Ice

This is the first in a series of articles on airframe icing and its effects. It is part of an on-going educational campaign by the CAA aimed at IFR pilots – particularly those who regularly fly at medium-level altitudes where airframe icing is most likely to occur.

Background

The icing education campaign arose out of recommendations made in the 1998 CAA Ministerial Inquiry following the Beech Baron accident in the Tararua Ranges. The Inquiry made a number of wide-ranging recommendations relating to aircraft icing certification standards, company operating procedures, and pilot training requirements. The Inquiry also recommended the implementation of an educational programme on icing. (We reported on this in the July/August, 2000 issue of *Vector.*)

This article touches briefly on aircraft icing certification levels, then examines the inherent icing hazards that exist in the New Zealand meteorological environment. Finally, we look at different types of airframe icing – where and how they occur and the effect they have on aircraft aerodynamics.

Aircraft Icing Certification Levels

Despite the US Federal Aviation Regulations (FARs) and the most current aircraft certification requirements, there is evidence that icing conditions and their effects on aircraft aerodynamics are not yet completely understood. Simply put, pilots must **not** be over reliant on de-icing and anti-icing equipment fitted aboard aircraft that have been certified for flight into icing conditions. Severe icing conditions can be outside the aircraft certification-icing envelope, and each pilot must be vigilant to avoid conditions beyond an aircraft's capabilities.

More specifically, CAA rule 91.421 *Operating in Icing Conditions* states that: "…a pilot-in-command operating an aircraft under IFR shall not fly an aircraft into known or forecast icing conditions unless the aircraft is certificated with ice protection equipment for flight in the type of known icing conditions".

It is vital that, as pilot in command, you know what level your aircraft is certificated to and that you abide by it – there is no room for complacency in this regard. There have been a number of reported instances in New Zealand of pilots commencing flights into known icing conditions that were more severe than the icing certification level of their aircraft.

Aircraft icing certification levels will be covered in more detail in a later article.

The New Zealand Icing Environment

In 1999 the CAA commissioned a study into New Zealand aircraft icing hazards. The resulting document (*The Aircraft Icing Handbook,* available on the CAA web site under **Safety Information – Publications – GAP booklets**) included a comparison with US icing accident rates. The New Zealand rate proved to be significantly lower. In fact, the New Zealand rate was so low that it was difficult to reconcile it with the opinion of local SAAB and ATR pilots that icing in

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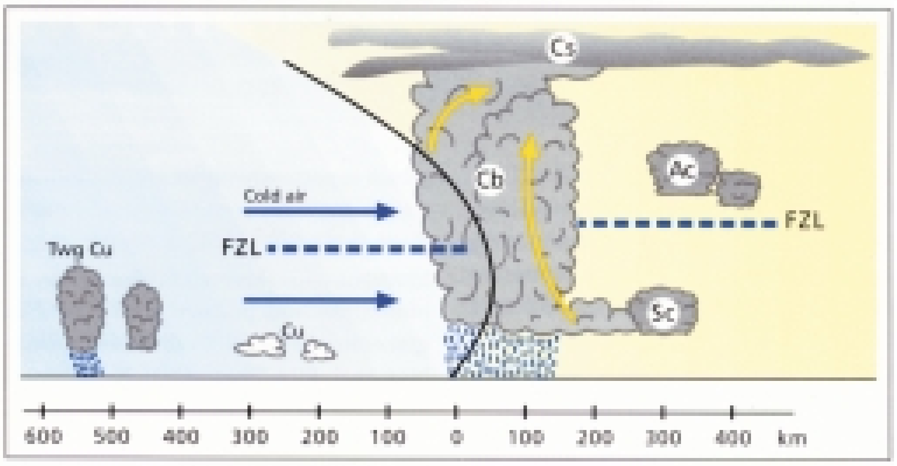
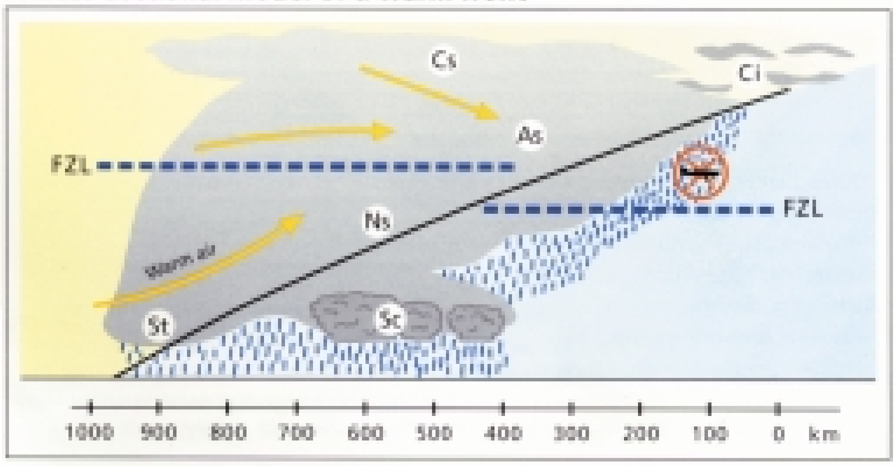
A cross-sectional model of a cold front



