Chapter 2

Aviation Weather Hazards

Introduction

Throughout its history, aviation has had an intimate relationship with the weather. Time has brought improvements - better aircraft, improved air navigation systems and a systemized program of pilot training. Despite this, weather continues to exact its toll.

In the aviation world, 'weather' tends to be used to mean not only "what's happening now?" but also "what's going to happen during my flight?". Based on the answer received, the pilot will opt to continue or cancel his flight. In this section we will examine some specific weather elements and how they affect flight.

Icing

One of simplest assumptions made about clouds is that cloud droplets are in a liquid form at temperatures warmer than 0°C and that they freeze into ice crystals within a few degrees below zero. In reality, however, 0°C marks the temperature below which water droplets become supercooled and are capable of freezing. While some of the droplets actually do freeze spontaneously just below 0°C, others persist in the liquid state at much lower temperatures.

Aircraft icing occurs when supercooled water droplets strike an aircraft whose temperature is colder than 0°C. The effects icing can have on an aircraft can be quite serious and include:

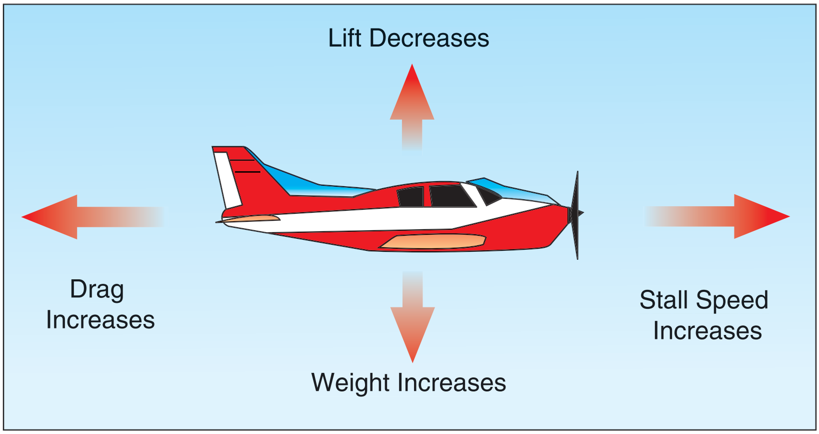

Fig. 2-1 - Effects of icing

- disruption of the smooth laminar flow over the wings causing a decrease in lift and an increase in the stall speed. This last effect is particularly dangerous. An "iced" aircraft is effectively an "experimental" aircraft with an unknown stall speed.
- increase in weight and drag thus increasing fuel consumption.
- partial or complete blockage of pitot heads and static ports giving erroneous instrument readings.
- restriction of visibility as windshear glazes over.

The Freezing Process

When a supercooled water droplet strikes an aircraft surface, it begins to freeze, releasing latent heat. This latent heat warms the remainder of the droplet to near 0°C, allowing the unfrozen part of the droplet to spread back across the surface until freezing is complete. The lower the air temperature and the colder the aircraft surface, the greater the fraction of the droplet that freezes immediately on impact. Similarly, the smaller the droplet, the greater the fraction of the droplet that freezes immediately on impact. Finally, the more frequent the droplets strike the aircraft surface, the greater the amount of water that will flow back over the aircraft surface. In general, the maximum potential for icing occurs with large droplets at temperatures just below 0°C .

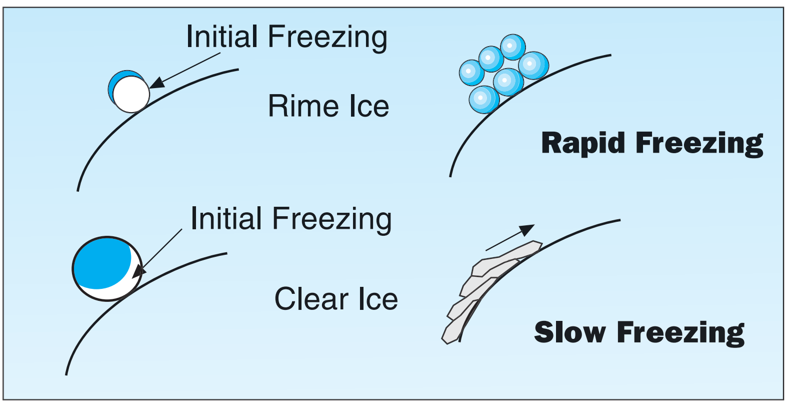

Fig. 2-2 - Freezing of supercooled droplets on impact

Types of Aircraft Ice

Rime Ice

Rime ice is a product of small droplets where each droplet has a chance to freeze completely before another droplet hits the same place. The ice that is formed is opaque and brittle because of the air trapped between the droplets. Rime ice tends to form on the leading edges of airfoils, builds forward into the air stream and has low adhesive properties.

Clear Ice

In the situation where each large droplet does not freeze completely before additional droplets become deposited on the first, supercooled water from each drop merges and spreads backwards across the aircraft surface before freezing completely to form an ice with high adhesive properties. Clear ice tends to range from transparent to a very tough opaque layer and will build back across the aircraft surface as well as forward into the air stream.

Mixed Ice

When the temperature and the range of droplet size vary widely, the ice that forms is a mixture of rime ice and clear ice. This type of ice usually has more adhesive properties than rime ice, is opaque in appearance, rough, and generally builds forward into the air stream faster than it spreads back over the aircraft surface.

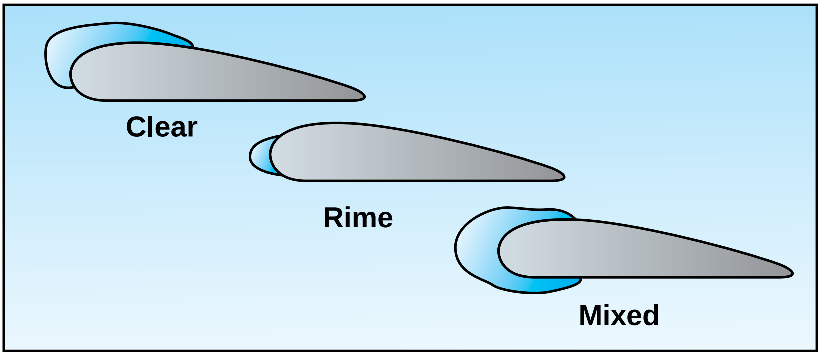

Fig. 2-3 - Accumulation patterns of different icing types

Meteorological Factors Affecting Icing

(a) Liquid Water Content of the Cloud

The liquid water content of a cloud is dependent on the size and number of droplets in a given volume of air. The greater the liquid water content, the more serious the icing potential. Clouds with strong vertical updrafts generally have a higher liquid water content as the updrafts prevent even the large drops from precipitating.

The strongest updrafts are to be found in convective clouds, clouds formed by abrupt orographic lift, and in lee wave clouds. Layer clouds tend to have weak updrafts and are generally composed of small droplets.

(b) Temperature Structure in the Cloud

Warm air can contain more water vapour than cold air. Thus, clouds that form in warm air masses will have a higher liquid water content than those that form in cold air.

The temperature structure in a cloud has a significant effect on the size and number of droplets. Larger supercooled droplets begin to freeze spontaneously around -10°C with the rate of freezing of all size of droplets increasing rapidly as temperatures fall below -15°C. By -40°C, virtually all the droplets will be frozen. The exceptions are clouds with very strong vertical updrafts, such as towering cumulus or cumulonimbus, where liquid water droplets can be carried to great heights before freezing.

These factors allow the icing intensities to change rapidly with time so that it is possible for aircraft only minutes apart to encounter entirely different icing conditions in the same area. Despite this, some generally accepted rules have been developed:

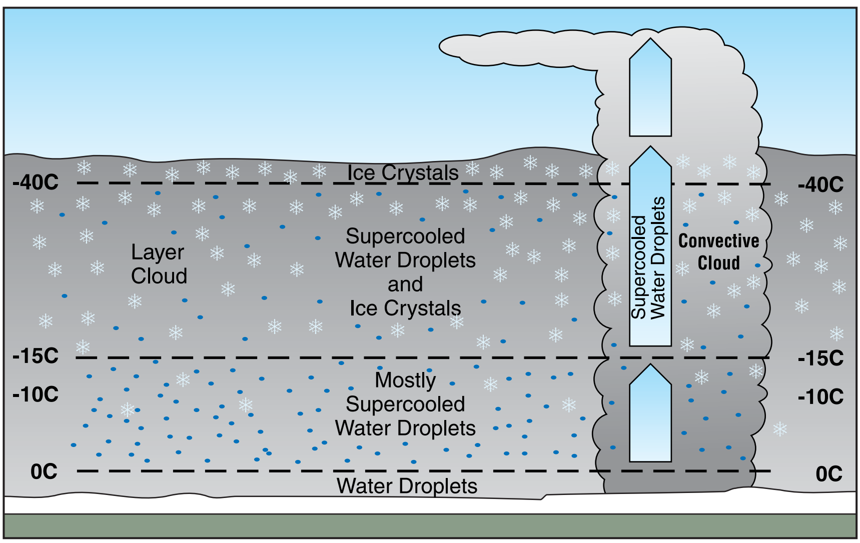

Fig. 2-4 - Distribution of water droplet-ice crystals in cloud

(1) Within large cumulus and cumulonimbus clouds:

- at temperatures between 0°C and -25°C, severe clear icing likely.
- at temperatures between -25°C and -40°C, light rime icing likely; small possibility of moderate to severe rime or mixed icing in newly developed clouds.
- at temperatures below -40°C, little chance of icing.

(2) Within layer cloud:

- the most significant icing layer is generally confined to the 0°C to -15°C temperature range.

- icing is usually less severe than in convective cloud due to the weaker updrafts and smaller droplets.
- icing layers tend to be shallow in depth but great in horizontal extent.

(3) Situations in which icing may be greater than expected:

- air moving across large unfrozen lakes in the fall and winter will increase its moisture content and destabilize rapidly due to heating from below. The cloud that forms, while resembling a layer cloud, will actually be a convective cloud capped by an inversion with relatively strong updrafts and a large concentration of supercooled drops.
- thick layer cloud formed by rapid mass ascent, such as in an intensifying low or along mountain slopes, will also have enhanced concentrations of supercooled drops. Furthermore, there is a strong possibility that such lift will destabilize the air mass resulting in embedded convective clouds with their enhanced icing potential.
- lenticular clouds can have very strong vertical currents associated with them. Icing can be severe and, because of the droplet size, tend toward clear icing.

