCEDURES AND TECHNIQUES

Airways Procedures

69. Airways are normally 10 nm wide; upper ATS routes and advisory air routes have no width but are usually deemed to be 10 nm wide. Centreline datums are magnetic and usually delineated either by VOR radials, NDB bearings or marker beacons. The lower limit of an airway may be either an altitude or a flight level. In the UK airspace, the upper limit of an airway is normally FL 245 with upper ATS routes continuing to FL 460. Except for RNAV routes a radio navigation aid is normally located where there is a change in direction. DMEs are frequently collocated with (or in close proximity to) VORs; significant points are occasionally indicated by 'fan markers' (see para 84), but their use is becoming less common.

70. **Flight Management Systems**. Most aircraft now have a flight management system (FMS), which can hold a library of waypoints to facilitate route flying. Retrieval of waypoints from the database should be carried out with care, watching for ambiguity and cross-checking bearings by dead reckoning.

71. **Position Reporting**. It is essential that the controlling authority is constantly aware of the positions and flight levels of all aircraft using an airway. Historically, this has been achieved by aircraft passing 'position reports' over the radio to ATC (a system still employed when using Procedural

Control). The use of radar and transponders for identification of position, and Mode C for flight levels, reduces the need for position reports (AIPs state national requirements). Within most controlled airspace in Europe and North America, the controller will place the aircraft under radar control and, after giving initial clearances, only call the aircraft with changing information, e.g. frequency changes or new flight level etc. Aircrew should anticipate making a position report to the controller at designated compulsory reporting points (marked by a solid triangle on en route charts), the remainder being on request (marked by a hollow triangle). A position report is also required when being handed from one controlling authority to another. A radio flight log (such as RAF Form 441H) should be used for flight planning and recording RT messages and position reports.

72. **Format**. The format of the position report is:

a. The aircraft identification.

b. The aircraft position.

c. The time of the position (Note 1).

d. The altitude or flight level (Note 2).

e. The next position and its estimate (Note 2).

f. The following position (Note 2).

Note 1: The time should be passed in minutes unless this would result in ambiguity when hours and minutes Co-ordinated Universal Time (UTC) should be used.

Note 2: Subject to national requirements, elements e and f may be omitted. Element d may also be omitted if SSR Mode C is continuously available.

73. **Other Reporting**. There are other occasions when, in addition to routine position reports, the aircraft may be required to confirm or report position, altitude or FL. These include:

a. **Change in Flight Level**. A request for change in flight level should include the aircraft identification, the new level requested and the revised estimate at the next reporting point if applicable. Even where the Flight Plan has pre-notified an intended change of flight level, ATC must give permission before it is actioned.

b. **Change in True Airspeed (TAS)**. ATC should be advised if the average TAS varies by more than $\pm$5% of that notified in the flight plan (F2919/CA 48), or last approved by ATC.

c. **Change in Time Estimates**. ATC should be advised if the ETA at the next notified reporting point or destination changes by more than 3 minutes.

d. **Deviation from Track**. It is sometimes necessary to deviate from track to avoid localized areas of bad weather. The need for such a deviation should be anticipated and requested from ATC in good time. If such a deviation causes the aircraft to leave controlled airspace, then positive clearance must be obtained to re-enter controlled airspace.

e. **Change in Route**. A request for a change in routeing should be made in the following form:

(1) Aircraft Identification.

(2) Type of flight plan (normally IFR).

(3) Description of new route, including flight levels and speeds commencing from the position/time that the change is requested.

(4) Any other information e.g. new destination and alternate if changed.

f. **Other In-flight Reports**. The following reports should be made without being requested by ATC:

(1) The time and flight level on reaching a holding point or a point to which cleared.

(2) The time when leaving a holding point.

(3) When leaving one flight level on being assigned a different flight level.

(4) On reaching a new assigned flight level.

Note: Holding points will be considered later in this chapter.

Flying Techniques

74. **General Tracking Procedure**. On airways and RNAV routes an aircraft is required to approach and leave designated waypoints on specified radials - a procedure known as tracking. The sequence, to track either in or out, is:

a. Determine position relative to required radial.

b. Fly a heading towards radial (interception).

c. Determine the drift.

d. Fly a heading to maintain radial.

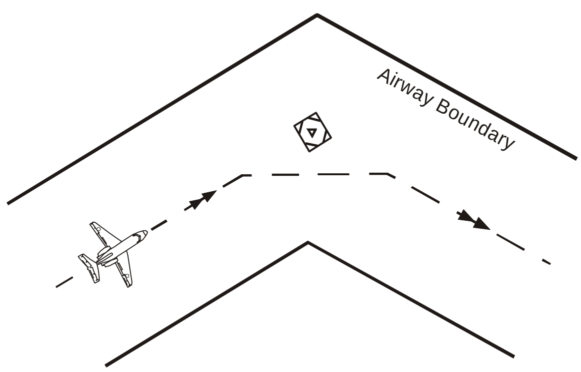
In carrying out the interception, any suitable angle may be used. Normally, it is only necessary to use the 'double track error' method (i.e. calculate the 'track error' between actual bearing and required bearing and double it) to determine the interception angle, up to a maximum of 45º.

75. **Primary Navigation Reference**. Where a radial defines the airway centreline, the primary means of maintaining that centreline is by reference to the VOR or NDB on which the radial is based. In this manner, all aircraft utilize the same navigation reference.

76. **Tracking using a Horizontal Situation Indicator (HSI)**. The centreline of an airway is normally defined by a radial from a beacon. The procedure for tracking down a radial, using an HSI presentation, is explained in Volume 9, Chapter 21.

77. **Turning at a Beacon**. When approaching the overhead of a beacon, the bearing indication may fluctuate. If this occurs, the pilot should concentrate on maintaining a steady heading. Where the route demands a large turn at the beacon, it is accepted practice to anticipate the overhead and cut the corner slightly (see Fig 3). This will prevent a large overshoot towards the edge of the airway.

8-30 Fig 2 Anticipating the Beacon



78. **Tracking Out**. Because an aircraft will normally commence tracking out close to or overhead the waypoint, an interception of up to 30º will be adequate in most cases.

79. **Changes of Level**. Pilots of aircraft commencing a climb or descent in accordance with an ATC clearance should inform the controller if they anticipate that their vertical speed will be less than 500 ft per minute, or if it actually becomes so.

Timing

80. Apart from a GPS or INS fix, there are a number of ways of checking flight progress and amending estimates between waypoints. These include:

a. Dead Reckoning.

b. DME Ranges.

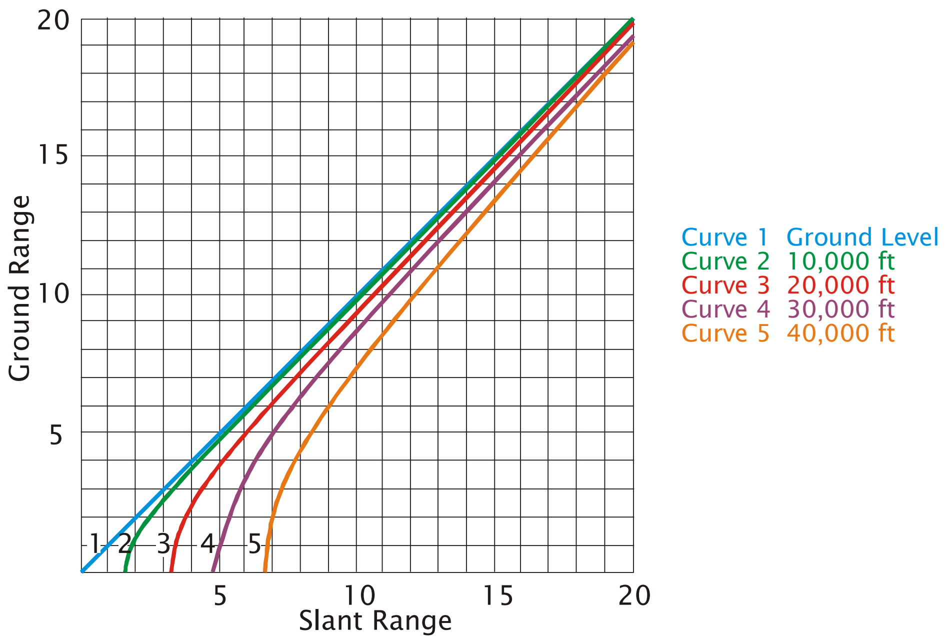
c. Passing abeam other VORs.

d. Marker beacons.

81. **Dead Reckoning**. The basic timing and flight progress is calculated at the flight planning stage. The estimates for significant points are not likely to exceed 3 min in error for short legs. However, minor errors will be proportionally greater on longer legs; e.g. 2 mins late on a 10 min leg - no amendment of estimate necessary, but a 20 min leg (in the same direction at the same groundspeed) would be 4 mins longer, therefore estimate revision would be necessary. The same technique over the flight as a whole may be used to amend the ETA at the destination.

82. **DME**. DME is frequently collocated with VOR, providing a simple means of checking timing. As the equipment indicates slant range, there will be an increasing error between plan and indicated ranges within 20 nm of the overhead; one means of deriving a correction is the graph at Fig 4. Directly overhead a DME, the range will equal the height of the aircraft (e.g. at FL 420 the DME would read approx 7 nm).

8-30 Fig 3 Slant Range Graph



83. **Crossing a VOR Radial**. Where DME is not collocated with VOR at a reporting point, crossing a radial from another VOR at or near a right angle to track can provide an accurate timing check.

84. **Marker Beacons**. Marker beacons give an aural and visual indication of passing a significant point, the accuracy of this indication decreasing with increase in height. Although most marker beacons are associated with ILS, some are situated along airways; these are fan markers and provide range information. Note that the signal strength required to provide an aural indication is less than that needed to operate a light.

Alterations to Cleared Route

85. ATC may sometimes change the clearance of an aircraft en route. This may be an actual re-routeing or simply a radar vector for separation followed by an instruction to resume normal navigation to the original reporting point. It is not unusual to be routed directly to a waypoint or beacon further down the airway. It is good practice to be aware of possible alternative routeings and to have any adjacent charts available. A sound knowledge of the route, through pre-flight planning, will allow a re-route instruction to be executed expeditiously.

86. When a re-routeing is given, the following actions should be carried out before reaching the starting point of the new section:

a. Write down the new clearance. Resolve any ambiguity (e.g. name or identification of a facility) and read the clearance back to ATC.

b. Transfer the route to the en route charts.

c. Enter new waypoints into the FMS.

d. Alter heading after cross-checking FMS with chart and by dead reckoning.

e. Mark appropriate facilities and RT frequencies.

f. Calculate new ETAs and safety altitudes.

Traffic Alert and Collision Avoidance System (TCAS)

87. Aircraft equipped with TCAS may receive warnings that demand action to prevent a potential mid-air collision. Within CAS, the crew should take the following actions:

a. In the event of a Traffic Advisory warning, the crew should commence a visual search for the potential threat. If the threat is not seen, ATC assistance should be requested to decide whether a change of flight path is required. If the threat is seen, and considered to be a collision risk, the pilot should manoeuvre, then resume previously cleared flight path, advising ATC of deviations from clearance.

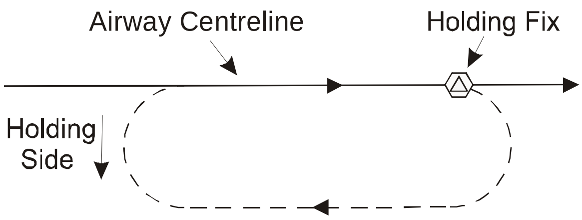
b. In the event of a Resolution Advisory indicating a risk of collision, the required manoeuvre should be initiated immediately, whilst the crew search visually for the threat. Once TCAS indicates that adequate separation has been achieved, or visual/ATC information shows that there is no longer a conflict, the aircraft should be promptly returned to its intended flight path and ATC informed.

88. TCAS operations are described in Volume 7, Chapter 16.

En Route Holding

89. ATC may instruct an aircraft, during transit, to hold at a nominated point (usually overhead a beacon or reporting point). The standard hold in such circumstance will be a right-hand hold, based on the inbound centreline of the airway (Fig 5).

8-30 Fig 4 En Route Holding Pattern (Standard ICAO - Turning Right at the Fix)



90. Wherever possible, 280 kt IAS should be used for holding procedures within airways route structures (see FIH for IAS requirements for holding patterns).

91. If ATC give an onward clearance time (OCT), the crew must adjust the hold pattern to overfly the holding fix at the OCT, before continuing the flight.

PLANNING FOR AIRWAYS FLIGHTS

92. There are many of the considerations which aircrew must take into account when planning an overseas airways flight. The advice given in the following paragraphs does not cover aircraft type-specific aspects and cannot cover all eventualities.

Aeronautical Documentation

93. Aeronautical documents (including the AIP) are described in Volume 9, Chapter 13, and must include the latest amendments. The following are pertinent to overseas and airways planning:

a. Flight Information Handbook (FIH).

b. En Route Supplements (ERS).

c. UK Military Aeronautical Planning Document (MAPD).

d. Terminal charts (TAP, SID and STAR). The Terminal Charts Catalogue lists current availability.

e. No 1 AIDU (RAF) Terminal Charts Specification & Legend.

f. En Route Charts (ERC).

g. Radio Communications Failure - National Procedures.

h. Topographical Charts. The MOD Aero-nautical Chart Catalogue (available in-Flight Planning sections) provides information on world coverage of charts and Projected Map Displays.

94. No 1 AIDU maintains a comprehensive library of aeronautical information world-wide, and requests for information may be made direct to that unit.

Overseas Flight Planning

95. **Diplomatic Clearances**. Before a military or state-owned aircraft may fly though the sovereign airspace of another country, permission must be obtained from the government of that country for the

flight to proceed. The procedures for obtaining the Diplomatic Clearance to conduct the flight are contained in AP1158, Approval and Diplomatic Clearance for Flights to Destinations Abroad. It is the responsibility of the aircraft operating authority to obtain Diplomatic Clearance and this is usually done through the Station operations staff.

96. **Flight Notification Signal**. Captains should send a flight notification signal to request diplomatic clearance and give notice of flight details to units and ATC authorities concerned. This signal includes routeing, times and notification of requirements at landing destinations, e.g. fuel uplifts, accommodation needs, customs clearance etc.

97. **National Procedures**. National procedures are listed within the UK MAPD Vol 3, Pt 2 International Planning Information, Section 2-2.