A cross-sectional model of a warm front



The above diagrams show the typical cloud types anf freezing levels associated with frontal activity. The FZL can vary considerably, depending on latitude, season and airmass characteristics. Note the area above the FZL ahead of the warm front where freezing rain is likely to occur.

Diagrams adaped from *Weather to Fly* by Walter Wagtendonk.

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New Zealand was as severe, if not worse, than their counterparts experience in Europe and the US.

The New Zealand icing hazard often involves conveyor belt flows which, when subjected to suitable lifting and cooling, can pose a significant icing hazard. New Zealand's alpine chain is exposed to a relatively warm maritime airflow (conveyor belt) that is lifted and cooled (orographic lifting) by our mountainous interior. Sea surface temperatures are warmer, producing a higher moisture content in the maritime airflow than is experienced in higher-latitude countries such as North America and Northern Europe – thus the potential for icing at altitude (between 8000 and 20,000 feet) in New Zealand exists.

Weather patterns, specifically surface weather, are more extreme in Europe and North America – a simple product of colder latitude and continental modification. Without the benefit of research or a historical comparison, one can only speculate that New Zealand's surface weather is comparatively benign, yet the propensity for icing at altitude is equal to, if not greater than, that in colder continental environments. In this context, the FAA Flight Safety Research Section has recorded most US icing accidents during the approach and landing phase of flight. The tendency for higher-altitude icing in New Zealand could explain the statistical disparity between North America and New Zealand ice-related accidents.

While the incidence of low-altitude icing may be relatively small in New Zealand, the risk of severe icing at altitude exists – a risk as great, if not greater, than elsewhere in the world. Examples of New Zealand icing-related occurrences include:

- In 1987 a Cessna Caravan crashed off the coast of Kaikoura after descending out of control from 11,000 feet.
- In 1994 a SAAB 340 experienced loss of airspeed and a series of roll upsets at 11,000 feet while in the Tory holding pattern.
- In 1997 a Beech Baron climbed to 10,000 feet over the Tararua Ranges before the pilot lost control in forecast icing conditions.