Supercooled Large Drop Icing

Supercooled large drop (SLD) icing has, until fairly recently, only been associated with freezing rain. Several accidents and significant icing events have revealed the existence of a deadly form of SLD icing in non-typical situations and locations. It was found that large cloud drops, the size of freezing drizzle drops, could exist within some stratiform cloud layers, whose cloud top is usually at 10,000 feet or less. The air temperature within the cloud (and above) remains below 0°C but warmer than -18°C throughout the cloud layer. These large drops of liquid water form near the cloud top, in the presence of light to moderate mechanical turbulence, and remain throughout the cloud layer. SLD icing is usually severe and clear. Ice accretion onto flight surfaces of 2.5 cm or more in 15 minutes or less have been observed.

There are a few indicators that may help announce SLD icing beforehand. SLD icing-producing stratiform clouds often occur in a stable air mass, in the presence of a gentle upslope circulation, sometimes coming from a large body of water. The air above the cloud layer is always dry, with no significant cloud layers above. The presence of freezing drizzle underneath, or liquid drizzle when the surface air temperature is slightly above 0°C, is a sure indication of SLD icing within the cloud. Other areas where this type of icing is found is in the cloud to the southwest of a low pressure centre and behind cold fronts where low level stratocumulus are common (cloud tops often below 13,000 feet). Constant and careful attention must be paid when flying a holding pattern within a cloud layer in winter.

Over the Prairies, SLD icing-producing clouds are common in a easterly to northeasterly flow off Hudson Bay, in north-eastern Manitoba, in northern Saskatchewan, and in Alberta. These low-level clouds often produce drizzle or freezing drizzle.

The Glory: A Warning Sign for Aircraft Icing

Photo 2-1 - Glory surrounding aircraft shadow on cloud top credit: Alister Ling

The glory is one of the most common forms of halo visible in the sky. For the pilot it is a warning sign of potential icing because it is only visible when there are liquid water droplets in the cloud. If the air temperature at cloud level is below freezing, icing will occur in those clouds that produce a glory.

A glory can be seen by looking downwards and seeing it surround the shadow that your aircraft casts onto the cloud tops. They can also be seen by looking upwards towards the sun (or bright moon) through clouds made of liquid droplets.

It is possible to be high enough above the clouds or fog that your shadow is too small to see at the center of the glory. Although ice crystals often produce other halos and arcs, only water droplets form bullseyes.

Aerodynamic Factors Affecting Icing

There are various aerodynamic factors that affect the collection efficiency of an aircraft surface. Collection efficiency can be defined as the fraction of liquid water droplets that actually strike the aircraft relative to the number of droplets encountered along the flight path.

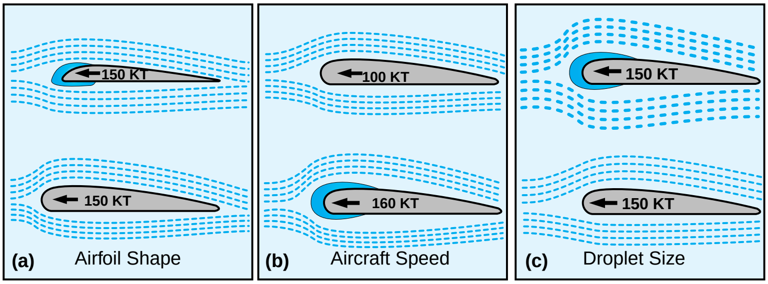

Fig. 2-5 -Variations in collection efficiency

Collection efficiency is dependent on three factors:

(a) The radius of curvature of the aircraft component. Airfoils with a big radius of curvature disrupt the airflow (like a bow wave) causing the smaller supercooled droplets to be carried around the airfoil by the air stream. For this reason, large thick components (thick wings, canopies) collect ice less efficiently than thin components (thin wings, struts, antenna).

(b) Speed. The faster the aircraft the less chance the droplets have to be diverted around the airfoil by the air stream.

(c) Droplet size. The larger the droplet the more difficult it is for the air stream to displace it.

Other Forms of Icing

(a) Freezing Rain and Ice Pellets

Freezing rain occurs when liquid water drops that are above freezing fall into a layer of air whose temperature is colder than 0°C and supercool before hitting some object. The most common scenario leading to freezing rain in Western Canada is "warm overrunning". In this case, warm air (above 0°C) is forced up and over colder air at the surface. In such a scenario, rain that falls into the cold air supercools, resulting in freezing rain that can last for hours especially if cold air continues to drain into the area from the surrounding terrain. When the cold air is sufficiently deep, the freezing raindrops can freeze completely before reaching the surface causing ice pellets. Pilots should be aware, however, that ice pellets at the surface imply freezing rain aloft. Such conditions are relatively common in the winter and tend to last a little longer in valleys than over flat terrain.

(b) Freezing Drizzle or Snow Grains

Freezing drizzle is different from freezing rain in that the water droplets are smaller. Another important difference is that freezing drizzle may develop in air masses whose entire temperature profile is below freezing. In other words, freezing drizzle can occur without the presence of a warm layer (above 0°C) aloft. In this case, favorable areas for the development of freezing drizzle are in moist maritime air masses, preferably in areas of moderate to strong upslope flow. The icing associated with freezing drizzle may have a significant impact on aviation. Similar to ice pellets, snow grains imply the presence of freezing drizzle aloft.

(c) Snow
Dry snow will not adhere to an aircraft surface and will not normally cause icing problems. Wet snow, however, can freeze hard to an aircraft surface that is at subzero temperatures and be extremely difficult to remove. A very dangerous situation can arise when an aircraft attempts to take off with wet snow on the flight surfaces. Once the aircraft is set in motion, evaporational cooling will cause the wet snow to freeze hard causing a drastic reduction in lift as well as increasing the weight and drag. Wet snow can also freeze to the windscreens making visibility difficult to impossible.

(d) Freezing Spray
Freezing spray develops over open water when there is an outbreak of Arctic air. While the water itself is near or above freezing, any water that is picked up by the wind or is splashed onto an object will quickly freeze, causing a rapid increase in weight and shifting the centre of gravity.

(e) Freezing Fog
Freezing fog is a common occurrence during the winter. Fog is simply "a cloud touching the ground" and, like its airborne cousin, will have a high percentage of supercooled water droplets at temperatures just below freezing (0°C to -10°C). Aircraft landing, taking off, or even taxiing, in freezing fog should anticipate rime icing.

Visibility

Reduced visibility is the meteorological component which impacts flight operations the most. Topographic features all tend to look the same at low levels making good route navigation essential. This can only be done in times of clear visibility.

Types of Visibility

There are several terms used to describe the different types of visibility used by the aviation community.

(a) **Horizontal visibility** - the furthest visibility obtained horizontally in a specific direction by referencing objects or lights at known distances.

(b) **Prevailing visibility** - the ground level visibility which is common to one-half or more of the horizon circle.

(c) **Vertical visibility** - the maximum visibility obtained by looking vertically upwards into a surface-based obstruction such as fog or snow.

(d) Slant visibility - visibility observed by looking forward and downwards from the cockpit of the aircraft.

(e) Flight visibility - the average range of visibility at any given time forward from the cockpit of an aircraft in flight.

Causes of Reduced Visibility

(a) Lithometers

Lithometers are dry particles suspended in the atmosphere and include haze, smoke, sand and dust. Of these, smoke and haze cause the most problems. The most common sources of smoke are forest fires. Smoke from distant sources will resemble haze but, near a fire, smoke can reduce the visibility significantly.

(b) Precipitation

Rain can reduce visibility, however, the restriction is seldom less than one mile other than in the heaviest showers beneath cumulonimbus clouds. Drizzle, because of the greater number of drops in each volume of air, is usually more effective than rain at reducing the visibility, especially when accompanied by fog.

Snow affects visibility more than rain or drizzle and can easily reduce it to less than one mile. Blowing snow is a product of strong winds picking up the snow particles and lifting them into the air. Fresh fallen snow is easily disturbed and can be lifted a few hundred feet. Under extreme conditions, the cockpit visibility will be excellent during a landing approach until the aircraft flares, at which time the horizontal visibility will be reduced abruptly.

(c) Fog

Fog is the most common and persistent visibility obstruction encountered by the aviation community. A cloud based on the ground, fog, can consist of water droplets, supercooled water droplets, ice crystals or a mix of supercooled droplets and ice crystals.

(i) Radiation Fog

Radiation fog begins to form over land usually under clear skies and light winds typically after midnight and peaks early in the morning. As the land surface loses heat and radiates it into space, the air above the land is cooled and loses its ability to hold moisture. If an abundance of condensation nuclei is present in the atmosphere, radiation fog may develop before the temperature-dewpoint spread reaches zero. After sunrise, the fog begins to burn off from the edges over land but any fog that has drifted over water will take longer to burn off.

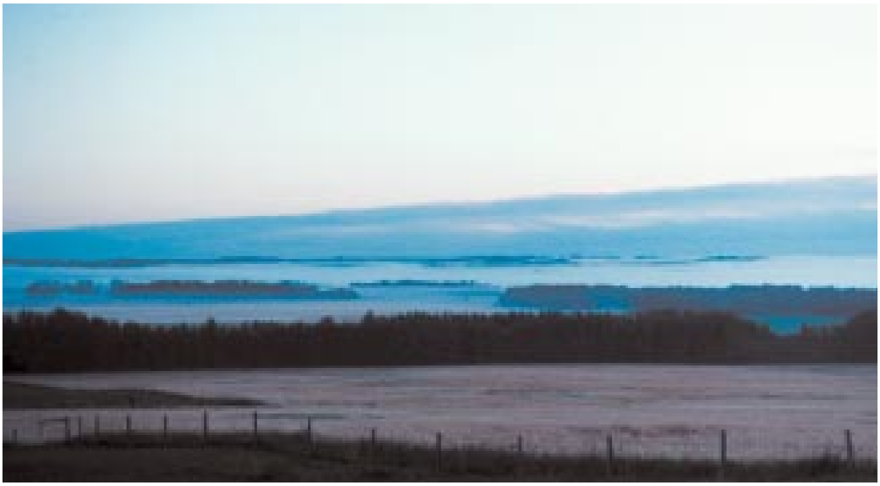

Photo 2-2 - Radiation fog in a valley credit: Alister Ling

(ii) Precipitation or Frontal Fog

Precipitation fog, or frontal fog, forms ahead of warm fronts when precipitation falls through a cooler layer of air near the ground. The precipitation saturates the air at the surface and fog forms. Breaks in the precipitation usually results in the fog becoming thicker.