Flight Preparation

98. **Destination**. Captains should check that:

a. Airfield facilities and services are sufficient for operation of aircraft type, e.g. field lengths, fuel etc.

b. Where an airfield operates a ‘prior permission required’ (PPR) system for approval to land, this has been obtained.

99. **Route Planning**. Aircrew should include the following within route planning:

a. If the flight is to be GAT, select suitable airways and/or RNAV routes (consult ATC preferred routes and Route Availability Document). For OAT flight, select TACAN or other military routes.

b. From the MAPD, determine national requirements for each country to be over flown, in respect of division of airspace, vertical separation, minimum navigation and communication equipment, Flight Plan requirements, ATC procedures and any supplementary route information.

c. Choose suitable SID and STAR procedures.

d. Select suitable Flight Levels by determining upper and lower limits of airways to be used and considering flight profile required.

e. Select suitable diversion (alternate) airfields for use en route and at destinations.

f. Prepare a radio log listing radio frequency for airways control, ATCC sectors, airfield approach, weather broadcasts and emergency assistance.

g. Study taxi patterns at destinations. At airfields operating to all-weather standards, there may be distinct holding points for Cat 1 and Cat 2/3 operations. These holding points are marked on Aerodrome Charts.

h. Select suitable navigation aids.

i. Study airways structure adjacent to route, in anticipation of possible ATC re-routeings.

j. From topographical charts, identify suitable radar check points and features to assist with visual identification of destination and diversion airfields.

k. Prepare a communications failure plan covering all stages of flight from airborne to landing.

l. Identify altimeter setting regions and calculate safety altitudes.

m. Check route and forecast meteorology for any Aircraft Scheduled Performance restrictions, including terrain clearance in event of single-engine failure.

100. **Fuel Planning**. Fuel planning is covered in Volume 9, Chapter 15. Aircrew should allow for wind effect in their planning (a forecast headwind component should be taken into calculation, but where a tailwind component is forecast, use of 'still air' might be prudent). Aircrew should calculate critical point, point of no return and holding allowances as appropriate.

101. **ATC Flight Plan**. An ATC flight plan (F2919/CA48) should be prepared in accordance with the instructions set out in the UK MAPD and in compliance with any national requirements. The flight plan should then be submitted to ATC with the required period of notice.

102. **NOTAMs**. Aircrew must check NOTAMs and Pre-flight Information Bulletins.

103. **Chart Preparation**. Aircrew should highlight the following on their chart, for quick reference:

a. Selected route to destination and alternate/diversion airfields.

b. Selected navigation aids.

c. NOTAMs in close proximity to route.

d. Significant fuel points such as top of climb, top of descent, critical point, point of no return.

e. Regional QNH boundaries and SALT.

104. **Final Preparation**. On the day of departure, aircrew should check the latest meteorological information and NOTAMs prior to flight.

105. **Departure Time**. For flow control purposes, ATC may allocate a calculated take off time (CTOT). In such event, the crew should plan start-up and taxi to make good that time.

Human Factors and Airways Flying

Airways, Instrument and Night flying all rely on the pilot interpreting instruments and procedures to navigate. Modern automatic navigation systems are so accurate and reliable that Airways flying can be boring and monotonous and can lead to a comfy relaxed state where decreased arousal can slip into loss of Situation Awareness.

CHAPTER 31 – AIRFIELD DEPARTURE, ARRIVAL AND APPROACH PROCEDURES

Introduction

1. Instrument procedures and standards have been developed to ensure the highest possible level of safety in flight operations. The main reference document for this annex is No 1 AIDU Terminal Charts, Specification and Legend which is available on the AIDU MilFlip web site. Other reference documents are detailed in paras 2, 4a, 4b, 6a and 6b. The latest editions of these reference documents are authoritative over the content of this annex.

Terminal Chart Standards

2. There are several design standards for Terminal Charts. The main standards that will affect UK aircrew are the ICAO Procedures for Air Navigation Services-Aircraft Operations (PANS-OPS) and NATO Military Instrument Procedures and Standards (MIPS). NATO has expressed the aim to move towards ICAO standards for military flight operations, but ICAO PANS-OPS are not particularly adapted to the unique manoeuvring capability that many military aircraft have. As a result MIPS have been developed. The USA produces the United States Standard for Terminal Instrument Procedures (TERPS). Procedures are also produced under EU-OPS and are issued through the European Aviation Safety Agency (EASA). Individual nations may issue their own standards but where there are differences from PANS-OPS, nations are required by ICAO to publish the details.

3. Although there are several agencies producing instrument procedures, it must be understood that they are primarily designed to provide protection from obstacles by creating protected airspace around the aircraft track. Whichever standards are applied to the design of an instrument procedure, it is important that the procedure is flown as it is depicted on the appropriate chart to ensure that the aircraft does not exceed the boundaries of the protected airspace.

Procedures for Air Navigation Services-Aircraft Operations (PANS-OPS)

4. **Procedures for Air Navigation Services-Aircraft Operations (PANS-OPS)**. Instrument approach procedures for NATO military airfields were designed in accordance with Allied Publications Air Traffic Control (APATC) criteria. NATO nations have now adopted ICAO criteria for procedure design. These ICAO standards are published in two documents, Procedures for Air Navigation Services-Aircraft Operations (PANS-OPS), volumes 1 and 2.

a. **PANS-OPS Vol 1, Flight Procedures**. Volume 1 is intended to provide aircrew with an insight into how instrument procedures are designed and how to adhere to them in flight.

b. **PANS-OPS Vol 2, Construction of Visual and Instrument Flight Procedures**. Volume 2 defines the criteria by which procedures are constructed.

5. **Exceptions to PANS-OPS**. None of the criteria set out in PANS-OPS are binding on an ICAO member but exceptions are published in national AIPs.

Military Instrument Procedures and Standards (MIPS)

6. **Military Instrument Procedures and Standards (MIPS)**. PANS-OPS do not cover all military flying, e.g. TACAN and High-Performance Military Aircraft (HPMA) procedures are not catered for. As a result, additional criteria have been designed to meet NATO requirements which are termed Military

Instrument Procedures and Standards (MIPS). As with PANS-OPS, the NATO criteria are not binding on ICAO member nations, but they are required to publish exceptions in their national Military AIP and also in the Allied Air Traffic Control Publication (AATCP-1). MIPS are described in two documents, which should be consulted to determine the differences:

a. **Allied Flight Procedures Publication (AFPP –1 (A))**. AFPP-1(A) is issued by STANAG 7199 and is intended to provide aircrew with an insight into how instrument procedures are designed and how to adhere to them in flight.

b. **Allied Air Traffic Control Publication (AATCP-1)**. AATCP-1 is issued by STANAG 3759 and defines the criteria by which procedures are constructed.

NATO military airfield instrument procedures designed employing either NATO AATCP-1 or ICAO (PANS-OPS) criteria are identified on the procedure charts as MIPS.

7. The procedures in PANS-OPS Vol I and AFPP-1(A) are intended to be strictly adhered to by flight crews in order to achieve and maintain the highest possible level of safety in flight operations. Flight crews will find pertinent and specific information/exceptions in national civil and military AIPs.

US Terminal Instrument Procedures (TERPS)

8. US Terminal Instrument Procedures (TERPS) philosophy for the construction of procedures differs from PANS-OPS in several areas which affect the way procedures are flown; e.g. turn radius, visual manoeuvring, ILS procedures and the missed approach. In PANS-OPS, aircraft category plays a significant role in affecting the final approach minima. Also, angles of bank and maximum speeds by aircraft category for holding, departures and the initial and intermediate segments of instrument approaches may differ from TERPS.

European Aviation Safety Agency (EASA) EU-OPS

9. Within the European Union (EU) only, EU-OPS have been developed based on the now superseded JAR-OPS. EU-OPS are issued through the European Aviation Safety Agency (EASA).

10. Some authorities issue airfield instrument charts based on EU-OPS criteria. These charts are clearly marked as being designed using EU-OPS criteria.

11. Aircraft Categories are based on the aircraft indicated airspeed at the threshold (V_{AT}) and the values reflect those of PANS-OPS.

12. Under EU-OPS an Instrument Approach (IA) may be commenced if the reported RVR/Visibility is less than the specified minima for landing. However, the IA shall not be continued beyond the Outer Marker (OM) or equivalent, or below 1000 ft above the aerodrome is no OM or equivalent exists. If after passing the OM/1000 ft point, the reported RVR/Visibility falls below the specified minimum, the IA may continue to DA/H or MDA/H and a landing completed if the required visual reference is established and maintained. The touchdown zone RVR is always controlling.

13. The No1 AIDU Terminal Charts Specification and Legend has an explanation of how EU-OPS calculates DA/H, RVR and other visibility criteria with regard to aircraft category and the type of approach. Readers should refer to the AIDU document.

Procedure Identification

14. The publisher of a procedure should identify what criteria a procedure is based on. On No1 AIDU charts, the design authority will be identified under the airfield name and also in the minima table. Some nations use special criteria in the design of procedures. Where these differ significantly from PANS-OPS, the procedure should be marked 'NATIONAL'. When planning to fly such procedures, pilots should consult the relevant national regulations.

Non-standard Procedures

15. The standards used to produce instrument charts are designed to ensure that safe flight operations for all users result from their application. There may be instances where non-standard procedures that deviate from these standards may be approved provided they are fully documented and an equivalent level of safety exists. The appropriate national authority is the approving authority for non-standard procedures. Military procedures that deviate from the standards may not achieve an equivalent level of safety. Where this occurs, they shall be marked 'MILITARY USE ONLY' and also, when applicable, 'NON-STANDARD'.

General Considerations

16. Instrument procedures assume that all engines are operating. All procedures depict tracks, and pilots should maintain the track by adjusting the aircraft heading to counter wind effects. For all pilots, the adherence to the published speeds for their aircraft is vital to remain within protected airspace. It is particularly important for helicopters to maintain minimum speeds as they may be subject to high drift angles which could cause an excursion from protected airspace. Put simply, protected airspace is defined to ensure that aircraft remain at a safe distance, horizontally and vertically, from obstacles.

17. **Track**. Procedure charts depict the track the aircraft is to follow. The track is the projection on the earth's surface of the path of the aircraft, usually expressed in degrees from North specifying true or magnetic. Wind effects must be applied to the aircraft heading to maintain the track. Obstacle clearance is provided assuming the pilot will maintain the depicted track.

18. **Angle of Bank (AOB)**. Unless otherwise specified, the Angle of Bank (AOB) used for PANS-OPS is as follows:

a. Approach procedures are based on an average achieved AOB of 25º or the AOB giving a rate of turn of 3º/sec, whichever is less.

b. Departure and missed approach procedures are based on an average achieved AOB of 15º. MIPS procedures are generally the same but visual climb over airport (VCOA) departures are based on 23º AOB.

c. The AOB for HPMA is 30º for all segments.

d. TERPS procedures are generally based on an AOB of 25º but there are exceptions with regard to circling AOBs which depend upon aircraft category, see Paragraph 54.

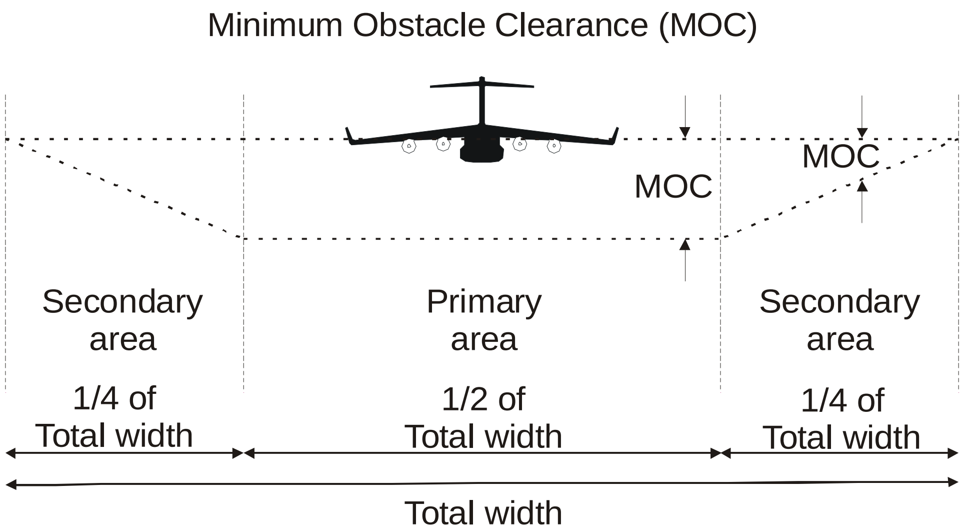
19. **Established on Course**. PANS-OPS defines 'established on course' as being within half full-scale deflection for a VOR/DME or ILS localizer and within ± 5º of the final bearing for an NDB. MIPS apply the same criteria as a VOR/DME for a TACAN procedure. Deviation from these tolerances may reduce the safety margin with regard to obstacle clearance.

20. **Obstacle Clearance**. Obstacle clearance is a primary safety consideration in the development of instrument procedures with defined criteria laid down in PANS-OPS Volume 2. Operationally, the obstacle clearance applied to each procedure is considered the minimum required for an acceptable level of safety. This implies that departing from a procedure will reduce the clearance to an unsafe level.

21. **Protected Airspace**. Where track guidance is provided in a procedure, the volume of protected air around the track is divided symmetrically about the track. The volume of air is divided into Primary and Secondary areas (Fig 1). The Primary area, centred on the track, provides Minimum Obstacle Clearance (MOC) for its whole width. In the Secondary area, which bounds the Primary area on each side, the MOC gradually reduces to zero as the distance from the track increases. The Primary area measures half the total width of the protected area, with one quarter of the protected area forming the Secondary areas either side. The width of the area is determined by the accuracy of the navigational facility that the procedure is based upon and will increase as the distance from the aid increases.

22. **TERPS Protected Airspace**. The protected airspace in TERPS procedures may be determined using different criteria but will follow the general principles of PANS-OPS to provide safe obstacle clearance. TERPS uses the term Required Obstacle Clearance (ROC) vice the PANS-OPS term MOC.

8-31 Fig 1 The Relationship of Minimum Obstacle Clearance in Area Cross Section



23 **Accuracy of Fixes**. Fixes and points used in procedures are normally based upon standard navigation systems. Accuracies will depend upon the tolerances of the ground-based system, the airborne receiving system and the flight technical tolerance. The tolerances used in the production of procedure charts are summarized in Table 1.