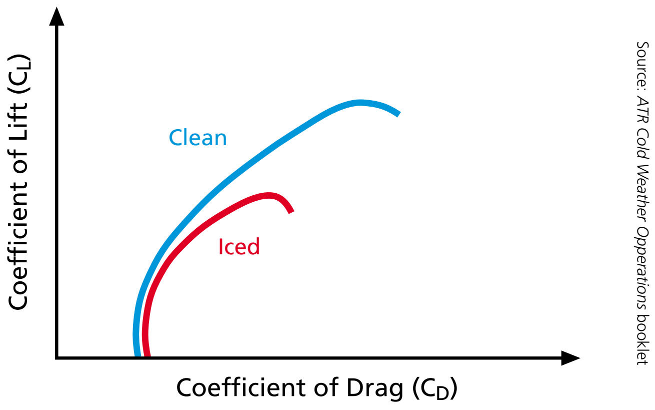
None of this means that we should discount the possibility of lower-level airframe icing in New Zealand. Severe icing can occur when **any** onshore conveyor is lifted and cooled, and it should be taken seriously by pilots. While it would be convenient to define specific locations and altitudes where this occurs, it is impractical to do so, as the variables defy simplification. Known ice areas and routes include the 'Otaki Iceberg;' Nelson-to-Christchurch, Timaru-to-Alexandra, and over the Southern Alps. Identification and advice on these hazardous areas are best left to individual operators and their pilot training programmes, rather than elaborating on them here.

Aerodynamic Considerations

Any in-flight icing can be a serious hazard to flight, particularly when operating over terrain that does not permit a descent into warmer conditions. The effects of ice on aircraft aerodynamics are many and varied.

Mainplane Icing

Although ice can accrete on many aeroplane surfaces, of most concern is mainplane aerofoil icing. Ice destroys the smooth flow of air over the wing, diminishing its ability to generate lift. Ice increases drag, increases the aircraft weight, and degrades the pilot's control authority. As power is added to compensate



The effect of ice build-ups on C_L and C_D for a typical aerofoil.

for the additional drag and the aircraft nose is lifted to maintain altitude (thus increasing the angle of attack), additional ice will begin to accumulate on the underside of the wings and fuselage. Testing has shown that ice accumulation (on the leading edges or upper wing surfaces) no thicker than a piece of coarse sandpaper can reduce lift by as much as 30 percent and increase drag by as much as 40 percent. Larger accretions can reduce lift even more and increase drag by more than 80 percent.

> ***"It is vital that, as pilot in command, you know what level your aircraft is certificated to and that you abide by it…"***

Some aerofoil designs are less sensitive to contamination than others. An infinite variety of shapes, thickness and textures of ice can accrete at various locations on the aerofoil. Each ice shape essentially produces a new aerofoil with unique lift, drag, stall angle and pitching moment characteristics that are different from the wing's own aerofoil, and from other ice shapes. These shapes create a range of effects. Some effects are relatively benign. Others may alter the aerodynamic characteristics so drastically that all or part of the aerofoil stalls suddenly and without warning. Sometimes the difference in ice accretion between a benign shape and a more hazardous shape appears insignificant.

The effects of severe icing are often exclusively associated with ice thickness. On other occasions, a layer of ice having substantial chord-wise extent is more adverse than a seven-centimetre ice accretion having upper and lower horn-shaped ridges. Ice can contribute to partial or total wing stall followed by roll, aileron snatch or reduced aileron effectiveness.

Tailplane Icing

One hazard of severe structural icing is the tailplane or empennage stall. Sharp-edged surfaces are more susceptible to collecting ice than large blunt ones. For this reason, the tailplane may begin accumulating ice before the wings. The tailplane will also accumulate ice more quickly. Because pilots cannot readily see the tailplane, they may be unaware of the situation until a stall occurs when the critical angle of attack is exceeded (this may occur at a relatively high airspeed). Since the tailplane counters the natural nose-down tendency caused by the centre of lift of the main wing, the aeroplane will react by pitching nose down, sometimes uncontrollably. Application of flaps can initiate or aggravate this process. Caution should be used when applying flaps during an approach if there is the possibility of tailplane icing.