(iii) Steam Fog

Steam fog forms when very cold arctic air moves over relatively warmer water. In this case moisture evaporates from the water surface and saturates the air. The extremely cold air cannot hold all the evaporated moisture, so the excess condenses into fog. The result looks like steam or smoke rising from the water, and is usually no more than 50 to 100 feet thick. Steam fog, also called arctic sea smoke, can produce significant icing conditions.

(iv) Advection Fog

Fog that forms when warm moist air moves across a snow, ice or cold water surface.

(v) Ice Fog

Ice fog occurs when water vapour sublimates directly into ice crystals. In conditions of light winds and temperatures colder than -30°C or so, water vapour from manmade sources or cracks in ice-covered rivers can form widespread and persistent ice fog. The fog produced by local heating systems, and even aircraft engines, can reduce the local visibility to near zero, closing an airport for hours or even days.

(d) Snow Squalls and Streamers

Snow squalls are relatively small areas of heavy snowfall. They develop when cold arctic air passes over a relatively warm water surface, such as Lake Winnipeg, before freeze-up. An injection of heat and moisture from the lake into the low levels of the atmosphere destabilizes the air mass. If sufficient destabilization occurs, convective clouds begin to develop with snow beginning shortly thereafter. Snowsqualls usually develop in bands of cloud, or streamers, that form parallel to the direction of flow. Movement of these snow squalls can generally be tied to the mean winds between 3,000 and 5,000 feet. Not only can snowsqualls reduce visibility to near zero but, due to their convective nature, significant icing and turbulence are often encountered within the clouds.

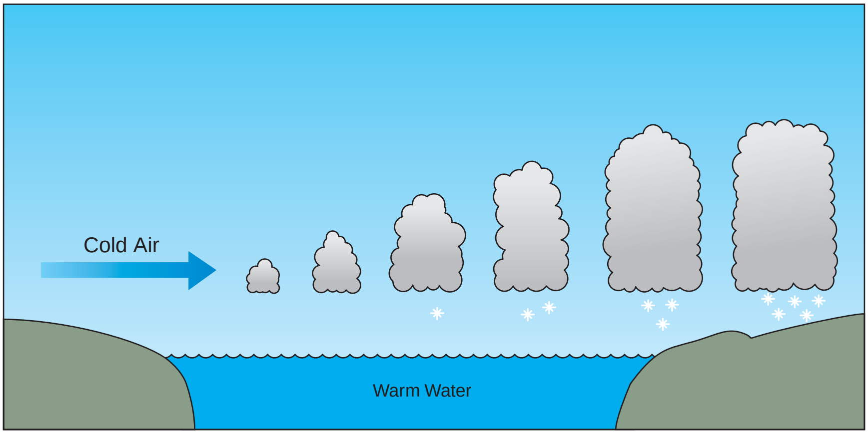

Fig. 2-6 - Snowsqualls building over open water

Wind, Shear and Turbulence

The "why" of winds are quite well understood. It is the daily variations of the winds, where they blow and how strong, that remains a constant problem for meteorologists to unravel. The problem becomes even more difficult when local effects such as wind flow through coastal inlets or in mountain valleys are added to the dilemma. The result of these effects can give one airport persistent light winds while another has nightly episodes of strong gusty winds.

Stability and the Diurnal Variation in Wind

In a stable weather pattern, daytime winds are generally stronger and gustier than nighttime winds. During the day, the heating from the sun sets up convective mixing which carries the stronger winds aloft down to the surface and mixes them with the slower surface winds. This causes the surface wind to increase in speed and become gusty, while at the same time reducing the wind speeds aloft in the mixed layer.

After sunset, the surface of the earth cools which, in turn, cools the air near the surface resulting in the development of a temperature inversion. This inversion deepens as cooling continues, ending the convective mixing and causing the surface winds to slacken.

Wind Shear

Wind shear is nothing more than a change in wind direction and/or wind speed over the distance between two points. If the points are in a vertical direction then it is called vertical shear, if they are in a horizontal direction than it is called horizontal shear.

In the aviation world, the major concern is how abruptly the change occurs. If the change is gradual, a change in direction or speed will result in nothing more than a minor change in the ground speed. If the change is abrupt, however, there will be a rapid change of airspeed or track. Depending on the aircraft type, it may take a significant time to correct the situation, placing the aircraft in peril, particularly during takeoff and landing.

Significant shearing can occur when the surface wind blowing along a valley varies significantly from the free flowing wind above the valley. Changes in direction of 90° and speed changes of 25 knots are reasonably common in mountainous terrain.

Updrafts and downdrafts also induce shears. An abrupt downdraft will cause a brief decrease in the wing's attack angle resulting in a loss of lift. An updraft will increase the wing's attack angle and consequently increase the lift, however, there is a risk that it could be increased beyond the stall angle.

Shears can also be encountered along fronts. Frontal zones are generally thick enough that the change is gradual, however, cold frontal zones as thin as 200 feet have been measured. Significant directional shears across a warm front have also been observed with the directional change greater than 90 degrees over several hundred feet. Pilots doing a take-off or a landing approach through a frontal surface that is just above the ground should be wary.

Mechanical turbulence is a form of shear induced when a rough surface disrupts the smooth wind flow. The amount of shearing and the depth of the shearing layer depends on the wind speed, the roughness of the obstruction and the stability of the air.

The Relationship Between Wind Shear and Turbulence

Turbulence is the direct result of wind shear. The stronger the shear the greater the tendency for the laminar flow of the air to break down into eddies resulting in turbulence. However, not all shear zones are turbulent, so the absence of turbulence does not infer that there is no shear.

Low-Level Jets - Frontal

In developing low pressure systems, a narrow band of very strong winds often develops just ahead of the cold front and above the warm frontal zone. Meteorologists call these bands of strong winds "low-level jets". They are typically located between

500 and 5,000 feet and can be several hundred feet wide. Wind speeds associated with low-level jets can reach as high as 100 knots in more intense storms. The main problem with these features is that they can produce severe turbulence, or at least significant changes in airspeed. Critical periods for low-level windshear or turbulence with these features are one to three hours prior to a cold frontal passage. These conditions are made worse by the fact that they occur in the low levels of the atmosphere and affect aircraft in the more important phases of flight - landing and take off.

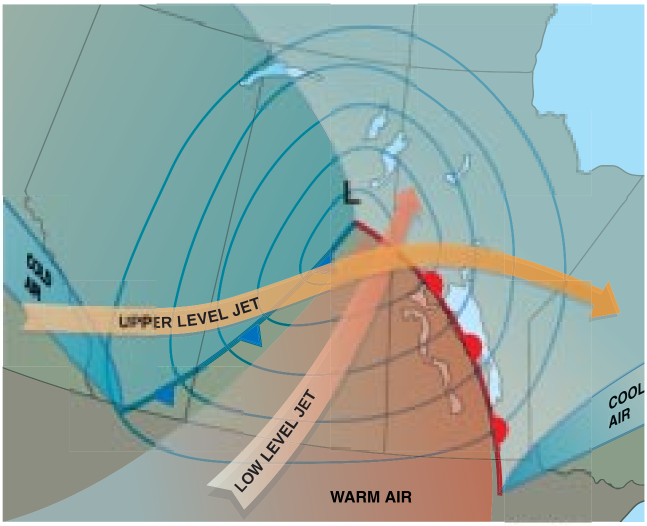

Fig. 2-7 - Idealized low and frontal system showing the position of the low-level and upper-level jet

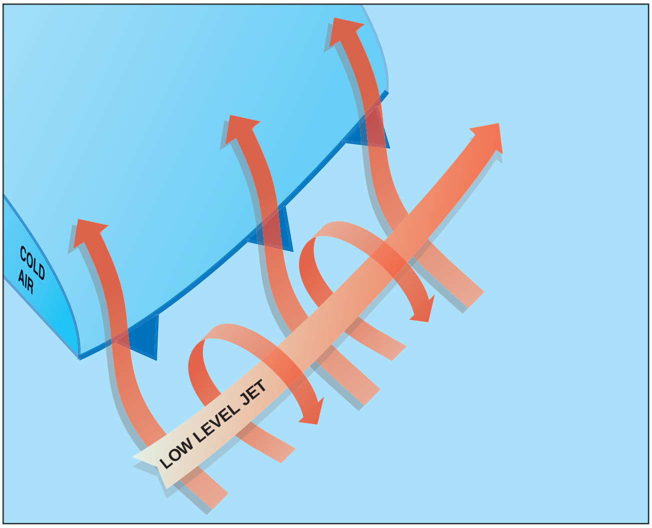

Fig. 2-8 - Complex winds around a low-level jet can result in significant low-level wind shear and turbulence

Low-Level Jets - Nocturnal

There is another type of low-level jet known as "the low-level nocturnal jet". This jet is a band of relatively high wind speeds, typically centred at altitudes ranging between 700 and 2,000 feet above the ground (just below the top of the nocturnal inversion) but on occasion can be as high as 3,000 feet. Wind speeds usually range between 20 and 40 knots but have been observed up to 60 knots.

The low-level nocturnal jet tends to form over relatively flat terrain and resembles a ribbon of wind in that it is thousands of miles long, a few hundred feet thick and up to hundreds of miles wide. Low-level nocturnal jets have been observed in mountainous terrain but tend to be localized in character.

The low-level nocturnal jet forms mainly in the summer on clear nights (this allows the inversion to form). The winds just below the top of the inversion will begin to increase just after sunset, reach its maximum speed a couple of hours after midnight, then dissipate in the morning as the sun's heat destroys the inversion.

Topographical Effects on Wind

(a) Lee Effects

When the winds blow against a steep cliff or over rugged terrain, gusty turbulent winds result. Eddies often form downwind of the hills, which create stationary zones of stronger and lighter winds. These zones of strong winds are fairly predictable and usually persist as long as the wind direction and stability of the air stream do not change. The lighter winds, which occur in areas called wind shadows, can vary in speed and direction, particularly downwind of higher hills. In the lee of the hills, the wind is usually gusty and the wind direction is often completely opposite to the wind blowing over the top of the hills. Smaller reverse eddies may also be encountered close to the hills. The Livingstone Range to the west of Claresholm, Alberta produces areas where the wind can be calm but, a short distance away, the winds will be strong westerly.