Table 1 Summary of Fix Tolerances Used in the Production of PANS-OPS Procedure

Navigation Facility	Tolerance	
Terminal Area Surveillance Radar	± 0.8 nm (*1.5 km*)	Within 20 nm (*37 km*)
En-route Surveillance Radar	± 1.7 nm (*3.1 km*)	Within 40 nm (*74 km*)
DME	± 0.25 nm (*0.46 km*)	+ 1.5 % of distance to antenna
Overhead VOR [1]	or d = 0.033 h *d = 0.2 h*	d and h in nm *d and h in km*

[1] Based on a circular cone of ambiguity generated by a straight line passing through the facility and making an angle of 50º from the vertical.

24. **Flight Management Systems (FMS) and Area Navigation Equipment (RNAV)**. FMS and RNAV equipment may be used to fly conventional procedures provided that the procedure is monitored using the basic display normally associated with that procedure and the tolerances for flight using raw data on the basic display are complied with. Lead radials are for use by non-RNAV equipped aircraft and are not intended to restrict the use of turn anticipation by FMS.

Aircraft Categories

25. Aircraft performance has a direct effect on the airspace and visibility required for the various manoeuvres associated with instrument approach procedures and the most important factor is aircraft speed. It should be noted that the speed ranges specified by category may be different to the category speeds of procedures designed under other criteria. PANS-OPS aircraft categories are summarized in Table 2.

Table 2 Aircraft Categories

Aircraft Category	Velocity at Threshold V_{AT} (kt)	Speed Range for Initial Approach (kt)	Speed Range for Final Approach (kt)	Max Speed Circling (kt)	Max Speed for Missed Approach (kt)	
					Intermediate	Final
A	91	90 to 150 (110)*	70 to 100	100	100	110
B	91 to 120	120 to 180 (140)*	85 to 130	135	130	150
C	121 to 140	160 to 240	115 to 160	180	160	240
D	141 to 165	185 to 250	130 to 185	205	185	265
E	166 to 210	185 to 250	155 to 230	240	230	275
H	N/A	70 to 120**	60 to 90***	N/A	90	90
H(P_{IN}S)	N/A	70 to 120	60 to 90	N/A	70 or 90	70 or 90

* Maximum speed for reversal and racetrack procedures.

** Maximum speed for reversal and racetrack procedures below 6000 ft is 100 kt and above 6000 ft is 110 kt.

*** Helicopter Point in Space (P_{IN}S) procedures.

26. The instrument approach chart (IAC) will specify the individual categories of aircraft for which the procedure is approved. Normally, procedures will be designed to provide protected airspace and obstacle clearance for aircraft up to and including category D. Where airspace requirements are critical procedures may be restricted to lower categories.

27. A procedure may specify a maximum IAS for a particular segment without reference to aircraft category. It is essential that pilots adhere to the approved limits to remain safely clear of obstacles.

British Military Aircraft Categories

28. The Manual of Military Air Traffic Management (MMATM) (Chapter 1) categorizes British military aircraft according to the normal approach speed at DH/MDH (DA/MDA) or V_{AT} + 15 kt, where V_{AT} is the target threshold speed. The speeds are the same as in column 2 of Table 2. Helicopters are Cat A.

Aircraft captains have discretion to move aircraft into a higher or lower category when circumstances dictate a significantly higher or lower approach speed than normal.

High Performance Military Aircraft (HPMA)

29. **High Performance Military Aircraft (HPMA)**. An additional NATO performance category, HPMA, is designed for aircraft meeting the criteria given below and is identified in the procedure title as HPMA. HPMA shall be capable of flying an instrument procedure within the parameters given in the following sub-paras, while adhering to the segment speeds. Performance criteria may be specified that are higher than those given. Such restrictions will be specified, and it is the responsibility of the pilot in command to ensure that the aircraft can fly the actual procedure.

a. Departure: Minimum climb gradient - 8.75 % (5.0º).

b. Initial Approach Segment: Maximum rate of descent – 1000 ft/nm.

c. Bank Angle: Minimum 30º for all segments to be established within 5 sec.

d. Maximum ac dimensions for ILS – wing span 30 m and glide path antenna to wheel base maximum 6 m.

e. Height loss on precision approach transition to missed approach – Maximum 100 ft.

f. Missed Approach Climb Gradient – 6.0 % (3.43º), with a transition time from level flight to the required climb gradient of maximum 10 sec.

g. Aircraft Category: For aircraft performance requirements, all HPMA are contained within one aircraft category.

30. **HPMA Departures**. The Obstacle Identification Surface (OIS) is a sloping surface of 7.95% used by the procedure designer to identify obstacles in the departure area. The origin for straight departures is 16 ft above the Departure End of the Runway (DER). For unidirectional departures, several OISs are considered. HPMA procedures use a standard 8.75% (5º) Procedure Design Gradient (PDG). The PDG origin is the same as the OIS and if the OIS is penetrated, the PDG will be increased and the higher climb gradient published on the procedure. For low, close in obstacles requiring an increased climb gradient to 200 ft or less above the DER, the obstacle(s) will be identified on the procedure by position and height but no climb gradient will be published.

31. **HPMA Speeds**. When constructing the various procedures for HPMA operations, a range of speeds are used to determine the area of protected airspace. Speeds should be annotated on the appropriate chart and pilots should adhere to these (see also Table 3).

Table 3 HPMA Speeds (IAS) for Procedure Calculations in Knots

Aircraft Category	Range of speeds for holding, initial approach, reversal, racetrack, intermediate segment.	Range of final approach speeds.	Max speed visual manoeuvring (circling)	Max speed missed approach (1)	
				Intermediate	Final
HPMA	250/300	90/185	220	300	350

Note: (1) For missed approach, where operationally required to avoid obstacles, reduced speeds as low as 250 kt may be used, provided the maximum speed is clearly noted on the procedure.

32. **HPMA Missed Approach**. The minimum required missed approach climb gradient is 6% (3.4º). The procedure may specify a missed approach turn (more than 15º) when at least 164 ft obstacle clearance is obtained and can be maintained with a minimum climb gradient.

33. **HPMA Visual Manoeuvring (Circling)**. Visual manoeuvring radii are drawn around the runway threshold(s) and joined by tangents to the arcs. The radii depend upon the airfield elevation (3.55 nm at sea level and 3.65 nm at 1000 ft airfield elevation). The protected area is calculated using a maximum speed of 220 kt IAS an AOB of 30º and a wind of ±25 kt. The following criteria also apply to HPMA circling approaches:

MOC ft (m)	Lower limit for OCH above aerodrome elevation ft (m)	Minimum Visibility nm (km)
300 (90)	550 (165)	1.7 (3.2)

34. **Additional Military Criteria.** Additional military criteria are detailed in AATCP-1 NATO Supplement to ICAO Doc 8168-Ops/611 – Vol 2. Some differences are as follows:

a. **ILS/(M)MLS**. For CAT 1 precision approaches (ILS/(M)MLS), a required missed approach climb gradient in excess of 5% (2.86º) may be published at certain locations. These minima will be marked as 'NON-STANDARD' and will be approved by national authorities.

b. **TACAN Final Approach Track Alignment**. In PANS-OPS straight in approaches the maximum angle between the final approach track and the runway centreline is 30º for CAT A/B aircraft and 15º for other categories. MIPS straight in TACAN procedures may be offset up to 30º for all categories.

c. **TACAN Final Approach Centre Line Intercept Distance**. In PANS-OPS the final track must intercept the runway centre line a minimum of 1400 m before the runway threshold. MIPS straight in TACAN procedures may intercept the runway centre line at the runway threshold.

35. **Safe Altitude (100 nm)**. A Minimum Safe Altitude (MSA) should be established within 100 nm (185 km) radius from the Aerodrome Reference Point (ARP). It will provide at least 984 ft (300 m) of obstacle clearance in non-mountainous areas and 1968 ft (600 m) in mountainous areas. When published, the altitudes will be rounded to the next higher 100 ft or 50 m increments. TERPS MSA provides at least 1000 ft of obstacle clearance for emergency use within a specified distance, usually 25 nm, from the facility on which the procedure is based.

DEPARTURES

General

36. In order to ensure acceptable clearance above obstacles during the departure phase, instrument departure procedures may be published as specific routes to be followed or as omnidirectional departures together with procedure design gradients and details of significant obstacles. Departure procedures are in general dictated by the terrain surrounding the airfield, ATC requirements, the location of navigation aids and airspace restrictions. The procedures assume that pilots will not compensate for wind effects when being radar vectored. Pilots are expected to compensate for known or estimated wind effects when flying departure route which are expressed as tracks to be made good.

Runway End Crossing Height or Screen Height

37. For PANS-OPS and MIPS, the origin of the Obstacle Identification Surface (OIS) begins at 16 ft (5 m) above the Departure End of Runway (DER).

Climb Gradient

38. PANS-OPS obstacle clearance during departures is based on a 2.5% gradient obstacle clearance (152 ft/nm) and an increasing 0.8% obstacle clearance (48 ft/nm), This equates to a minimum climb gradient of 3.3% (200 ft/nm). Minimum climb gradients exceeding 3.3% will be specified to an altitude/height after which 3.3% will be used. Unless the procedure specifies otherwise, aircraft should climb on track until reaching 400 ft above the DER at a minimum rate of climb of 200 ft/nm (3.3%) and then continue to climb at the same gradient until reaching a safe en-route altitude.

Omnidirectional Departures

39. The PANS-OPS Omnidirectional Departure is similar to the TERPS Diverse Departure where track guidance is not provided. An omnidirectional departure may be published even though obstacles penetrate the 2.5% Obstacle Identification Surface (OIS). Where this occurs, departure restrictions will apply as detailed in para 42. Where obstacles do not permit the development of omnidirectional procedures it is necessary to fly a SID or to ensure that the ceiling and visibility permit visual avoidance of obstacles.

40. **Beginning of the Departure**. The departure begins at the DER. As the point of lift off will vary, the procedure assumes that a turn at 394 ft (120 m) above the elevation of the airfield is not initiated sooner than 1968 ft (600 m) from the beginning of the runway. Procedures are normally designed/optimized for turns at a point 1968 ft (600 m) from the beginning of the runway. Any variations will be notified on the chart.

41. **Procedure Design Gradient (PDG)**. Unless otherwise stated, departure procedures assume a 3.3% (helicopters 5%) PDG and a straight climb on the extended runway centreline until reaching 394 ft (120 m) (helicopters 295 ft (90 m)) above the aerodrome elevation. Normally, at least 295 ft (90 m) of obstacle clearance is provided before turns greater than 15º are specified.

42. **Departure Considerations**. Omnidirectional departures are designed with the following considerations:

a. **Standard Case**. Where obstacles penetrate the 2.5% OIS and 295 ft (90 m) of obstacle clearance prevails, a 3.3% climb to 394 ft (120 m) will satisfy obstacle clearance requirements for a turn in any direction

b. **Specified Turn Altitude**. Where obstacles preclude omnidirectional turns at 394 ft (120 m) the procedure will specify a 3.3% climb gradient to an altitude where a safe omnidirectional turn can be made.

c. **Specified Climb Gradient**. The procedure may specify a minimum climb gradient of greater than 3.3% to an altitude before turns are permitted.

d. **Sector Departure.** The procedure may identify sectors for which either a minimum turn altitude or a minimum climb gradient is specified, e.g. 'Climb in sector 180º - 270º to 2000 ft before commencing a turn'.

Standard Instrument Departures

43. PANS-OPS uses the term Standard Instrument Departure (SID) to refer to departures using track guidance. A SID is an approved procedure for departing safely from a runway and climbing into the en route or airways structure. Routeing for a SID will be designed to ensure that major obstructions, prohibited and restricted airspace are avoided. It is a departure procedure that is normally developed to accommodate as many aircraft categories as possible but a SID that is limited to specific aircraft categories will be annotated as such. The SID terminates at the first fix/facility/waypoint of the en-route phase following the departure procedure. All tracks, points, fixes and altitudes/heights required in the SID will be published.

44. **Types of SID**. There are two basic types of SID; Straight and Turning.

a. **Straight Departures**. A departure is considered straight if the track is aligned within 15º of the runway centreline. When obstacles exist that affect the departure route, climb gradients greater than 3.3% may be specified and the altitude/height to which it extends will be given. After that point the climb gradient of 3.3% resumes. Increased gradients to a height of 200 ft (60 m) or less caused by close in obstacles are not specified. Details of any such obstacles will be given.

b. **Turning Departures**. Where the departing route requires a turn of more than 15º, a turning departure may be specified using an average AOB of 15º. Straight flight is assumed until reaching an altitude/height of at least 394 ft (120 m) or 295 ft (90 m) for helicopters. Turns may be specified at an altitude/height, at a fix or overhead a facility. If an obstacle prohibits turns before the DER, or prior to reaching an altitude/height, an earliest turning point or a minimum turn altitude/height will be specified. After a turn, it may be necessary to fly a compass heading/track to intercept a specified radial/bearing and the procedure will specify the turning point, the track to be made good and the radial/bearing to be intercepted.

c. **Turning Departure Speeds**. Turning departures are designed with maximum speeds. If the designed speeds are below the standard maximums, they will be published by aircraft category or by a general note. Crews must comply with the published maximum speed to remain within protected airspace. If higher speeds are required for safe aircraft performance, ATC may approve the higher speed or offer an alternative SID. The maximum turning speeds, by aircraft category, are shown in Table 4 and are those of the final missed approach increased by 10%. Any deviation from the published speeds will be annotated on the departure chart.

Table 4 Turning Departure Maximum Speeds (IAS)

Aeroplane Category	Maximum Speed kt
A	225
B	305
C	490
D	540
E	560
H	165

Visual Climb Over Airport (VCOA)

45. Where an aircraft performance does not meet the specified climb gradient, a Visual Climb Over Airfield (VCOA) procedure may be specified. A Visual Climb Area (VCA) is constructed based on the Aerodrome Reference Point (ARP) as the centre of a circle.

a. An omnidirectional VCOA allows for a turn in any direction once a defined altitude is reached. A visual climb must be performed up to this altitude.

b. Where an omnidirectional VCOA is not feasible, a VCOA departure route, after the initial visual climb, may be constructed.

c. Obstacles inside the VCA are subject to see and avoid manoeuvres.

Obstacle Clearance

46. The MOC at the DER equals zero. From that point it increases by 0.8% of the horizontal distance in the direction of flight assuming a maximum turn of 15º. In the turn initiation area and turn area, a MOC of 295 ft (90 m) is provided. The MOC may be increased in mountainous terrain. Whenever a suitably located DME exists, additional height/distance information intended for obstacle clearance may be given. RNAV waypoint or other suitable fixes may be used to provide a means of monitoring climb performance.

Radar Vectors

47. Pilots should not accept radar vectors during departure unless:

a. They are above the minimum altitude(s)/height(s) required to maintain obstacle clearance in the event of engine failure. This relates to engine failure between V_1 and minimum sector altitude or the end of the contingency procedure as appropriate.

b. The departure route is non-critical with respect to obstacle clearance.

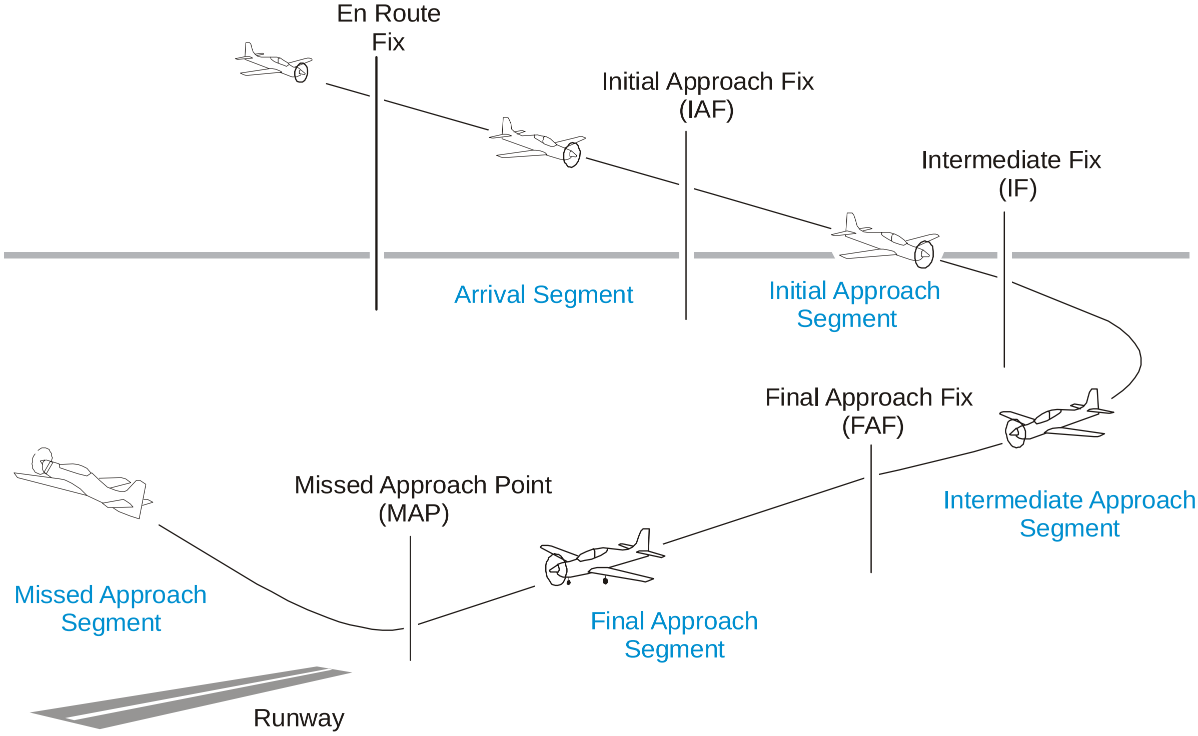
APPROACH AND ARRIVAL PROCEDURES

48. Approach and arrival procedures are in general dictated by the terrain surrounding the airfield, ATC requirements, the location of navigation aids and airspace restrictions. The type of operations contemplated and the aircraft to be accommodated will also be factors in the design of the procedures.

49. The procedures assume that pilots will not compensate for wind effects when being radar vectored. Pilots are expected to compensate for known or estimated wind effects when flying approach routes which are expressed as tracks to be made good.

50. An instrument approach may have five separate segments, arrival, initial, intermediate, final and missed approach (Fig 2). In addition, an area for circling the airfield under visual conditions is also considered.

8-31 Fig 2 The Segments of an Approach



Types of Approach

51. There are two types of approach, straight-in and circling.

a. **Straight-in Approach**. A straight-in approach is aligned with the runway centre line. In the case of non-precision approaches, a straight-in approach is considered acceptable if the angle between the final approach track and the runway centre line is 30º or less.

b. **Circling Approach**. Where terrain or other constraints cause the final approach track alignment or descent gradient to fall outside the criteria for a straight-in approach, a circling approach will be specified.

Circling Approach – Differences between PANS-OPS, MIPS and TERPS

52. PANS-OPS circling protected airspace is typically larger than MILS and TERPS and the obstacle clearance is higher. TERPS also relates AOB to aircraft category. The result is that to use a PANS-OPS circling AOB of 20º, and a higher max circling speed, on a TERPS procedure could cause an infringement of the safe limits. Knowledge of the AOB and maximum speed for the procedure in use is therefore essential.

Table 5 Difference Between PANS-OPS and TERPS

	TERPS		PANS-OPS	
Aircraft Category	Max Circ Speed (kt)	AOB	Max Circ Speed (kt)	AOB
A	90	25º	100	20º
B	120	25º	135	20º
C	140	20º	180	20º
D	165	20º	205	20º
E	210	22º	240	20º

53. PANS-OPS and MIPS procedures require the pilot to maintain visual contact with the runway environment throughout the entire circling manoeuvre. The runway environment means being visual

with such features as the runway threshold, approach lighting aids or other features identifiable with the runway. TERPS circling procedures require the pilot to remain in visual contact with the airport environment, but they only allow descent below the circling MDA/MDH when the runway environment is in sight.

Obstacle Clearance Altitude/Height (OCA/H)

54. For each individual approach procedure and Obstacle Clearance Altitude/Height (OCA/H) is published on the chart. The OCA/H are defined as:

a. In a precision approach procedure, the lowest altitude (OCA) or alternatively the lowest height above the elevation of the relevant runway threshold (OCH), at which a missed approach must be initiated to ensure compliance with the appropriate obstacle clearance criteria.

b. In a non-precision approach procedure, the lowest altitude (OCA) or alternatively the lowest height above aerodrome elevation or the elevation of the relevant runway threshold, if the threshold elevation is more than 7 ft (2 m) below the aerodrome elevation (OCH), below which an aircraft cannot descend without infringing the appropriate obstacle clearance criteria.

c. In a visual (circling) procedure, the lowest altitude (OCA) or alternatively the lowest height above the aerodrome elevation (OCH) below which an aircraft cannot descend without infringing the appropriate obstacle clearance criteria.

55. In mountainous regions or where a Final Approach Fix (FAF) is incorporated into a non-precision approach procedure, and the length of the final approach is in excess of 6 nm (11 km), an additional margin may be applied to the MOC.

OCA/H Adjustment

56. Under certain circumstances, the OCA/H annotated on the procedure chart will have been adjusted from the standard.

a. **Remote Altimeter Setting**. When the altimeter setting is derived from a source other than the aerodrome, and more than 5 nm (9 km) from the threshold, the OCA/H shall be increased. Further adjustment is made in mountainous areas.

b. **Forecast Altimeter Setting**. Where the altimeter setting used in a procedure is based on a forecast value, the OCA/H will be increased. The chart will be annotated as such.

c. **Final Approach Track Intersection**. When the final approach track intersects the extended runway centre line between 5º and 30º the OCA/H is reduced.

d. **Final Approach Track Intersection Greater than 30º**. When the final approach track intersects the extended runway centre line at more than 30º, or the descent gradient exceeds 6.5%, the OCA/H for visual manoeuvring (circling) becomes the lower limit and is applied to the approach procedure.

Descent Minima

57. Descent minima are developed by adding a number of operational factors to OCA/H to produce, in the case of precision approaches, Decision Altitude (DA) or Decision Height (DH) and, in the case of non-precision approaches, Minimum Descent Altitude (MDA) or Minimum Descent Height (MDH).

Descent Gradient

58. In designing IAPs, adequate space is allowed for descent from the facility crossing altitude/height to the runway threshold for a straight-in approach or to OCA/H for circling approaches. This is achieved by establishing a maximum allowable descent gradient for each segment of the procedure. The minimum/optimum descent gradient/angle in the final approach of a procedure with a FAF is 5.2% / 3.0º (316 ft/nm (52 m/km)). Other gradients may be specified.

59. Gradients may be expressed in several forms, either as a Ratio of the rise (vertical height) to the run (horizontal distance), an angle (the Slope) or as a percentage (the Grade). Gradients in relation to aviation may be expressed in one or more of these measurements.

A Ratio will normally be expressed as ft/nm and can be calculated as:

$$\frac{\text{Vertical distance}}{\text{Horizontal Distance}} \qquad \frac{\text{(ft)}}{\text{(nm)}}$$

The Ratio multiplied by 100 will give the Grade:

$$\frac{\text{Vertical distance}}{\text{Horizontal Distance}} \times 100 = \text{Grade (\%)}$$

Gradients in aviation are often expressed as a Grade. To calculate the ft/nm this equates to:

$$\text{Vertical distance} = \frac{\text{Grade (\%)}}{100} \times \text{Horizontal Distance}$$

Visualising the right-angled triangle forming the gradient, there will be an angle between the horizontal plane and the slope. The Tangent of this angle multiplied by 100 will give the Grade. Thus:

$$\text{Tan}\ \alpha \times 100 = \text{Grade} \quad \text{(where } \alpha \text{ is the slope angle)}$$

From this it can be seen that:

$$\text{Slope (in º)} = \text{Arctan}\ \frac{\text{Grade (\%)}}{100}$$

Example: Given a grade of 5.2%

$$\text{Vertical distance} = \frac{5.2}{100} \times 6076 \quad \text{(a)}$$

(a) 6076 ft = 1 nm

Thus: Vertical distance = 316 ft and the ratio will be 316 ft/nm

And:

$$\text{Slope (in º)} = \text{Arctan}\ \frac{5.2}{100}$$

Thus: The Slope = 2.98º

Rounding the figures for gradients in the aviation context:

A Grade of 5.2% equates to a Slope of 3º and a Ratio of 300 ft/nm

Procedure Altitude/Height

60. In addition to minimum IFR altitudes established for each segment of the procedure, procedure altitudes/heights will also be provided. Procedure altitudes/heights will, in all cases, be at or above any minimum crossing altitude associated with the segment. Procedure altitude/height will be established taking into account the air traffic control needs for that phase of flight.

61. Procedure altitudes/heights are developed to place the aircraft at altitudes/heights that would normally be flown to intercept and fly an optimum 5.2 per cent (3º (300 ft/nm)) descent path angle in the final approach segment to a 50 ft (15 m) threshold crossing for non-precision approach procedures and procedures with vertical guidance. In no case will a procedure altitude/height be less than any OCA/H.

ARRIVAL SEGMENT

62. A standard instrument arrival (STAR) route permits transition from the en-route phase to the approach phase. The arrival route normally ends at the Initial Approach Fix (IAF). Omnidirectional or sector arrivals can be provided taking into account Minimum Sector Altitudes (MSA). Minimum sector altitudes or terminal arrival altitudes are established for each aerodrome and provide at least 1 000 ft obstacle clearance within 25 NM of the navigation aid, initial approach fix or intermediate fix associated with the approach procedure for that aerodrome. When terminal area radar is employed, the aircraft is vectored to a fix, or onto the intermediate or final approach track, at a point where the approach may be continued by the pilot by referring to the instrument approach chart.

INITIAL APPROACH SEGMENT

63. The initial approach segment begins at the IAF and ends at the Intermediate Fix (IF). Aircraft speed and configuration will depend on the distance from the aerodrome, and the descent required. Normally track guidance is provided along the initial approach segment to the IF, with a maximum angle of interception of 90° for a precision approach and 120° for a non-precision approach. The initial approach segment provides at least 1 000 ft of obstacle clearance in the primary area reducing laterally to zero at the outer edge of the secondary area.

64. Under PANS-OPS criteria, the optimum descent gradient is 4.0% (250 ft/nm) (Cat H 6.5% (400 ft/nm)). Where a higher descent gradient is necessary to avoid obstacles, the maximum permissible is 8.0% (500 ft/nm)(Cat H 10 %(600 ft/nm)). At locations where high altitude procedures provide an operational advantage for military operations (HPMA) the optimum descent gradient is 13.1% (800 ft/nm). The maximum permissible descent gradient is 16.4% (1000 ft/nm).

Reversal Procedure

65. Where no suitable IAF or IF is available to construct the instrument procedure in the form shown in Fig 2, a reversal procedure, racetrack or holding pattern is required. The reversal procedure may be in the form of a procedure or base turn. Entry is restricted to a specific direction or sector. In these cases, a specific pattern, normally a base turn or procedure turn, is prescribed. The direction and timing specified must be adhered to so as to remain within the protected airspace. There are three generally recognised manoeuvres related to the reversal procedure.

a. **45º/180º Procedure Turn**. The 45º/180º procedure turn (Fig 3) starts at the facility and consists of:

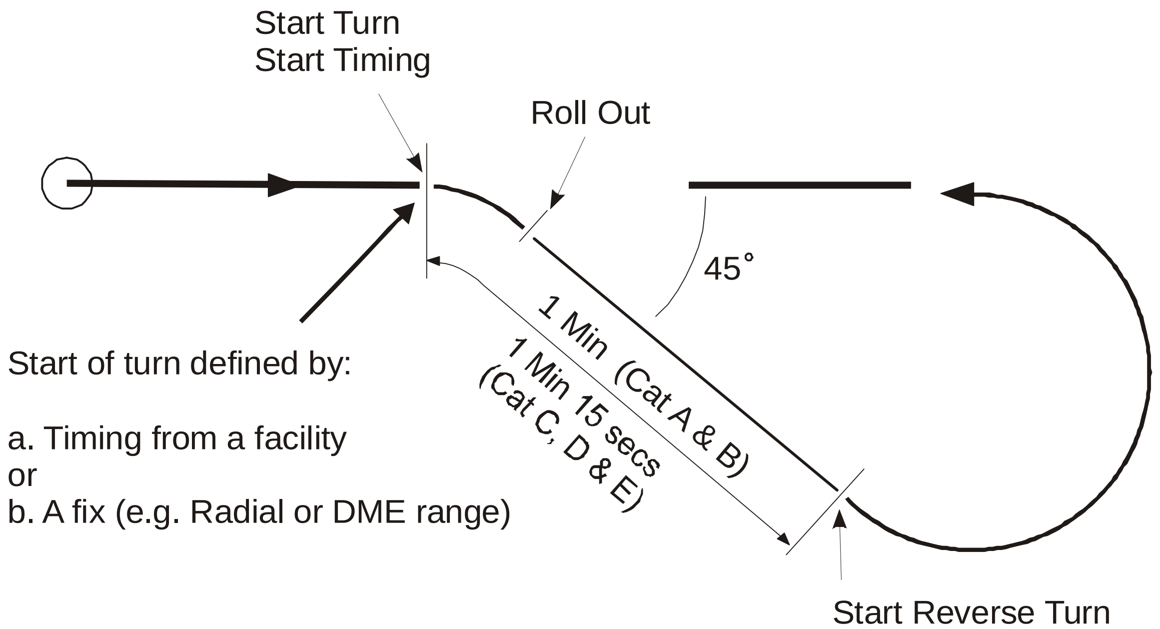
i. A straight leg with track guidance, either timed or limited by a radial or DME distance.

ii. A 45º turn.

iii. A timed straight leg, without track guidance, of 1 min for Cat A and B aircraft and 1 min 15 sec for Cat C, D and E aircraft, from the start of the turn.

iv. A 180º turn in the opposite direction to intercept the inbound track.