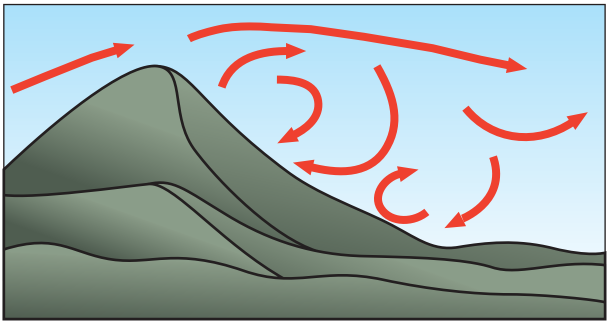

Fig. 2-9 - Lee effects

(b) Friction Effects

The winds that blow well above the surface of the earth are not strongly influenced by the presence of the earth itself. Closer to the earth, however, frictional effects decrease the speed of the air movement and back the wind (turns the wind direction counter-clockwise) towards the lower pressure. For example, in the northern hemisphere, a southerly wind becomes more southeasterly when blowing over rougher ground. There can be a significant reduction in the wind speed over a rough terrain when compared to the wind produced by the same pressure gradient over a relatively smooth prairie.

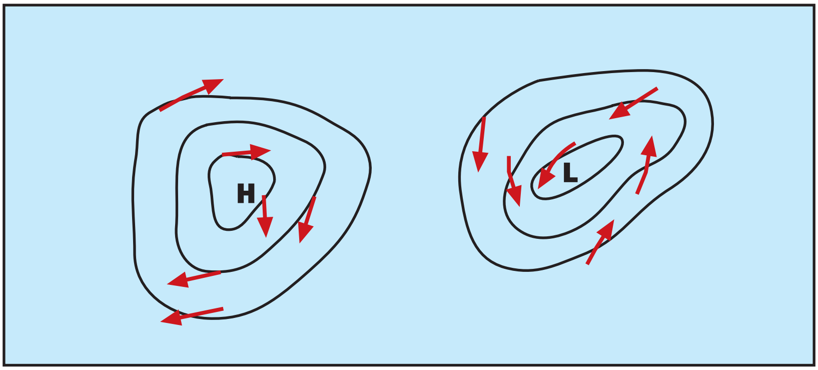

Fig. 2-10 - Friction effects

(c) Converging Winds

When two or more winds flow together or converge, a stronger wind is created. Similar effects can be noted where two or more valleys come together.

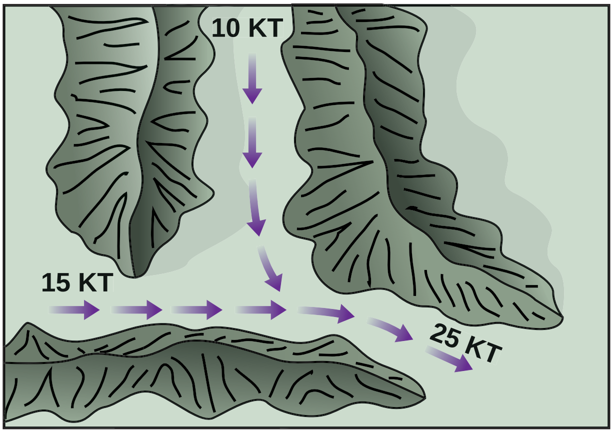

Fig. 2-11 - Converging winds

(d) Diverging Winds

A divergence of the air stream occurs when a single air stream splits into two or more streams. Each will have a lower speed than the parent air stream.

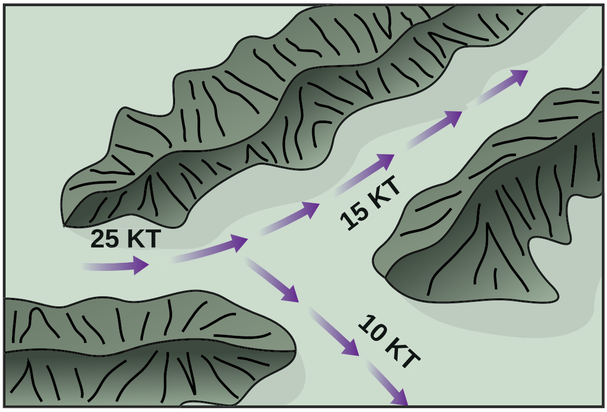

Fig. 2-12 - Diverging winds

(e) Corner Winds

When the prevailing wind encounters a headland, there is a tendency for the wind to curl around the feature. This change in direction, if done abruptly, can result in turbulence.

(f) Funnelled or Gap Winds

When winds are forced to flow through a narrow opening or gap, such as an inlet or narrow section of a pass, the wind speed will increase and may even double in strength. This effect is similar to pinching a water hose and is called funnelling.

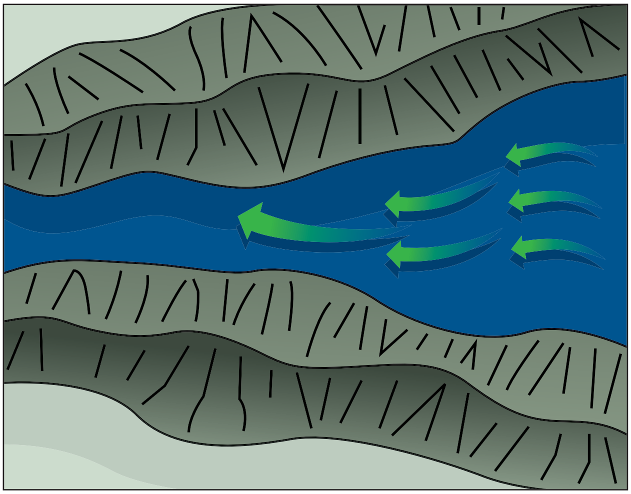

Fig. 2-13 - Funnelled winds

(g) Channelled Winds

The topography can also change the direction of the winds by forcing the flow along the direction of a pass or valley. This is referred to as channelling.

(h) Sea and Land Breezes

Sea and land breezes are only observed under light wind conditions, and depend on temperature differences between adjoining regions.

A sea breeze occurs when the air over the land is heated more rapidly than the air over the adjacent water surface. As a result, the warmer air rises and the relatively cool air from the water flows onshore to replace it. By late afternoon, the time of maximum heating, the sea breeze circulation may be 1,500 to 3,000 feet deep, have obtained speeds of 10 to 15 knots and extend as far as 50 nautical miles inland.

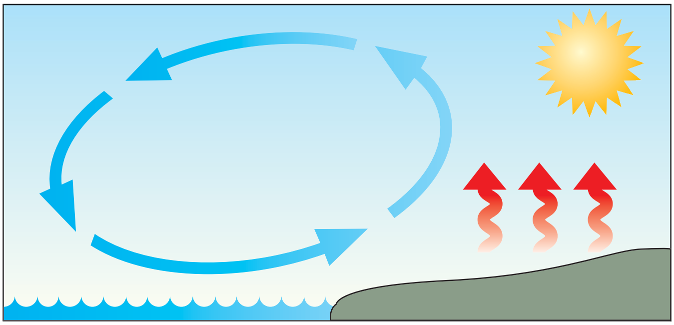

Fig. 2-14 - Sea breeze

During the evening the sea breeze subsides. At night, as the land cools, a land breeze develops in the opposite direction and flows from the land out over the water. It is generally not as strong as the sea breeze, but at times it can be quite gusty.

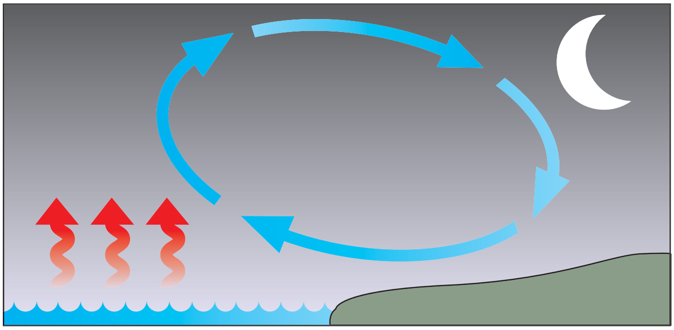

Fig. 2-15 - Land breeze

Both land and sea breezes can be influenced by channelling and funnelling resulting in almost frontal-like conditions, with sudden wind shifts and gusty winds that may reach up to 50 knots. Example of this can be found near the larger lakes in the Prairies and are often referred to as "lake effect winds".

(i) Anabatic and Katabatic Winds

During the day, the sides of the valleys become warmer than the valley bottoms since they are better exposed to the sun. As a result, the winds blow up the slope. These daytime, upslope winds are called anabatic winds. Gently sloped valley sides, especially those facing south, are more efficiently heated than those of a steep, narrow valley. As a result, valley breezes will be stronger in the wider valleys. An anabatic wind, if extended to sufficient height, will produce cloud. In addition, such a wind offers additional lift to aircraft and gliders. This effect occurs in the Oldman River Valley, to the west of the Lethbridge Airport, where a westerly flow is enhanced by this heating of the valley sides making it quite turbulent on the bluffs on the east side of the valley. This is generally a low-level effect and only noticeable up to 200 to300 feet above the bluffs.

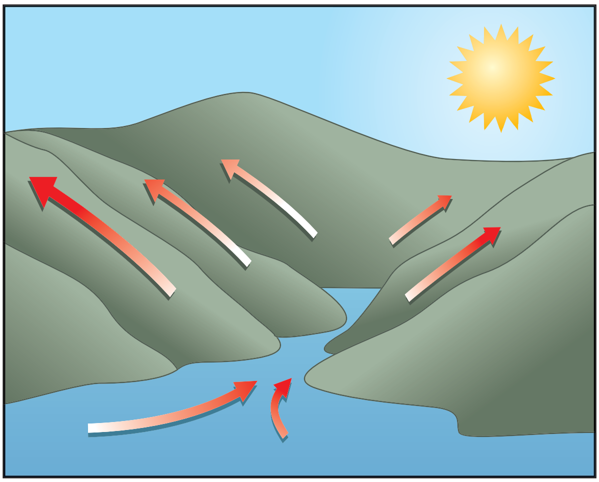

Fig. 2-16 - Anabatic winds

At night, the air cools over the mountain slopes and sinks to the valley floor. If the valley floor is sloping, the winds will move along the valley towards lower ground. The cool night winds are called drainage winds, or katabatic winds, and are often quite gusty and usually stronger than anabatic winds. Some valley airports have windsocks situated at various locations along their runways to show the changeable conditions due to the katabatic flow. Katabatic winds are observed frequently in locales such as Banff or Jasper.