8-31 Fig 3 45º / 180º Procedure Turn



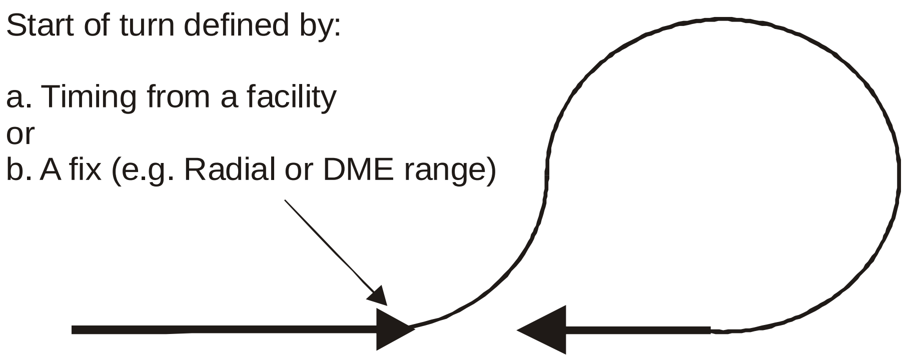
b. **80º/260º Procedure Turn**. The 80º/260º procedure turn (Fig 4) starts at the facility and consists of:

i. A straight leg with track guidance, either timed or limited by a radial or DME distance.

ii. An 80º turn.

iii. A 260º turn in the opposite direction to intercept the inbound track.

8-31 Fig 4 80º / 260º Procedure Turn

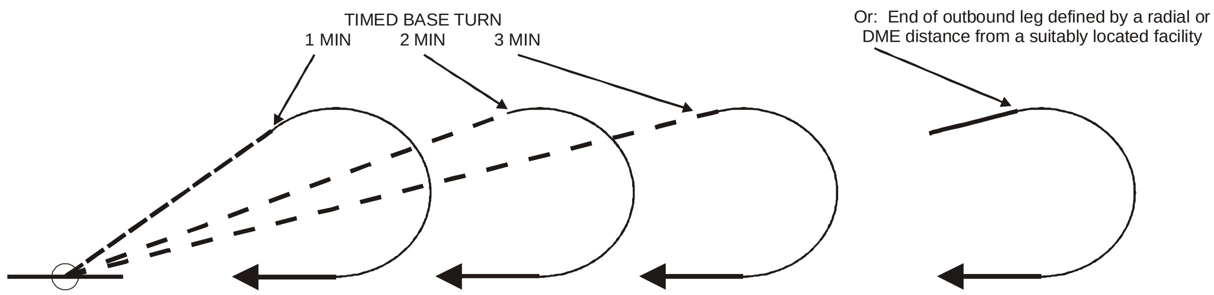


c. **A Base Turn**. A Base Turn (Fig 5) consisting of:

i. A specified outbound track and timing or DME distance from a facility. Followed by:

ii. A turn to intercept the inbound track.

8-31 Fig 5 A Base Turn



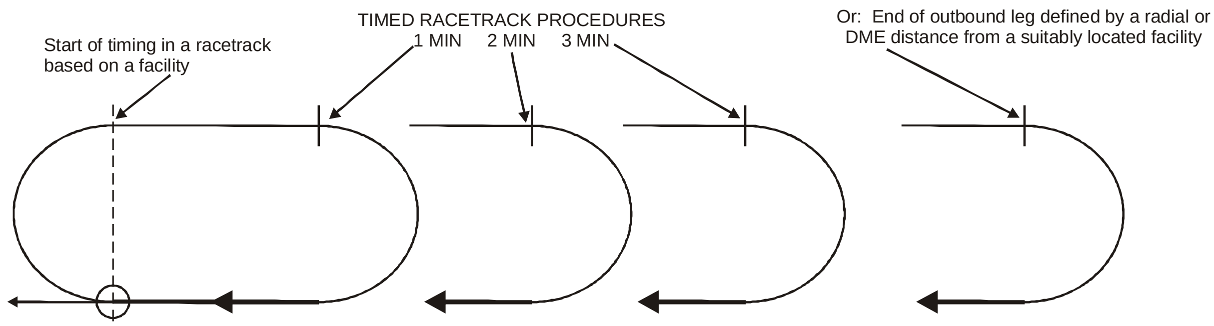
Racetrack Procedure

66. A racetrack procedure (Fig 6) is used where sufficient distance is not available in a straight segment to accommodate the required loss of altitude and when entry into a reversal procedure is not practical. It is not a holding procedure. The racetrack is used when aircraft arrive overhead a fix from various directions and consists of:

a. A turn from the inbound track through 180º from overhead the facility or fix onto the outbound track for 1, 2 or 3 minutes. Alternatively, the turn may be limited by a DME distance or radial rather than timing. Followed by:

b. A 180º turn in the same direction to return to the inbound track.

8-31 Fig 6 A Racetrack Procedure



67. **Entry into a Racetrack Procedure**. Aircraft entering (Fig 7) a racetrack procedure are expected to enter the procedure in a manner similar to that prescribed for a holding procedure entry (Fig 8) with the following considerations:

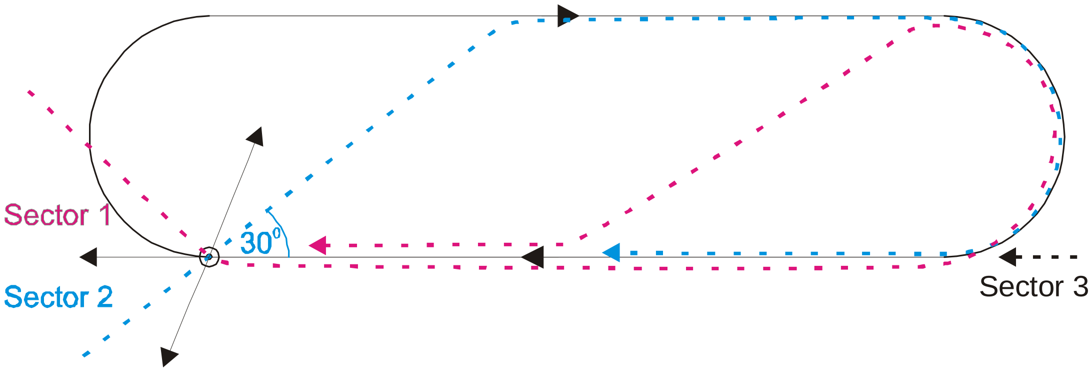
a. An offset entry from Sector 2 shall limit the time on the 30º offset track to 1 min 30 sec, after which the pilot is expected to turn to a heading parallel to the inbound track for the remainder of the outbound time. If the outbound time is only 1 min the time on the 30º offset track shall be 1 min also.

b. A Parallel entry shall not return directly to the facility without first intercepting the inbound track when proceeding to the final segment of the procedure.

c. All manoeuvring shall be done in so far as possible on the manoeuvring side of the inbound track.

Note: The procedures for entry are as above unless other restrictions are specified.

8-31 Fig 7 A Racetrack Entry Procedures



Hold Entry Procedures

68. Entry into the holding pattern shall be according to heading in relation to the three entry sectors (Fig 8) recognising a zone of flexibility of 5º either side of the sector boundaries.

69. **Sector 1 Procedure (Parallel Entry)**. On reaching the fix, the aircraft is turned onto the outbound heading for the appropriate time or DME limiting distance (if published). The aircraft is then turned onto the holding side to intercept the inbound track or return to the fix. On the second arrival over the holding fix the aircraft is turned to follow the holding pattern.

70. **Sector 2 Procedure (Offset Entry)**. On reaching the fix, the aircraft is turned onto a heading to make good a track making an angle of 30º from the reciprocal of the inbound track on the holding side.

a. The aircraft will fly outbound:

i. For the appropriate period of time, where timing is specified, or

ii. Until the limiting DME distance is reached (where specified), or

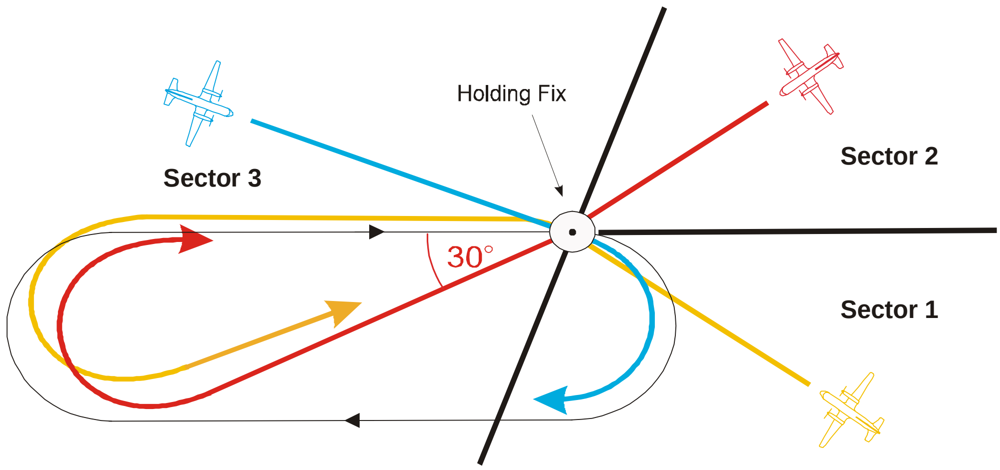
iii. Where a limiting radial is also specified, either until the limiting DME distance is reached or until the limiting radial is encountered, whichever occurs first.

b. The aircraft is turned to intercept the inbound holding track.

c. On the second arrival over the holding fix, the aircraft is turned to follow the holding pattern.

71. **Sector 3 Procedure (Direct Entry).** Having reached the fix, the aircraft is turned to follow the holding pattern.

8-31 Fig 8 Entry to a Holding Procedure



72. **DME Arc Entry.** A DME arc entry procedure will only be specified when there is a specific operational difficulty which precludes the use of other entry procedures. On reaching the fix, the aircraft shall enter the holding pattern using either the Sector 1 or Sector 3 entry procedure.

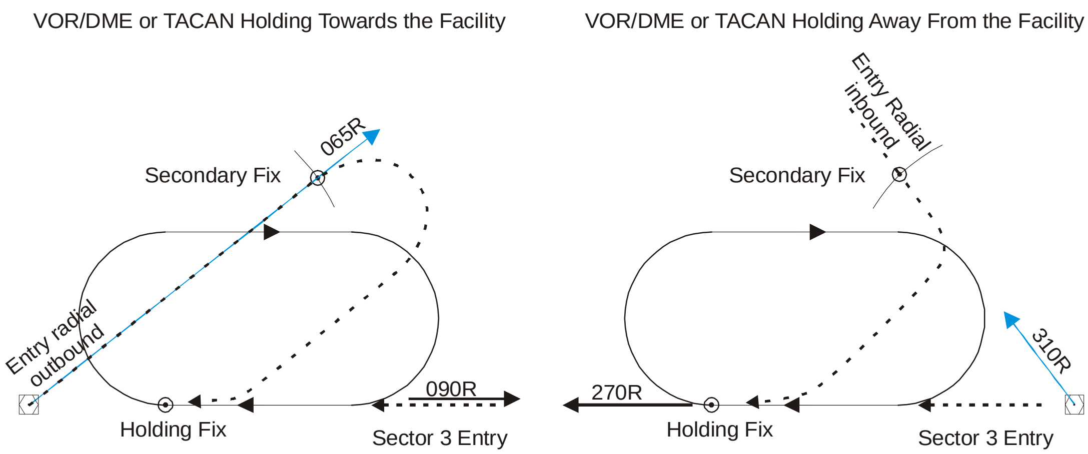
Cone of Ambiguity

73. There is an area directly above a directional beacon where the received signal will be lost. This area is known as the Cone of Ambiguity or Cone of Silence. VOR has a cone of ambiguity of 50º while a TACAN has one of 60º. Holding fixes therefore are not usually placed overhead the beacon, but low altitude holds may be overhead the beacon.

Special Entry Procedure for VOR/DME or TACAN Holding

74. Where an entry radial to a secondary fix of a VOR/DME or TACAN holding pattern is specified (Fig 9), Sector 1 and 2 entries are not authorised. The holding pattern is entered via the published radial or the Sector 3 procedure. On reaching the fix, the aircraft is turned to follow the holding pattern. Some British military airfields have exceptions to this and those procedures are clearly annotated on the appropriate chart.

8-31 Fig 9 VOR/DME and TACAN Holding



The arrival to the holding pattern may be along the axis of the inbound track, along a published track or by radar vectoring. The entry point may be via the holding fix or via the secondary fix.

75. PANS-OPS describes several other methods of entry to VOR/DME holding patterns. These are detailed on the appropriate chart. Further guidance can be found in the AIDU Terminal Charts Specification and Legend.

76. The outbound heading is flown for one minute if below FL 140 or one and a half minutes if above FL 140. The length of the outbound leg may be specified in terms of a DME distance instead.