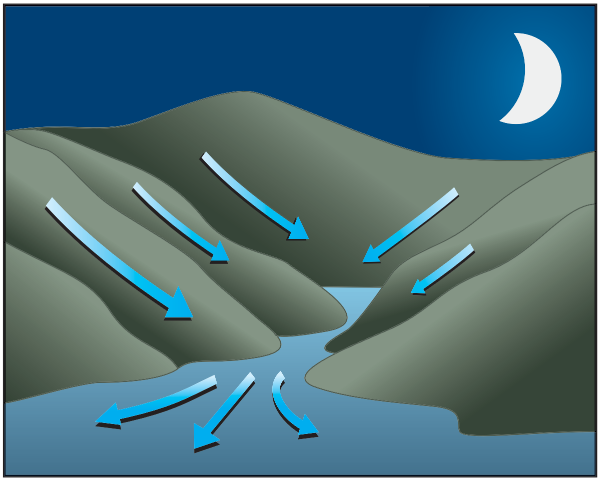

Fig. 2-17 - Katabatic winds

(j) Glacier Winds

Under extreme cooling conditions, such as an underlying ice cover, the katabatic winds can develop to hazardous proportions. As the ice is providing the cooling, a shallow wind of 80 knots or more can form and will persist during the day and night. In some locations the katabatic flow "pulsates" with the cold air building up to some critical value before being released to rush downslope.

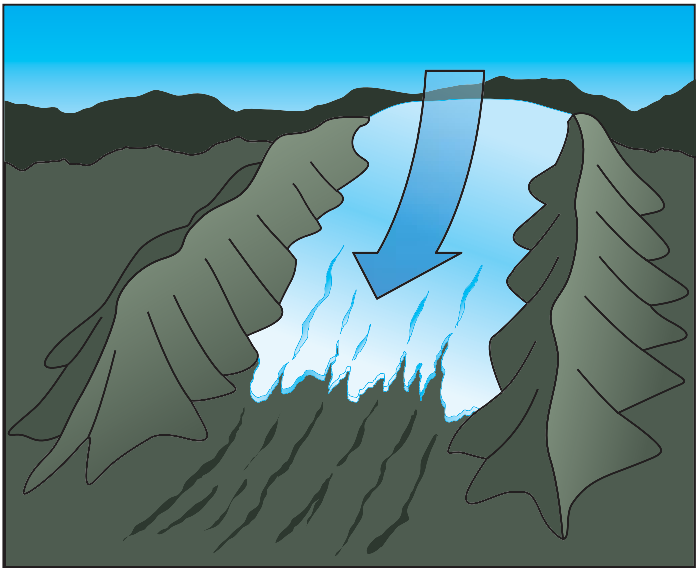

Fig. 2-18 - Glacier winds

It is important to recognize that combinations of these effects can operate at any given time. Katabatic winds are easily funnelled resulting in winds of unexpected directions and strengths in narrow passes. Around glaciers in the summer, wind fields can be chaotic. Katabatic winds from the top of the glacier struggle for dominance with localized convection, or anabatic winds, induced by heated rock slopes below the ice. Many sightseeing pilots prefer to avoid glaciated areas during the afternoon hours.

Lee Waves

When air flows across a mountain or hill, it is disturbed the same way as water flowing over a rock. The air initially is displaced upwards across the mountain, dips sharply on the lee side, then rises and falls in a series of waves downstream. These waves are called "mountain waves" or "lee waves" and are most notable for their turbulence. They often develop on the lee side of the Rocky Mountains.

The Formation of Lee Waves

The development of lee waves requires that several conditions be met:

(a) the wind direction must be within 30 degrees of perpendicular to the mountain or hill. The greater the height of the mountain and the sharper the drop off to the lee side, the more extensive the induced oscillations.

(b) wind speed should exceed 15 knots for small hills and 30 knots for mountain ridges. A jet stream with its associated strong winds below the jet axis is an ideal situation.

(c) the wind direction should be constant while increasing in speed with height throughout the troposphere.

(c) the air should be stable near the mountain peaks but less stable below. The unstable layer encourages the air to ascend and the stable layer encourages the development of a downstream wave pattern.

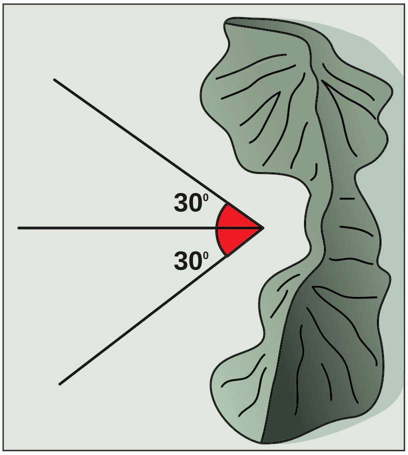

Fig. 2-19 - Angles for lee wave development

While all these conditions can be met at any time of the year, winter wind speeds are generally stronger resulting in more dangerous lee waves.

Characteristics of Lee Waves

Once a lee wave pattern has been established, it follows several basic rules:

- stronger the wind, the longer the wavelength. The typical wavelength is about 6 miles but can vary from as short as 3 miles to as long as 15 miles.
- position of the individual wave crests will remain nearly stationary with the wind blowing through them as long as the mean wind speed remains nearly constant.
- individual wave amplitude can exceed 3,000 feet.
- layer of lee waves often extends from just below the tops of the mountains to 4,000 to 6,000 feet above the tops but can extend higher.
- induced vertical currents within the wave can reach values of 4,500 feet per minute.
- wind speed is stronger through the wave crest and slower through the wave trough.
- wave closest to the obstruction will be the strongest with the waves further downstream getting progressively weaker.
- a large eddy called a "rotor" may form below each wave crest.
- mountain ranges downstream may amplify or nullify induced wave patterns.
- downdrafts are frequently found on the downwind side of the obstruction. These downdrafts typically reach values of 2,000 feet per minute but downdrafts up to 5,000 feet per minute have been reported. The strongest downdraft is usually found at a height near the top of the summit and could force an aircraft into the ground.

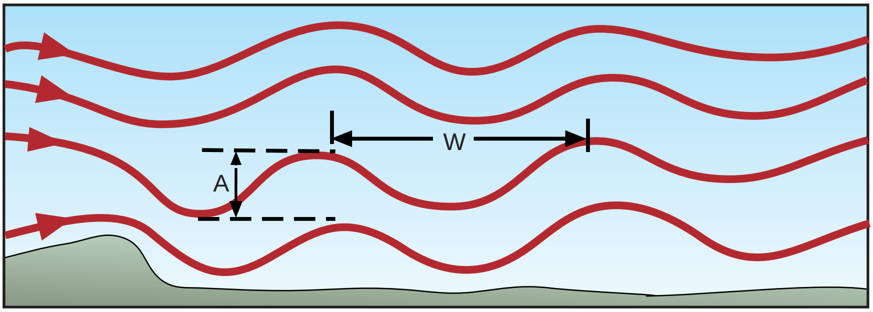

Fig. 2-20 - Amplitude (A) and wavelength (W) in lee waves

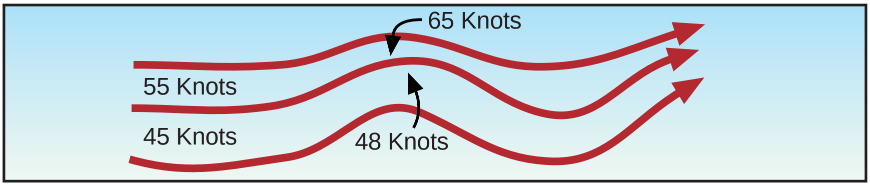

Fig. 2-21 - Stronger wind in wave crest in lee waves

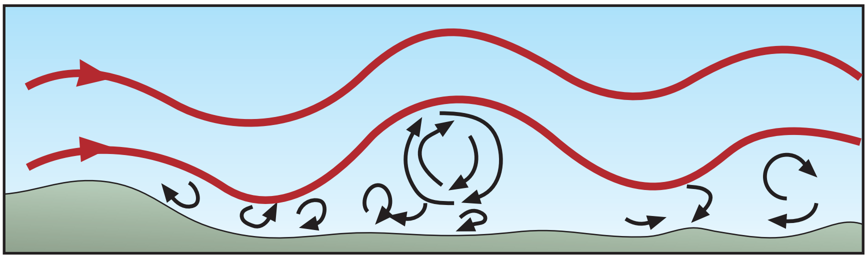

Fig. 2-22 - A rotor may form beneath wave crests

Clouds Associated with Lee Waves

Lee waves involve lift and, if sufficient moisture is available, characteristic clouds will form. The signature clouds may be absent, however, due to the air being too dry or the cloud being embedded within other clouds and not visible. It is essential to realize, nevertheless, that the absence of lee wave clouds does not mean that there are no lee waves present.

(a) Cap cloud

A cloud often forms over the peak of the mountain range and remains stationary. Frequently, it may have an almost "waterfall" appearance on the leeward side of the mountain. This effect is caused by subsidence and often signifies a strong downdraft just to the lee of the mountaintop.

(b) Lenticular clouds

A lens shaped cloud may be found at the crest of each wave. These clouds may be separated vertically with several thousand feet between each cloud or may form so close together they resemble a "stack of plates." When air flows through the crest it is often laminar, making the cloud smooth in appearance. On occasion, when the shear results in turbulence, the lenticular cloud will take on a ragged and wind torn appearance.

(c) Rotor cloud

A rotor cloud may form in association with the rotor. It will appear as a long line of stratocumulus, a few miles downwind and parallel to the ridge. Its base will be normally below the peak of the ridge, but its top can extend above it. The turbulence associated with a rotor cloud is severe within and near the rotor cloud.

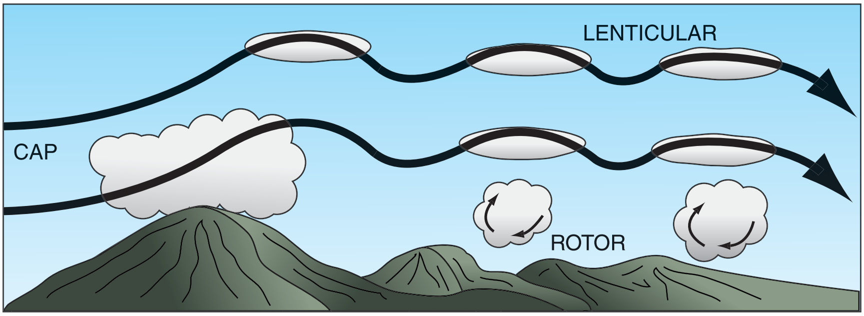

Fig. 2-23 - Characteristic clouds formed by lee waves

Fronts

A front is the transition or mixing zone between two air masses. While only the surface front is shown on a weather map, it is important to realize that an air mass is three-dimensional and resembles a “wedge”. If the colder air mass is advancing, then the leading edge of the transition zone is described as being a cold front. If the colder air mass is retreating, then the trailing edge of the transition zone is described as being a warm front.

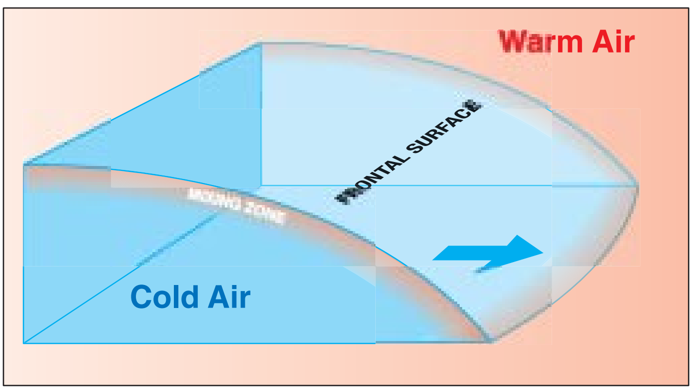

Fig. 2-24 - Cross-section of a cold front

The movement of a front is dependent on the motion of the cold air nearly perpendicular to the front, both at the surface and aloft. When the winds blow across a front, it tends to move with the wind. When winds blow parallel to a front, the front moves slowly or even becomes quasistationary. The motion of the warm air does not affect the motion of the front.

On surface charts, fronts are usually drawn as relatively straight lines. In reality, this is seldom so. Cold air flows across the surface like water. When advancing, it readily moves across level ground but in hilly or mountainous terrain it is held up until it either finds a gap or deepens to the point where it can flow over the barrier. Cold air also readily accelerates downhill resulting in rapid motion along valleys. When retreating, cold air moves slowly and leaves pools of cold air in low-lying areas that take time to modify out of existence.

Frontal Weather

When two different air masses encounter each other across a front, the cooler, denser air will lift the warm air. When this happens, the weather at a front can vary from clear skies to widespread cloud and rain with embedded thunderstorms. The weather occurring at a front depends on:

(a) amount of moisture available
Sufficient moisture must be present for clouds to form. Insufficient moisture results in "dry" or "inactive" fronts that may be marked by only changes of temperature, pressure and wind. An inactive front can become active quickly if it encounters an area of moisture.

(b) stability of the air being lifted
The degree of stability influences the type of clouds being formed. Unstable air will produce cumuliform clouds accompanied by showery weather and more turbulent conditions. Stable air will produce stratiform cloud accompanied by steady precipitation and little or no turbulence.

(c) slope of the front
A shallow frontal surface such as a warm front produces widespread cloud and steady precipitation. Such areas are susceptible to the formation of low stratus cloud and fog and may have an area of freezing precipitation. Passage of such a front is usually noted by the end of the steady precipitation, followed by a slow reduction in the cloud cover.
A steep frontal surface, such as is seen in cold fronts, tends to produce a narrow band of convective weather. Although blustery, the period of bad weather is short-lived and the improvement behind the front is dramatic.

(d) speed of the front
A fast-moving cold front enhances the vertical motion along the front, which, in turn, causes the instability to be accentuated. The result is more vigorous convective-type weather and the potential for the development of squall lines and severe weather.

Frontal Waves and Occlusions

Small-scale changes in pressure along a front can create localized alterations in the wind field resulting in a bending of the front. This bending takes on a wave-like appearance as part of the front begins to move as a warm front and another part moves as a cold front. Such a structure is known as a frontal wave. There are two types of frontal waves:

(a) Stable Waves

The wave structure moves along the front but does not develop beyond the wave appearance. Such features, known as stable waves, tend to move rapidly (25 to 60 knots) along the front and are accompanied by a localized area of heavier cloud and precipitation. The air mass stability around the wave determines the cloud and precipitation type. Since the wave moves rapidly, the associated weather duration tends to be short.

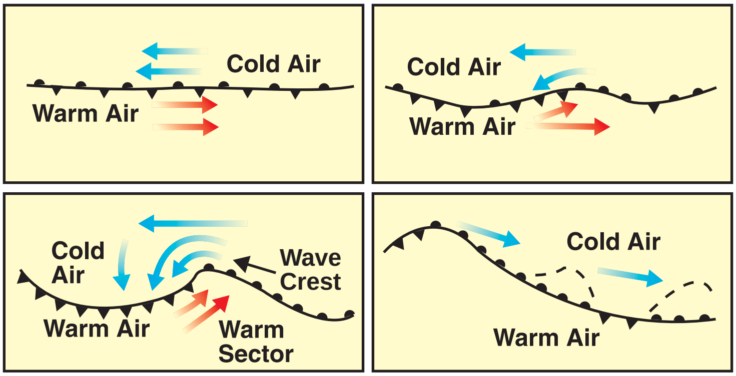

Fig. 2-25 - Stable wave

(b) Unstable (Occluding) Waves

Given additional support for development, such as an upper trough, the surface pressure will continue to fall near the frontal wave, causing the formation of a low pressure centre and strengthening winds. The wind behind the cold front increases causing the cold front to accelerate and begin to wrap around the low. Eventually, it catches up with the warm front and the two fronts occlude or "close together." At this point, the low is at maximum intensity.

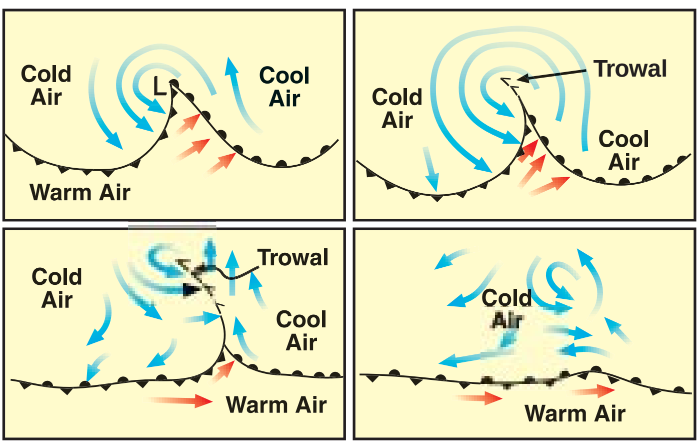

Fig. 2-26 - Formation of an occluding wave

Occlusions occur because the air behind the cold front is colder and denser than the cool air mass ahead of the warm front. Thus, it undercuts not only the warm sector of the original wave but also the warm front, forcing both features aloft. As the warm sector is lifted higher and higher, the surface portion becomes smaller and smaller. Along the occlusion, the weather is a combination of a warm front and a cold front; that is, a mix of layer clouds with steady precipitation and embedded convective clouds with enhanced showery precipitation. Such a cloud mass should be approached with caution as both icing and turbulence can be quite variable. Eventually, the frontal wave and occlusion both move away from the low, leaving only an upper frontal band curling back towards the low. This upper structure continues to weaken as it moves farther and farther away from the low that initially formed it .

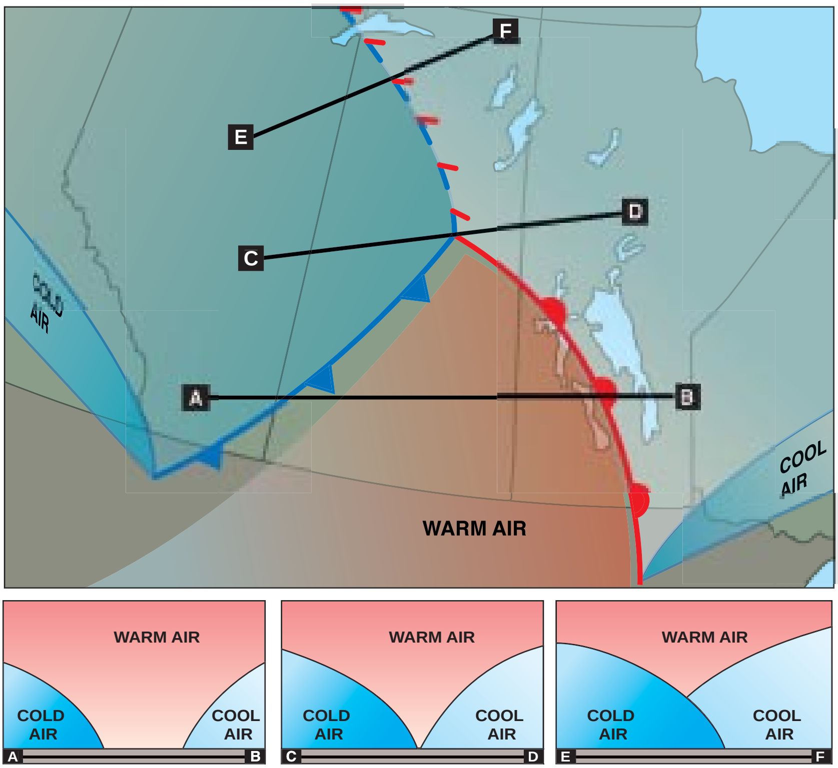

Fig. 2-27 - Frontal cross-sections

Thunderstorms

No other weather encountered by a pilot can be as violent or threatening as a thunderstorm. Thunderstorms produce many hazards to the aviation community, and, since they are so common on the prairies in summer time, it is important that pilots understand their nature and how to deal with them. To produce a thunderstorm, there are several ingredients which must be in place. These include:

- an unstable airmass
- moisture in the low levels
- something to trigger them, e.g. daytime heating, upper level cooling
- for severe thunderstorms, wind shear.

The Life Cycle of a Thunderstorm

The thunderstorm, which may cover an area ranging from 5 miles in diameter to, in the extreme case, as much as 50 miles, usually consists of two or more cells in different stages of their life cycle. The stages of life of individual cells are:

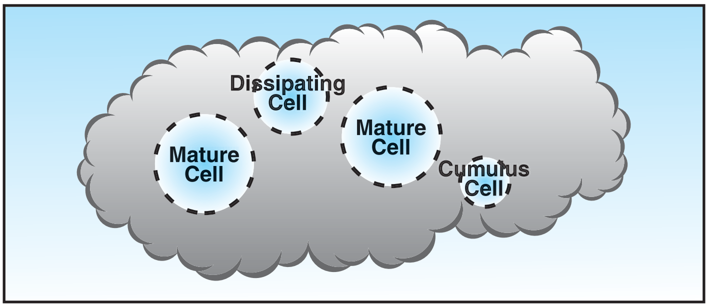

Fig. 2-28 -Top-down view of a thunderstorm "family" containing cells in different stages of development

(a) Cumulus Stage

The cumulus stage is marked by updrafts only. These updrafts can reach values of up to 3,000 feet per minute and cause the cloud to build rapidly upwards, carrying supercooled water droplets well above the freezing level. Near the end of this stage, the cloud may well have a base more than 5 miles across and a vertical extent in excess of 20,000 feet. The average life of this stage is about 20 minutes.