Table 6 Holding Speeds

<table>
<tr><td colspan="4">Holding patterns are to be entered and flown at or below the following indicated airspeeds</td></tr>
<tr><td>Levels (Altitude or Flight Levels)</td><td colspan="2">Normal Conditions</td><td>Turbulence Conditions</td></tr>
<tr><td>Up to 14000 ft</td><td colspan="2">230 kt [1]
170 kt [3]</td><td>280 kt [2]
170 kt [3]</td></tr>
<tr><td>Above 14000 ft to 20000 ft inclusive

Above 20000 ft to 34000 ft inclusive</td><td colspan="2">240 kt [4]

265 kt [4]</td><td>280 kt
Or
0.8 Mach
(whichever is less) [2]</td></tr>
<tr><td>Above 34000 ft</td><td colspan="2">0.83 Mach</td><td>0.83 Mach</td></tr>
<tr><td colspan="4">1. When a holding speed in the initial segment of the approach procedure is higher, the holding speed may be increased.
2. These speeds may be used with prior ATC clearance.
3. For Cat A and B aircraft only.
4. Wherever possible, 280 kt should be used for holding procedures associated with airway route structures.</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="4">Helicopter Procedures</td></tr>
<tr><td colspan="2">Maximum speed up to 6000 ft</td><td colspan="2">100 kt</td></tr>
<tr><td colspan="2">Maximum speed above 6000 ft</td><td colspan="2">170 kt</td></tr>
<tr><td colspan="4">All turns are to be made at an AOB of 25º or rate of 3º/sec, whichever requires the lesser bank</td></tr>
</table>

Flight Procedures for Racetrack, Reversal and Holding Procedures

77. Unless otherwise specified, entry to a reversal procedure shall be from a track within ±30º of the outbound track of the reversal procedure. For Base Turns, where the ±30º direct entry sector does not include the reciprocal of the inbound track the entry sector is expanded to include it.

78. **Speeds**. Speeds may be specified in addition to, or instead of, aircraft category restrictions. To ensure the aircraft remains within the protected area speeds must not be exceeded.

79. **Bank Angle**. Procedures are based on an average bank angle of 25º, or the bank angle giving a rate of turn of 3º/sec, whichever is less.

80. **Descent**. Aircraft shall cross a fix or facility on the specified track, descending as necessary to the procedure altitude/height while adhering to altitude/height restrictions associated with that segment. If

a further descent is specified after the inbound turn, it shall not be commenced until the aircraft is established on the inbound track. An aircraft is considered to be established when it is within half full-scale deflection for the ILS and VOR, or, within ±5º of the required bearing for the NDB.

81. **Timing**. When a procedure is based upon a facility, the outbound timing starts from abeam the facility, or, on attaining the outbound heading, whichever comes later. When a procedure is based on a fix, the outbound timing starts from attaining the outbound heading. The turn onto the inbound track should be started:

a. Within the specified time (adjusted for wind), or

b. When reaching a specified DME distance, or

c. When a radial/bearing specifying a limiting distance has been reached.

Whichever occurs first.

82. **Wind Effect**. To achieve a stabilised approach, due allowance should be made in both heading and timing to compensate for the effects of wind. Any limiting DME distances always terminate the outbound leg.

a. **Drift**. As drift allowance cannot be applied during the turns, 3 times the drift (up to a maximum of 30º) is allowed on the outbound leg. One times the drift is applied on the inbound leg. The bank may be varied (up to 25º or rate 1, whichever is the lesser bank) during the final part of the inbound turn to roll out on the desired track. For TACAN holds, or holds longer than 4 minutes in total, 2 times the drift is applied when outbound.

b. **Timing**. It is necessary to know or estimate the head/tail wind component on the outbound leg in order to correct the timing. Allow 1 second (1.5 seconds if above FL 140) per 2 kt of wind component; this should be added to the standard time for a headwind or subtracted for a tailwind. Note that timing action starts abeam the beacon.

83. **Descent Rates**. The specified timings and procedure altitudes are based on rates of descent (ROD) that do not exceed the following:

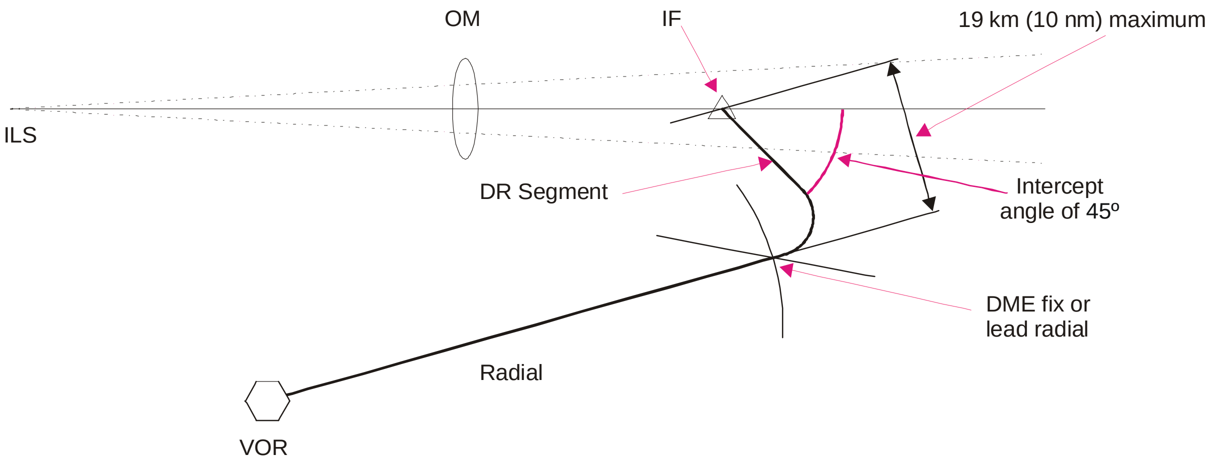
Table 7 Rates of Descent

Outbound Track	***Maximum ROD***	***Minimum ROD***
Category A/B	245 m/min (804 ft/min)	N/A
Category C/D/E/H	365 m/min (1197 ft/min)	N/A
Inbound Track	***Maximum ROD***	***Minimum ROD***
Category A/B	200 m/min (655 ft/min)	120 m/min (394 ft/min)
Category H	230 m/min (755 ft/min)	N/A
Category C/D/E	305 m/min (1000 ft/min)	180 m/min (590 ft/min)

84. **Shuttle**. There may be occasions where the required ROD between the end of the initial approach and the beginning of the final approach exceeds the values given above. In this case, a Shuttle may be prescribed, which is defined as a descent or climb conducted in a holding pattern.

85. **Dead Reckoning (DR) Segment**. An ILS procedure may include a dead reckoning (DR) segment from a fix to the localizer (Fig 10). The DR track will intercept the localizer at 45º and will not be more than 10 nm (19 km) in length. The point of interception is the beginning of the intermediate segment and will allow for proper glide path interception.

8-31 Fig 10 Dead Reckoning Segment



INTERMEDIATE APPROACH SEGMENT

General

86. During this segment the aircraft speed and configuration should be adjusted to prepare for the final approach. As such, the descent gradient is kept as shallow as possible. The obstacle clearance requirement reduces from 984 ft (300 m) to 492 ft (150 m) in the primary area, reducing laterally to zero at the outer edge of the secondary area. Where a final approach fix (FAF) is available, this segment begins when the aircraft is on the inbound track of the procedure turn, base turn or final inbound leg of the racetrack procedure. It ends at the FAF or final approach point (FAP) as applicable. Where no FAF is specified, the inbound track is the final approach segment.

FINAL APPROACH SEGMENT

General

87. The final approach segment is where alignment and descent for the landing are made. This may be to a runway for a straight in landing or to an aerodrome for a visual manoeuvre.

Approach Minima

88. **Approach Minima**. At the end of an instrument approach (with the exception of approved blind-landing systems approaches), the pilot must transfer from flight instruments to visual references for the landing. The required visual references are defined in the Manual of Military Air Traffic Management (Chapter 1). The minimum height for descent on instruments is pre-calculated and will be a Decision Height (DH)/Decision Altitude (DA) for a 'precision' approach, or a Minimum Descent Height (MDH)/Minimum Descent Altitude (MDA) for a 'non-precision' approach.

Determination of Decision Altitude (DA) or Decision Height (DH)

89. The DA/DH is calculated and depends upon several factors. These factors include aircraft category and performance, and the type of approach (e.g. ILS or MLS). The allowance made for these factors is applied to the OCA/H to determine the DA/DH. PANS-OPS references precision approaches to threshold elevation. MILS modifies this for PAR where TDZE is used as the datum. Thus, for a runway served by an ILS CAT 1 and a PAR, both operating at system minima, the DH on both AIDU charts would be 200ft but the DA on each chart may differ if the TDZE is higher than the threshold elevation.

90. The rules for calculating DH/DA by British military pilots, as described in the MMATM (Chapter 23), detail additional allowances that may be applied to the basic procedure minima. The pilot instrument rating, any Command allowance and, where appropriate, an engine out allowance must be applied. Allowances specific to aircraft type must also be taken into account. They will be laid down in the Aircrew Manual/Pilot's Notes and may consist of Pressure Error Correction, Temperature Error Correction, Helicopter Type Allowance and Standby Pressure Instrument Allowance.

Calculation of DH/DA for Precision Approaches

91. The DH/DA for precision approaches for fixed-wing aircraft is calculated as follows:

a. With full power available, the procedure minimum is obtained, and Master Green and Green rated pilots add this to any Command allowance to obtain their minimum. White and Amber rated pilots will further add any appropriate allowances to this minimum.

b. With one or more engines inoperative an appropriate engine-out allowance will be added to the DH/DA calculated at sub-paragraph a.

92. All AIDU procedures are for fixed-wing aircraft. All helicopters may operate down to 50 ft below the published minimum for fixed-wing Cat A aircraft as a baseline. Pilots will add any Command or rating allowance to this.

Calculation of MDH/MDA for Non-Precision Approaches

93. For fixed-wing Aircraft with full power available or with one or more engines inoperative, the procedure minimum for non-precision approaches will be calculated in accordance with the procedure detailed in Paragraph 91. Engine out allowance is not added directly to MDH/MDA but will be taken into account to avoid descending below this height/altitude. While a stepfix is employed in the final approach, any rating allowance is ignored in calculating the minimum height/altitude at the fix point.

94. The procedure minima for helicopters carrying out non-precision approaches will be calculated in accordance with the procedure detailed in Paragraph 92, excepting that the dispensation to subtract 50 ft from the minimum for category 'A' fixed-wing aircraft does not apply to non-precision approaches.

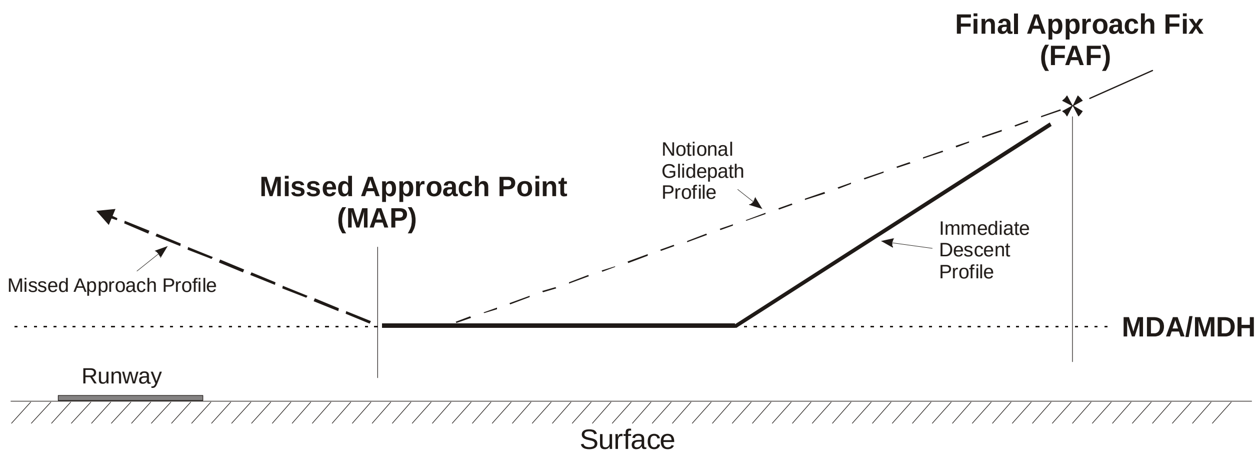
Types of Final Approach

95. The criteria for the final approach vary according to the type of approach. The different types of approach are:

a. **Precision Approaches**. A precision approach is an instrument approach using a facility which provides both azimuth and electronic glide-slope information. Precision Approach Radar (PAR), Instrument Landing System (ILS) and Microwave Landing System (MLS), when fully serviceable, are classed as precision approach aids. PAR procedures are not published in TAPs as they are passed by RT. On a precision approach, the aircraft is permitted to descend on the glidepath down to the declared DH/DA; the options at this point are either to continue the landing visually (if the required visual references are available), or to fly the Missed Approach procedure.

b. **Non-precision Approaches**. An instrument approach using a procedure which does not employ electronic glide-slope information is classed as a 'non-precision' approach. For such a procedure, the pilot will calculate an MDH/MDA. During the final approach segment, a descent to MDH/MDA is permitted from the Final Approach Fix (FAF), by flying either a notional glidepath profile or an immediate descent profile (see Fig 11). In the latter case, the maximum rate of descent allowed is 800 ft/nm (2,400 ft/min) in zero wind at 180 kt IAS. If an immediate descent profile is not permitted, it will be stated in the TAP. Descent below MDH/MDA is only permitted when the required visual references are obtained. Where the visual references are not available, the pilot must initiate the Missed Approach procedure no later than at the Missed Approach Point.

8-31 Fig 11 Descent Profiles - Non-Precision Approach



Non-precision Approach - General

96. PANS-OPS references non-precision approaches to airfield elevation. Where the runway threshold is more than 7 ft below the reference elevation, the MDA/MDH calculation for a non-precision approach will be referenced to the runway threshold elevation instead and a note will be added to the chart.

97. The Missed Approach Point (MAPt) for a non-precision approach is defined either by a fix, a facility or by timing and is shown in plan and profile on the chart. When it is based on a facility or fix, timing shall not be used. AIDU non-precision charts show the timing from the FAF/FAP to the MAPt.

Continuous Descent Final Approaches

98. The Continuous Descent Final Approach (CDFA) is the standard profile view depicted on No 1 AIDU TAP charts for non-precision approaches.