(b) Mature Stage

The appearance of precipitation beneath the base of the cell and the development of the downdraft mark the transition to this stage. The downdraft is caused by water drops which have become too heavy for the updraft to support and now begin to fall. At the same time, the drops begin to evaporate as they draw in dry air from the edge of the cloud, and then fall through the drier air beneath the base of the cloud. This evaporation causes the air to cool and become denser, resulting in a downwash of accelerating cold air. Typical downdraft speeds can reach values of 2,500 feet per minute.

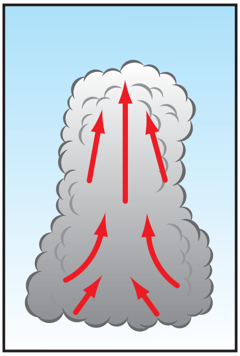
Fig. 2-29 - Cumulus stage

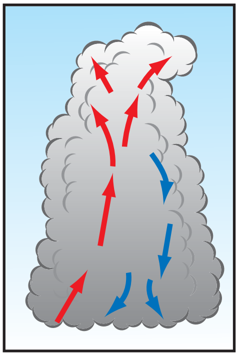
Fig. 2-30 - Mature stage

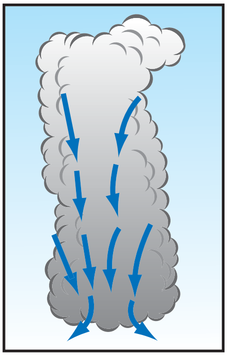
Fig. 2-31 - Dissipating Stage

The downdraft, when it hits the ground, spreads out in all directions but travels fastest in the direction that the storm is moving. The leading edge of this cold air is called the "gust front" and can extend ten to fifteen miles, or even farther, when channelled along mountain valleys in front of the storm. A rapid drop in temperature and a sharp rise in pressure characterize this horizontal flow of gusty surface winds.

At the same time, the updrafts continue to strengthen until they reach maximum speeds, possibly exceeding 6,000 feet per minute. The cloud reaches the tropopause which blocks the updraft, forcing the stream of air to spread out horizontally. Strong upper winds at the tropopause level assist in the spreading out of this flow in the downwind direction, producing the traditional anvil-shaped top. This is classically what is referred to as a cumulonimbus cloud (CB).

The thunderstorm may have a base measuring from 5 miles to more than 15 miles in diameter and a top ranging from as low as 20,000 to more than 50,000 feet. The mature stage is the most violent stage in the life a thunderstorm and usually lasts for 20 to 30 minutes.

Near the end of the mature stage, the downdraft has increased in size so that the updraft is almost completely "choked off," stopping the development of the cell. However, at times, the upper winds increase strongly with height causing the cell to tilt. In such a case, the precipitation falls through only a portion of the cell, allowing the updraft to persist and reach values of 10,000 feet per minute. Such cells are referred to as "steady state storms" that can last for several hours and produce the most severe weather, including tornadoes.

(c) Dissipating Stage

The dissipating stage of a cell is marked by the presence of downdrafts only. With no additional flow of moisture into the cloud from an updraft, the rain gradually tapers off and the downdrafts weaken. The cell may dissipate completely in 15 to 30 minutes, leaving clear skies or patchy cloud layers. At this stage the anvil, which is formed almost exclusively of ice crystals, often detaches and drifts off downwind.

Types of Thunderstorms

(a) Air Mass Thunderstorms

These thunderstorms form within a warm, moist air mass and are non-frontal in nature. They are usually a product of diurnal heating, tend to be isolated, reach maximum strength in the late afternoon, are seldom violent, and usually dissipate quickly after the setting of the sun. There is also a second form of air mass thunderstorm that is created by cold advection. In this case, cold air moves across warm land or water and becomes unstable. Of these two, it is the movement of cold air over warm water that results in the most frequent occurrence of this type of thunderstorm. Since the heating is constant, these thunderstorms can form at any time of day or night.

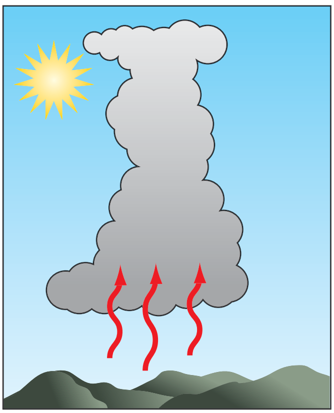

Fig. 2-32 - Air heated by warm land

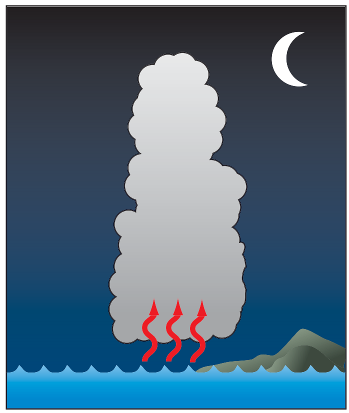

Fig. 2-33 - Cool air heated by warm water

(b) Frontal Thunderstorms

These thunderstorms form either as the result of a frontal surface lifting an unstable air mass or a stable air mass becoming unstable, as a result of the lifting. Frontal thunderstorms can be found along cold fronts, warm fronts and trowals. These thunderstorms tend to be numerous in the area, often form in lines, are frequently embedded in other cloud layers, and tend to be active during the afternoon and well into the evening. Cold frontal thunderstorms are normally more severe than warm frontal thunderstorms.

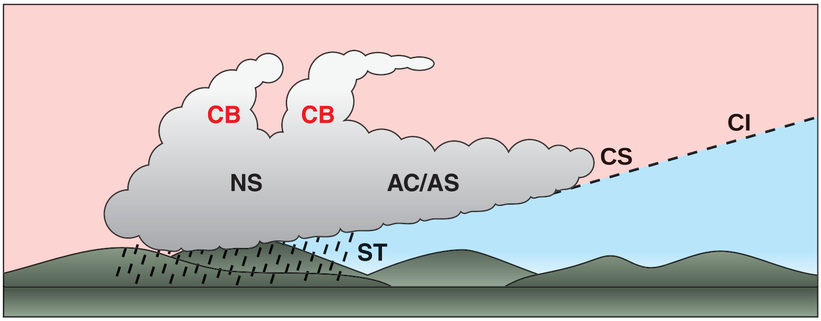

Fig. 2-34 - Warm frontal thunderstorms

(c) Squall Line Thunderstorms

A squall line (or line squall) is a line of thunderstorms. Squall lines can be several hundred miles long and have lower bases and higher tops than the average thunderstorm. Violent combinations of strong winds, hail, rain and lightning make them an extreme hazard not only to aircraft in the air, but also to those parked uncovered on the ground.

Squall line thunderstorms are most often found 50 to 300 miles ahead of a fast-moving cold front but can also be found in accompanying low pressure troughs, in areas of convergence, along mountain ranges and even along sea breeze fronts.

(d) Orographic Thunderstorms

Orographic thunderstorms occur when moist, unstable air is forced up a mountain slope. These are common in the foothills of the Rocky Mountains where, on a typical summer day, they form due to a combination of upslope flow and daytime heating. When they get high enough, the prevailing west-southwest flow aloft carries them eastwards. If conditions are favourable, they can persist for several hours, otherwise they dissipate fairly rapidly. Typically, they will begin to develop in mid-morning and can continue to form well into the afternoon. In such situations, these storms frequently produce copious amounts of hail across central Alberta.

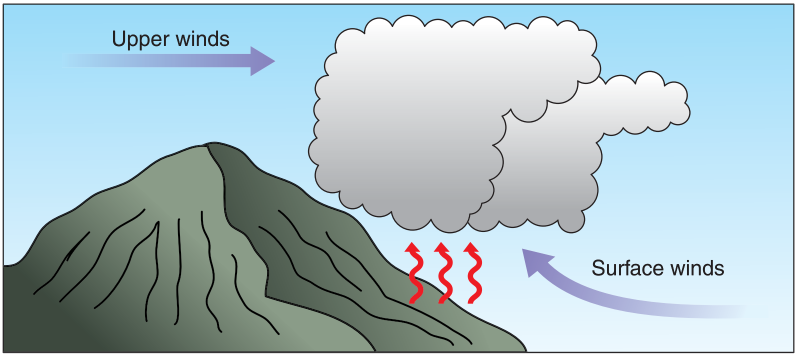

Fig. 2-35 - Orographic thunderstorms form on the foothills of the Rocky Mountains

(e) Nocturnal Thunderstorms

Nocturnal thunderstorms are those that develop during or persist all night. Usually, they are associated with an upper level weather feature moving through the area, are generally isolated, and tend to produce considerable lightning.

Severe Thunderstorms

The discussion of the life cycle of a thunderstorm does not fit the case of those that seem to last for extended periods of time and are most prolific in producing tornadoes and large hail. A particular type of severe thunderstorm is known as a "Supercell".

The Supercell storm typically begins as a multi-cellular thunderstorm. However, because the upper winds increase strongly with height, the cell begins to tilt. This causes the descending precipitation to fall through only a portion of the cell, allowing the updraft to persist.

The second stage of the supercell life cycle is clearly defined by the weather. At this stage, the largest hail fall generally occurs and funnel clouds are often observed.

The third and final stage of supercell evolution is the collapse phase. The storm's downdrafts increase in magnitude, and extend horizontally, while the updrafts are decreasing. It is at this time that the strongest tornadoes and straight-line winds occur.

While Supercells do occur over the Southern Prairies, Southern Ontario and Southwestern Quebec, they are rare elsewhere in Canada.

Thunderstorm Hazards

The environment in and around a thunderstorm can be the most hazardous encountered by an aircraft. In addition to the usual risks such as severe turbulence, severe clear icing, large hail, heavy precipitation, low visibility and electrical discharges within and near the cell, there are other hazards that occur in the surrounding environment.

(a) The Gust Front

The gust front is the leading edge of any downburst and can run many miles ahead of the storm. This may occur under relatively clear skies and, hence, can be particularly nasty for the unwary pilot. Aircraft taking off, landing, or operating at low levels can find themselves in rapidly changing wind fields that quickly threaten the aircraft's ability to remain airborne. In a matter of seconds, the wind direction can change by as much 180°, while at the same time the wind speed can approach 100 knots in the gusts. Extremely strong gust fronts can do considerable damage on the ground and are sometimes referred to as "plow winds." All of this will likely be accompanied by considerable mechanical turbulence and induced shear on the frontal boundary up to 6,500 feet above the ground.

(b) Downburst, Macroburst and Microburst

A downburst is a concentrated, severe downdraft which accompanies a descending column of precipitation underneath the cell. When it hits the ground, it induces an outward, horizontal burst of damaging winds. There are two types of downburst, the "macroburst" and the "microburst".

A macroburst is a downdraft of air with an outflow diameter of 2.2 nautical miles, or greater, with damaging winds that last from 5 to 20 minutes. Such occurrences are common in the summer but only rarely hit towns or airports.

On occasion, embedded within the downburst, is a violent column of descending air known as a "microburst". Microbursts have an outflow diameter of less than 2.2 nautical miles and peak winds lasting from 2 to 5 minutes. Such winds can literally force an aircraft into the ground.

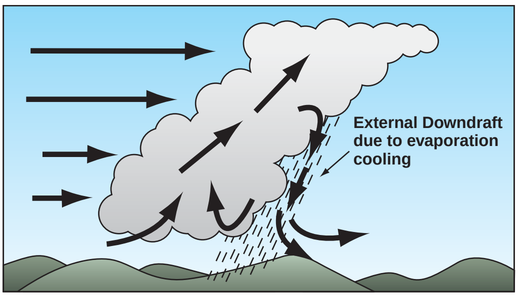

Fig. 2-36 - "Steady state" tilted thunderstorm

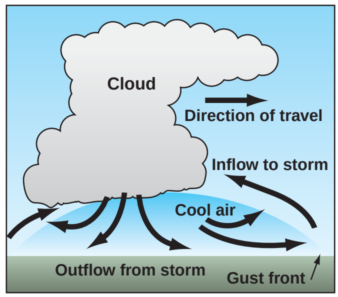

Fig. 2-37 - The gust front

(c) Funnel Cloud, Tornado and Waterspout

The most violent thunderstorms draw air into their base with great vigor. The incoming air tends to have some rotating motion and, if it should become concentrated in a small area, forms a rotating vortex in the cloud base in which wind speeds can exceed 200 knots. If the vortex becomes strong enough, it will begin to extend a funnel-shaped cloud downwards from the base. If the cloud does not reach the ground, it is called a funnel cloud. If it reaches the ground, it is refered to as a tornado and if it touches water, it is a waterspout.

Any severe thunderstorm should be avoided by a wide margin as all are extremely hazardous to aircraft.

Photo 2-3 - Severe thunderstorm credit: Alister Ling

F-Scale Number	Intensity Phrase	Wind Speed (kts)	Type of Damage Done
F0	**Weak** Tornado	35-62	Some damage to chimneys; breaks branches off trees; pushes over shallow-rooted trees; damages sign boards.
F1	**Moderate** Tornado	63-97	The lower limit is the beginning of hurricane wind speed; peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos pushed off the roads; attached garages may be destroyed.
F2	**Strong** Tornado	98-136	Considerable damage. Roofs torn off frame houses; mobile homes demolished; boxcars pushed over; large trees snapped or uprooted; light-object missiles generated.
F3	**Severe** Tornado	137-179	Roof and some walls torn off well constructed houses; trains overturned; most trees in forest uprooted
F4	**Devastating** Tornado	180-226	Well-constructed houses leveled; structures with weak foundations blown off some distance; cars thrown and large-object missiles generated.
F5	**Incredible** Tornado	227-285	Strong frame houses lifted off foundations and carried considerable distances to disintegrate; automobile-sized missiles fly through the air in excess of 100 meters; trees debarked; steel re-inforced concrete structures badly damaged.

Table 2-1 - The Fujita Scale

Waterspouts can occur over large lakes but are rare. The first sign that a waterspout may form is the cloud sagging down in one area. If this bulge continues downward to the sea surface, forming a vortex beneath it, water will be carried aloft in the lower 60 to 100 feet.

Cold Weather Operations

Operating an aircraft in extremely cold weather conditions can bring on a unique set of potential problems.

Temperature Inversion and Cold Air Outbreaks

Low level inversions are common in most areas during the fall and winter due to very cold outbreaks and strong radiation cooling. When cold air moves out over the open water, it becomes very unstable. Cloud can be seen to almost be “boiling” off the waters surface and forming vortices that rotate upwards. Such a condition can be very turbulent and there is a significant risk of serious icing. At the same time, the convection enhances any snowfall resulting in areas of extremely poor visibility.

Looming

Another interesting effect in cold air is the bending of low angle light rays as they pass through an inversion. This bending creates an effect known as “looming,” a form of mirage that causes objects normally beyond the horizon to appear above the horizon.

Ice Fog and Ice Crystals

Ice fog occurs when water vapour sublimates directly to ice crystals. In conditions of light winds and temperatures colder than -30°C or so, such as those that might be found in Cold Lake, water vapour from anthropogenic sources (man-made) can form widespread and persistent ice fog or ice crystals. In light winds, the visibility can be reduced to near zero, closing an airport for hours.

Blowing Snow

Blowing snow can occur almost anywhere where dry snow can be picked up by strong winds but poses the greatest risk away from the forested areas of the Prairies. As winds increase, blowing snow can, in extreme conditions, reduce horizontal visibility at runway level to less than 100 feet.

Whiteout

“Whiteout” is a phenomena that can occur when a layer of cloud of uniform thickness overlays a snow or ice-covered surface, such as a large frozen lake. Light rays are diffused when they pass through the cloud layer so that they strike the surface from all angles. This light is then reflected back and forth between the surface and cloud, eliminating all shadows. The result is a loss of depth perception, the horizon becoming impossible to discern, and dark objects seeming to float in a field of white. Disastrous accidents have occurred under such conditions where pilots have flown into the surface, unaware that they were descending and confident that they could see the ground.

Altimetry Errors

The basic barometric altimeter in an aircraft assumes a standard change of temperature with height in the atmosphere and, using this fact, certain pressure readings by the altimeter have been defined as being at certain altitudes. For example, a barometric altimeter set at 30.00" would indicate an altitude of 10,000 feet ASL when it senses the outside pressure of 20.00".

Cold air is much more dense than the assumed value used in the standard ICAO atmosphere. For this reason, any aircraft that is flying along a constant pressure surface will actually be descending as it moves into areas of colder air, although the indicated altitude will remain unchanged. Interestingly enough, a new altimeter setting obtained from a site in the cold air will not necessarily correct this problem and may increase the error.

Consider:

A pilot obtained an altimeter setting of 29.85" and plans to maintain a flight level of 10,000 feet enroute. As the aircraft moves into an area with a strong low-level inversion and very cold surface temperatures, the plane descends gradually as it follows the constant pressure surface corresponding to an indicated altitude of 10,000 feet. A new altimeter setting, say 30.85 inches, is obtained from an airport located in the bottom of a valley, deep in the cold air. This new setting is higher than the original setting and, when it is entered, the altimeter will show an increase in altitude (in this case the change is one inch and so the altimeter will show an increase from 10,000 to 11,000 feet). Unaware of what is happening, the pilot descends even further to reach the desired enroute altitude, compounding the height error.

If the aircraft were operating in cloud-shrouded mountains, an extremely hazardous situation can develop. There is no simple solution to this problem, other than to be aware of it and allow for additional altitude to clear obstacles.

Volcanic Ash

A major, but fortunately infrequent, threat to aviation is volcanic ash. When a volcano erupts, a large amount of rock is pulverized into dust and blasted upwards. The altitude is determined by the severity of the blast and, at times, the ash plume will extend into the stratosphere. This ash is then spread downwind by the winds aloft in the troposphere and the stratosphere.

The dust in the troposphere settles fairly rapidly and can limit visibility over a large area. For example, when Mt. St. Helens, Washington, erupted, there was ash fallout and limited visibility across southern Alberta and Saskatchewan.

Of greater concern is the volcanic ash that is ingested by aircraft engines at flight level. Piston-driven engines have failed due to plugged air filters while turbine engines have "flamed out."

The volcanic dust also contains considerable pumice material. Leading edges such as wings, struts, and turbine blades can all be abraded to the point where replacement becomes necessary. Windscreens have been abraded until they become opaque.

Deformation Zone

A deformation zone is defined as "an area in the atmosphere where winds converge along one axis and diverge along another. Deformation zones (or axis of deformation as they are sometimes referred to) can produce clouds and precipitation." More simply put, we are referring to areas in the atmosphere where the winds flow together (converge) or apart (diverge), resulting in areas where air parcels undergo stretching along one axis and contraction along another axis. Meteorologically, this is an area where significant cloud amounts, precipitation, icing and turbulence can occur to in the induced vertical currents.

For meteorologists, the most common form of deformation zones are the ones associated with upper lows. Northeast of the upper low,, a deformation zone usually forms in which the air is ascending. In this area, thick cloud layers form giving widespread precipitation. Depending on the temperatures aloft, this cloud may also contain significant icing. During the summer, the edges of this cloud area will often support thunderstorms in the afternoon. If this area of cloud is slow moving, or should it interact with terrain, then the upslope areas can see prolonged precipitation. Winds shear in the ascending air will often give turbulence in the middle and higher-levels.

A second deformation zone exists to the west and northwest of these lows. In this case the air is descending, so that widespread higher clouds usually only consist of whatever cloud is wrapped around the low. Precipitation here tends to be more intermittent or showery. Wind shear can also cause turbulence but most often it is confined to the low-levels.

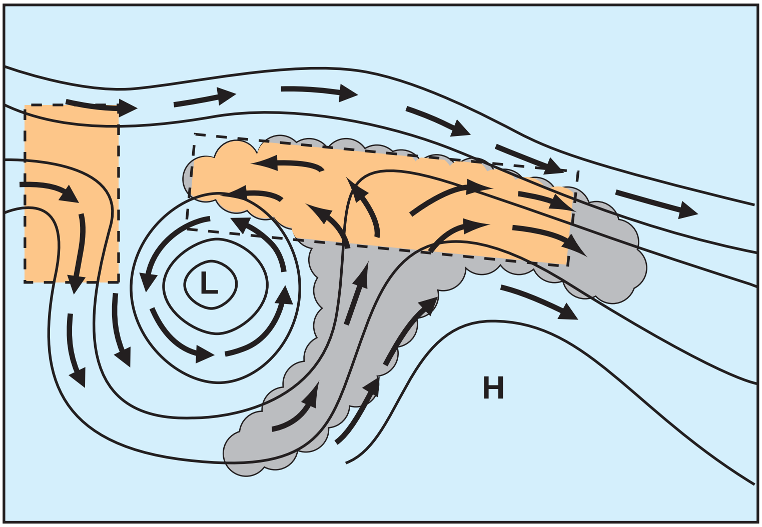

Fig. 2-38 - Deformation zones