99. Controlled flight into terrain (CFIT) is a major hazard in aviation, and evidence has shown that the majority of civilian CFIT accidents occur in the final approach segment of non-precision

approaches (NPA). The elimination of level flight segments at MDH/A and any major changes in power/thrust or configuration close to the runway, both of which can destabilise approaches, have been seen as ways to reduce the operational risk of CFIT and runway excursions. EASA legislation in the civilian fixed-wing sector has mandated that all approaches are flown using the Stabilised Approach (SAp) technique. A SAp is flown in a controlled and appropriate manner in terms of configuration, energy and control of flight path from a pre-determined point or altitude/height down to a point 50 feet above the threshold or the point where the flare manoeuvre is initiated if higher. The CDFA technique was introduced to ensure a NPA can be flown as a SAp.

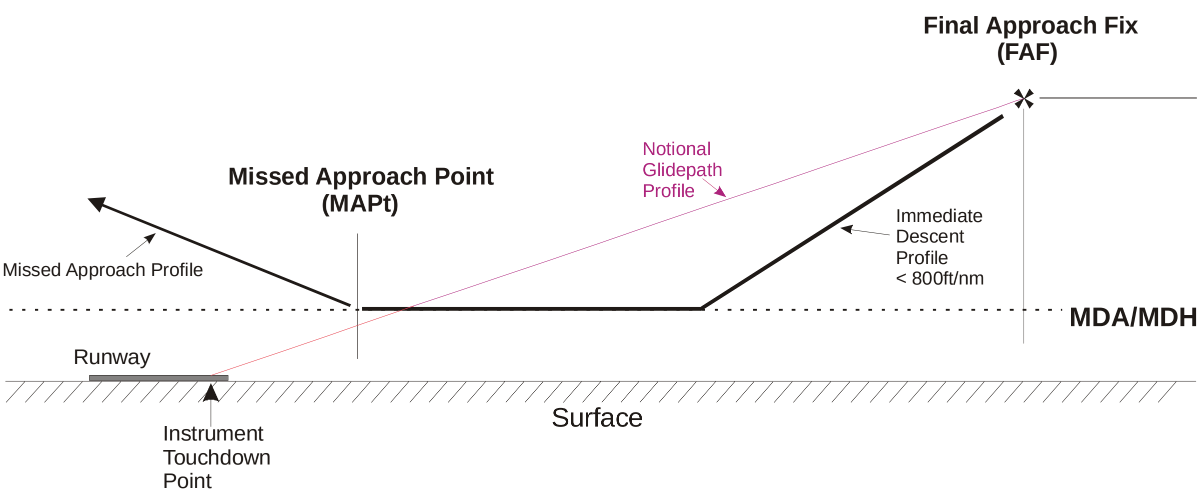
100. Without the glide-path information that is available on a precision approach, the traditional methods of flying a NPA are:

a. **Notional Glidepath**. A descent is started at or after the Final Approach Fix (FAF) to fly a vertical profile that approximates to that of a precision approach, such as the ILS. Use can be made of a table of heights against distance, a calculated rate of descent, or ATC advice to maintain the notional glidepath. During the approach, checks are required to ensure that the ac does not go below any step-down fixes specified in the procedure. At the bottom of the approach the ac should be levelled at or above the MDH/A and flown towards the Missed Approach Point (MAPt). (See Fig 12)

b. **Immediate Descent**. A descent is started at the FAF, using a maximum rate of 800 ft/nm, towards the approach minima or any intervening step-down height. The aircraft is then flown level until a lower height is allowed by the procedure, or the MAPt is reached. This technique is sometimes colloquially known as 'dive and drive'. (See Fig 12)

101. When the required visual references are obtained, the approach to touchdown can then be continued visually. This is where the key problem with large commercial aircraft flying NPAs often manifests itself; whilst the MAPt is the last point on the NPA at which a go-around may be safely commenced, it is not always possible to continue with a visual approach to the runway from there. Indeed, there are examples where the MAPt is directly above the threshold or even considerably beyond it. In those cases, it is unwise or impossible for an aeroplane to safely convert to a visual approach at the MAPt, although circling options may be available.

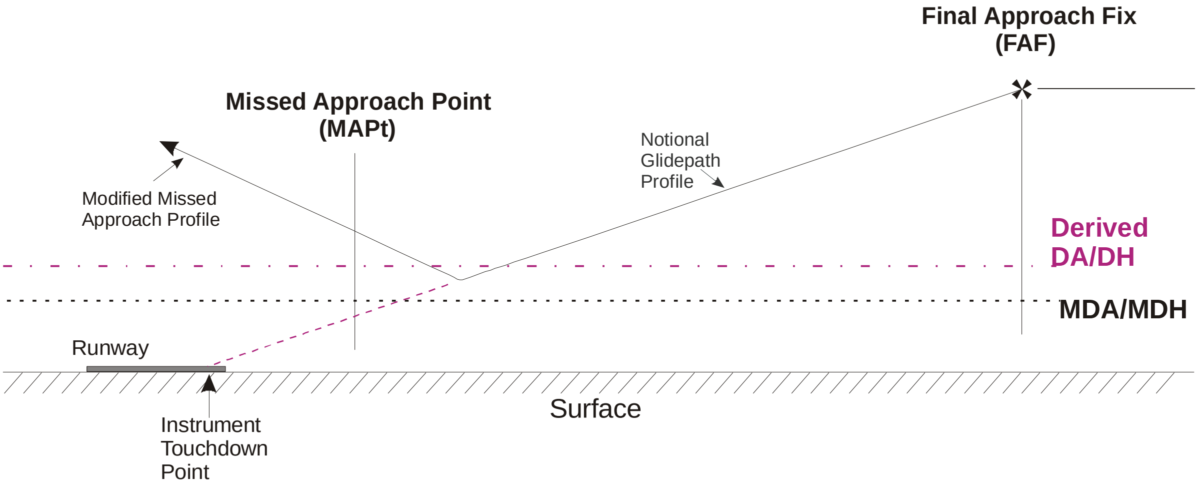
8-31 Fig 12 Descent Profiles – Non CDFA



CDFA Technique

102. The CDFA technique removes the potentially hazardous temptation to continue with an approach to touch-down from an inappropriate position. The final approach is flown with a notional glidepath that is calculated to give a continuous descent, without level offs, that respects all of the step-down fixes and will put the aircraft in a position to land safely. An allowance is added to the MDH/A to calculate a derived DH/A. A decision is made, approaching the derived DH/A, on whether the pilot has the required references to continue visually. If not, a go-around is commenced sufficiently early to ensure the aircraft does not descend below the approach minima. No attempt is made to level off at MDA/H and fly in towards the MAPt. In effect the CDFA NPA is flown like a precision approach with a DH/A, although it is important to remember it is still based on the underlying NPA procedure design and so there is no allowance for the aircraft to go below MDH/A whilst executing the go-around procedure. (See Fig 13).

8-31 Fig 13 Descent Profiles – CDFA



103. The height allowance required to carry out the initial go-around actions without descending below the MDH/A will vary according to aircraft type, and possibly vary further by configuration and serviceability. Type specific orders will specify the allowance to be added to the MDH/A to create a derived DH/A which is then used as the approach minima and passed to ATC if required.

104. When flying the approach to a derived DH, pilots should still be aware of the normal MAPt, and go-around if it is reached first. More usually the decision will be made before the original MAPt. In this case the aircraft should climb whilst continuing laterally towards the MAPt before commencing any turns, unless there is an overriding explicit ATC Clearance to turn earlier.

105. Aircrew may use other aids to assist in flying the NPA as a CDFA, for example a DME or RNAV derived distance against height table or ATC advisory heights on an SRA which can provide guidance to maintain a constant descent angle. These do not equate to the electronic glidepath information of a precision approach and as such they only offer guidance to the pilot and the limits of the underlying approach, such as step-fixes, should still be monitored and complied with.

Non-CDFA

106. There may be occasions when it is neither possible nor practical to fly a NPA as CDFA. If CDFA has been directed as the normal way of flying approaches regulations may permit the approach to be flown using one of the traditional techniques, although the problem of unstable approach segments will potentially be present (Fig 14a). The option to do this may be restricted to certain circumstances or

airfields, or the discretion may be given to aircraft commanders. With the aircraft flying level at MDH/A regulations may direct an increase to the minimum required visibility in order to allow earlier acquisition of the visual references and a safe transition to the normal descent path (Fig 14b).

8-31 Fig 14 Non CDFA to Published MAPt & RVR and Non CDFA with Increased RVR

Fig 14a Non CDFA to Published MAPt & RVR

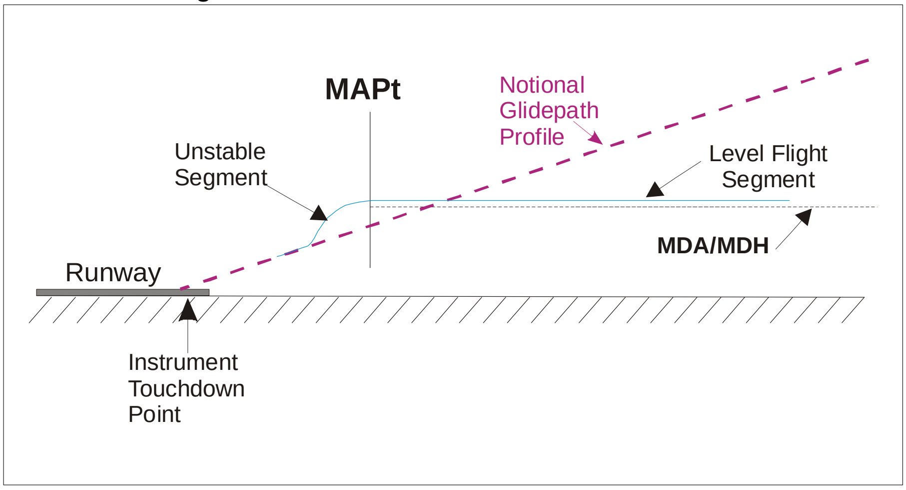
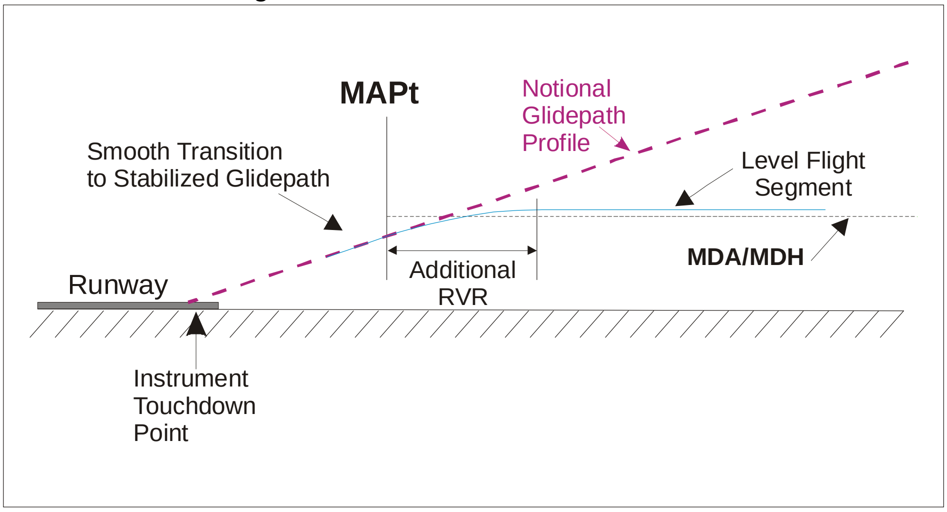


Fig 14b Non CDFA with Increased RVR



107. Some instrument TAPs present differing approach minima for CDFA and non-CDFA options. These only account for the additional visibility requirements, and importantly do not add to the original MDH/A as the vertical allowance depends on aircraft type and performance. Some TAPs have been modified to display a DH/A on the TAP. If regulations require an additional vertical increment for CDFA then this is added to the promulgated procedure minima for all NPA regardless of the publisher. Equally important for helicopter operators, who are normally allowed to subtract 50 ft from the published DH/A on precision approaches, is that this rule does not apply to NPA flown using CDFA techniques. In multi-crew aircraft the approach briefing should clearly state how the approach will be flown and the minima being used.

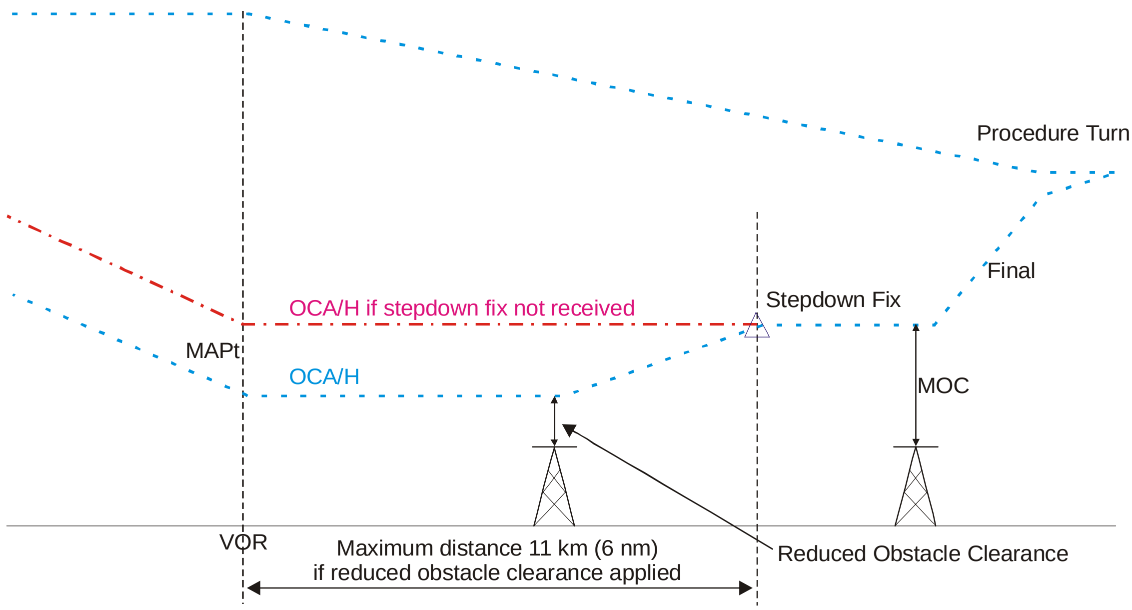
Non-precision Approach with a Final Approach Fix

108. **Non-precision Approach with a Final Approach Fix**. This segment begins at a facility or fix (FAF) and ends at the missed approach point (MAPt). The FAF is on the final approach track at a distance that permits selection of final approach configuration and descent to the appropriate MDA/H.

A non-precision approach provides the optimum final descent gradient of 5.2% or 3º (ROD 318 ft/nm (52 m/km)). The FAF is crossed at the procedure altitude/height in descent but no lower than the minimum crossing altitude associated with the FAF under ISA conditions. Delaying the descent until the FAF will cause a ROD greater than 3º.

109. **Stepdown Fixes**. A stepdown fix may be incorporated into a non-precision approach procedure. In this case, two OCA/H values are published; a higher value applicable to the primary procedure and a lower value applicable only if the stepdown fix is positively identified during the approach. Normally only one stepdown fix is specified. In the case of a VOR/DME procedure, several DME fixes may be depicted, each with its own associated minimum crossing altitude.

8-31 Fig 15 Stepdown Fix



110. **Stepdown Fix with DME**. Where a stepdown procedure uses a suitable DME, the pilot shall not commence descent until established on the specified track. Once on the track, descent shall begin while maintaining the aircraft at or above the published DME height/distance requirements.

Non-precision Approach without a Final Approach Fix

111. There may be instances where an aerodrome is served by a single facility, on or near the aerodrome, and no other facility is suitable for a FAF. A procedure may be designed in this case where the facility is both the FAF and the MAPt. These procedures indicate a minimum altitude/height for a reversal procedure or racetrack and also an OCA/H for the final approach.

112. In the absence of a FAF, descent to MDA/H is made once the aircraft is established inbound within 5º of the final approach track. In these procedures, the final approach track cannot normally be aligned on the runway centre line. Whether OCA/H for straight-in approach limits are published or not depends on the angular difference between the track and the runway and position of the track with respect to the runway threshold.

Precision Approach

113. Precision Approach Radar (PAR). A PAR is a precision approach system. Failure of the azimuth and range information renders the entire PAR inoperative. When the glide slope information becomes inoperative the PAR may revert to a non-precision approach system and non-precision approach minima apply. The PAR procedure shall include instructions for the pilot in the event of a loss of communications with the controller.

114. **Final Approach Point (FAP)**. The final approach segment begins at the final approach point (FAP). This is a point in space on the final approach track where the intermediate approach altitude/height intercepts the nominal glide path/microwave landing system (MLS) elevation angle.

115. **Final Approach Length**. The intermediate approach altitude/height generally intercepts the glide path/MLS elevation angle at heights from 1 000 ft to 3 000 ft above runway elevation. In this case, for a 3° glide path, interception occurs between 3 NM and 10 NM from the threshold. The intermediate approach track or radar vector is designed to place the aircraft on the localizer or the MLS azimuth specified for the final approach track at an altitude/height that is below the nominal glide path/MLS elevation angle.

116. **Outer Marker/DME Fix**. The outer marker or equivalent DME fix is normally used to verify the glide path/MLS elevation angle/altimeter relationship. Prior to crossing the fix, descent may be made on the glide path/MLS elevation angle to the altitude/height of the published fix crossing but descent below the fix crossing altitude/height should not be made prior to crossing the fix.

117. **Altimeters**. It is assumed that the aircraft altimeter reading on crossing the fix is correlated with the published altitude, allowing for altitude error and altimeter tolerances. Pressure altimeters are calibrated to indicate true altitude under ISA conditions. Any deviation from ISA will therefore result in an erroneous reading on the altimeter. If the temperature is higher than ISA, then the true altitude will be higher than the figure indicated by the altimeter. Similarly, the true altitude will be lower when the temperature is lower than ISA. *The altimeter error may be significant in extremely cold temperatures*.

118. **Loss of Glide Path**. In the event of loss of glide path/MLS elevation angle guidance during the approach, the procedure becomes a non-precision approach. The OCA/H and associated procedure published for the glide path/MLS elevation angle inoperative case will then apply.

119. **Missed Approach Point (MAPt)**.The Missed Approach Point (MAPt) for a precision approach is defined either by the intersection of the glide path with the relevant DA/DH and therefore may not be depicted on the chart.

Protection on the Precision Segment

120. The width of the final approach protection area for a precision approach is much narrower than that for a non-precision approach. The protection area assumes the pilot does not deviate more than half scale deflection from the centreline once established on track. Thereafter the aircraft should adhere to the on-course, on-glide path/elevation angle position since a more than half course sector deflection, or a more than half course fly-up deflection combined with other allowable system tolerances, could place the aircraft in the vicinity of the edge or bottom of the protected airspace where loss of protection from obstacles can occur.

121. Operators must consider weight, altitude and temperature limitations and wind velocity when determining the DA/H for a missed approach, since the OCA/H might be based on an obstacle in the missed approach area and since advantage may be taken of variable missed approach climb performances.

MISSED APPROACH SEGMENT

122. During a Missed Approach Procedure (MAP) the pilot has to change the aircraft's configuration, attitude and altitude. The MAP is therefore designed to be simple and consists of three phases, initial, intermediate and final (Fig 16).

123. Only one MAP is established for each instrument approach procedure. It is designed to give protection from obstacles and has a defined start and end point. The MAP should be initiated not lower than DA/DH in precision approach procedures, or at a specified point in non-precision approach procedures not lower than the MDA/H.

124. The Missed Approach Point (MAPt) is the point in an instrument approach procedure at, or before, which the prescribed missed approach must be initiated in order to ensure that the minimum obstacle clearance is not infringed. A missed approach must be carried out if the MAPt is reached before visual reference is acquired in order to maintain protection from obstacles. If a turn is specified in the missed approach procedure, the turn shall not be initiated until the aircraft has passed the MAPt and is established in the climb. Pilots should be aware that the MAPt is not necessarily a point in space from which a safe landing can be made.

125. A pilot is expected to fly the MAP as published. If the MAP is initiated before the MAPt is reached, the pilot will normally proceed to the MAPt and then follow the MAP to remain within protected airspace. The pilot may fly over the MAPt at a height greater than that required by the procedure. A MAP may be modified under certain circumstances, but the details will be published on the chart.

126. **MAP Gradient**. The normal gradient for a MAP is 2.5% (150 ft/nm). A gradient of 2% (120 ft/nm) may be used if surveys have been done to assure obstacle clearance. Gradients of 3, 4 or 5% may be used for aircraft with the required climb performance. Gradients other than 2.5% will be published on the chart along with the OCA/H for this gradient. The OCA/H for the normal gradient will also be published.

127. **Special Circumstances**. A Gradient of 2.5% may not be practicable for certain aircraft operating at near maximum AUW and/or engine-out conditions. A special procedure may be established with a possible increase in DA/DH or MDA/H.

Initial Phase

128. The initial phase begins at the MAPt and ends at the Start Of the Climb (SOC). This is a short phase where the pilot is changing the aircraft configuration and attitude and is initiating the climb. No turns are specified in this phase.

Intermediate Phase

129. The intermediate phase starts at the SOC and ends at the first point where 164 ft (50 m) of obstacle clearance is obtained and can be maintained. The climb is continued, normally straight ahead, but the track may change by a maximum of 15º.

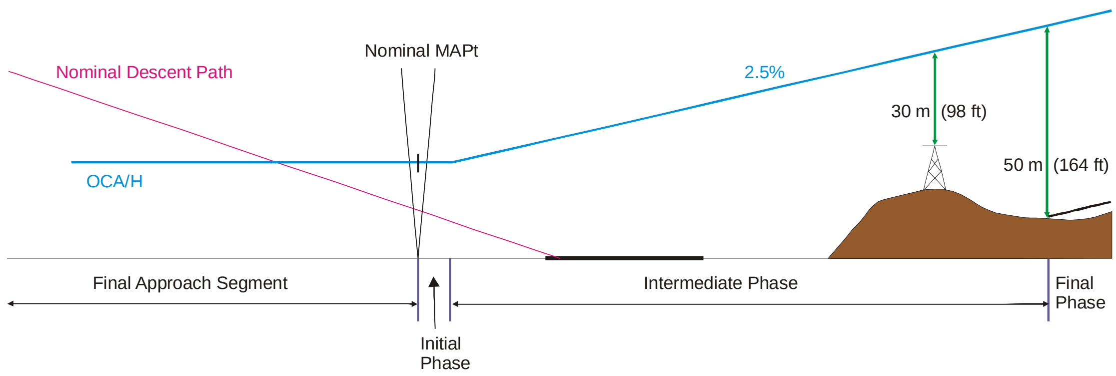
Final Phase

130. The final phase begins at the point where 164 ft (50 m) (for Cat H procedures, 131 ft (40 m)) of obstacle clearance is obtained and can be maintained. It extends to the point where a new approach, holding or a return to en-route flight is initiated.

Manoeuvres During the MAP

131. Turns during a MAP are only prescribed when necessary due to terrain or other factors. Speeds during the MAP are designed to ensure the aircraft remains within protected airspace. Pilots are expected to comply with instructions given on the chart without undue delay.

8-31 Fig 16 Missed Approach Phases



HELICOPTER PROCEDURES

132. There are several terms that are particular to helicopter procedures and are defined as follows:

a. **Height Above Landing** elevation (**HAL**).

b. **Height Above the Surface** (**HAS**) is the height of the MDA/DA above the highest terrain/surface within a 5200 ft radius of the MAPt in Point in Space procedures.

c. **Landing Area** refers to a portion of the heliport or airport runway used or intended to be used for helicopter landing and take-off.

d. **Landing Area Boundary** (**LAB**) is the beginning of the landing area of the heliport or runway.

e. **Point in Space Approach** is an instrument approach procedure to a point in space, identified as a missed approach point, which is more than 2600 ft from the landing area.

f. **Touchdown Zone** as used in helicopter procedures is identical to the landing area.

133. Helicopter only procedures shall bear an identification that includes the term 'COPTER', the type of facility providing the final approach course guidance and a numerical identification or the final approach course; e.g. COPTER VOR 090, COPTER NDB 270, COPTER PAR 327, COPTER ASR 327. If the procedure is designed for a runway, the runway identifier will be included, e.g. COPTER VOR RWY 30.

134. The criteria for helicopter procedures are based on airspeeds not exceeding 90 kt on the final approach and missed approach. For MIPS procedures, when a final approach speed of less than 90 kt is used, the maximum speed will be annotated on the approach plate.

135. **Point in Space Approach**. Where the centre of the landing area is more than 2600 ft from the MAPt, a point in space procedure may be developed. In such procedures, the point in space is the MAPt and, upon arrival at this point, helicopters shall proceed under VFR to the landing area or conduct the specified missed approach procedure.

136. **Descent Gradient**. The optimum descent gradient in all segments of helicopter approach procedures is 6.5% (400 ft/nm). However, to meet operational requirements, a gradient of as much as 13.1% (800 ft/nm) may be authorized. Gradients above 6.5% (400 ft/nm) shall be depicted on the approach chart.

Take-off and Landing Minima (Helicopters)

137. In the minima section of the procedure plate, the category is identified as ‘H’ followed by the abbreviated navaid and the final approach course heading, e.g. H-PAR 085 or H-PAR RWY 30 if the procedure is to a runway.

138. A decision height of 100 ft may be approved without approach lights (see also Table 8).

Visibility Minima

139. **Visibility Credit**. Where visibility credit for lighting facilities is allowed for fixed wing operations, the same type credit should be considered for helicopter operations. The approving authority will grant credit on an individual case basis. The minimum visibility required may be reduced by 0.4 km where approved approach light systems are operative. For precision approach procedures where RVR is approved and minima have been reduced to 0.4 km, RVR 400 m may also be authorized.

140. **Straight-in Minima**. The visibility minima for straight-in approaches are as follows:

a. **Non-precision Approaches**. (Landing area within 2600 ft of the MAPt). The minimum visibility required prior to applying credit for lights (see Para 124) is associated with the Height Above Landing elevation (HAL) as specified in Table 8.

Table 8 Effect of HAL on Visibility Minima

HAL (ft)	250-600	601-800	>800
Min Viz (km)	0.8	1.2	1.6

b. **Precision Approaches**. The minimum authorized visibility, prior to applying credit for lights, is 0.8 km (RVR 800 m).

141. **Take-off Minima**. Helicopter take-off minima will be in accordance with the appropriate national regulations.

Precision Approach Radar (PAR)

142. Navigational guidance for feeder routes, initial segments and intermediate segments may be provided by radar and/or other navigational facilities. The intermediate segment begins at the point where the initial approach course intercepts an extension of the final approach course and extends along the inbound final approach course to the point of interception of the glide slope. The minimum length of the intermediate segment is based on the angle if intersection between the initial approach and the intermediate course as follows:

Angle (degrees)	Minimum Length (nm)
30 and less	1.0
31-60	2.0
61-90	3.0
91-120	4.0

143. The final approach segment begins at the point of intercept of the glide path, the Final Approach Point (FAP). The final approach course shall be aligned to a landing area. The minimum distance from the FAP to the Ground Point of Intercept (GPI) is 2 nm.

144. For glide slope inoperative approaches, the Final Approach Fix (FAF) is on the final approach course within 5 nm of the landing threshold (but not less than the distance required by the descent gradient criteria). The FAF normally coincides with the FAP for PAR.

145. Glide slope angles greater than 6º shall not be established without the authorization of the approving authority.

146. The DH is adjusted wherever the glide slope angle exceeds 3.8º as follows:

GS Angle (deg)	3.00 to 3.80	3.81 to 5.70	Over 5.70
Minimum DH (ft)	100	150	200

Missed Approach Obstacle Clearance

147. No obstacle shall penetrate a 5% missed approach surface. The missed approach surface originates at the GPI elevation. When penetration of the 5% surface occurs, the DH may be raised by an amount equal to the maximum penetration of the surface or a higher climb gradient may be published. In this case the procedure will have two sets of DA/DH and associated minima, one standard and one for the higher climb gradient.

Human Factors and Departure, Arrival and Approach Procedures

There is little doubt that the most demanding flying and therefore the most potentially dangerous flying is when the aircraft is close to the ground. Rules, regulations and procedures are in place for good reasons and must be adhered to. Some procedures are complicated and can present potential for human error. Distraction, stress, weather, focussed attention and radio calls can degrade Situation Awareness and can be potentially fatal. Crew error in the approach phase of flight have resulted in numerous accidents. Think about minimising in-cockpit chat, adjust lighting for the conditions, remove possible distractions such as food and drink, plan and brief the approach early, rehearse the procedure during the transit if possible and if the cruise has been long and uninspiring consider a few minutes on 100% oxygen before top of descent.