Roll Upsets

Roll upsets due to airframe icing are a serious control problem, which can be fatal. They occur for a number of reasons:

- Ice build-ups on the wing lower surface and fuselage eventually cause a conventional stall as the angle of attack is progressively increased, which is followed by a roll upset.
- Under certain conditions, ice can form in ridges just forward of the ailerons disturbing the airflow over them in such a way as to create an aerodynamic imbalance. Eventually the aileron will 'snatch' or deflect out of the neutral position of its own accord and cause the aircraft to roll. This can happen at angles of attack that may be considerably less than the stalling angle. On un-powered controls, it is felt as a change in control-column force. Instead of requiring a force to deflect the aileron, force is required to return the aileron to the neutral position. Aileron instability sensed as an oscillation, vibration or buffeting in the control column is another clue that the airflow over the ailerons is disturbed.
- Loss of roll effectiveness can result when ice forms ahead of the ailerons and disrupts the airflow over them in such a way that it reduces their effectiveness to the point where roll performance is less than desirable. This is different from the aileron 'snatching' scenario, where aerodynamic balance is disrupted but effectiveness is essentially maintained.
- A further condition that can contribute to roll-control problems is the accumulation of more ice at the wings tips than the roots. This occurs because the wings tips are thinner, may have a different camber and a shorter chord, and often have a degree of aerodynamic washout relative to their roots. For these reasons, the wing tips will tend to accumulate ice quicker, thicker and further aft than on a general-purpose aerofoil. Such ice build-ups cause separation of the airflow at the wing tips, which compromises aileron effectiveness.

Note: Because of the broad range of environmental conditions, limited availability of data, and various aircraft configurations, pilots must use the information detailed in the manufacturer's Flight Manual for specific guidance on how to deal with roll upsets in icing conditions in their aircraft type.

Loss of Thrust

Loss of thrust or lift due to ice build-ups on the propellers, rotor blades, or around engine intakes is also a serious consideration. Not only will ice accretion significantly reduce the amount of thrust or lift produced, but is also likely to cause the propeller or rotor to become unbalanced. Unbalancing can threaten the integrity of engine and gearbox mounts – the consequences of which could become terminal very quickly.

Normal residual ice on a SAAB 340 propeller during airborne icing certification trials.

Photograph courtesy of SAAB.

Instrument Errors

The blockage of pitot intakes and static vents by ice will produce pressure instrument errors – the last thing that you want in IMC while trying to cope with airframe icing. Airspeed indicator error is the most common occurrence, but other pressure instruments will give erroneous readings if their static source becomes blocked. Similar problems can occur with fuel vents, EPR sensors, flap mechanisms and undercarriage operation.

The best defence against pitot icing is to ensure that the heating elements are working during the pre-flight and are switched on well in advance of any anticipated icing conditions.

Appendages

Ice accumulates on every exposed frontal surface of the aircraft – not just its wings, tail, fuselage and propellers – but also on the windshield, antennas, intakes, vents, and cowlings. Most aircraft do not have anti-ice equipment that is effective in controlling ice accretion on these appendages. A severe icing problem can therefore develop very quickly. In moderate to severe icing conditions some aircraft (especially some light twins) can become so iced up that flight is impossible.

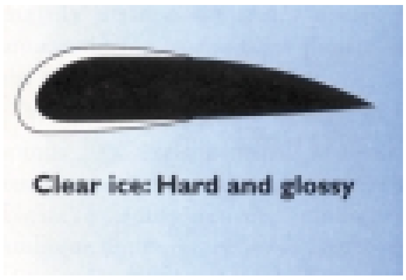
Ice accumulation on the nose of an aircraft.

Photograph courtesy of ATR

Types of Airframe Icing

Let's now look specifically at the different types of airframe icing, how and where they occur, and what effect they have on aircraft aerodynamics.

Clear Ice



Clear ice normally occurs when super-cooled water droplets freeze and then spread out on contact with a cold surface. The most likely temperature range for clear ice is between approximately 0° and –15°C. Super-cooled droplets (rain droplets that exist in the atmosphere at temperatures well below the normal freezing point of water) are unstable and will freeze on contact with any surface below 0°C. As each droplet freezes, latent heat is released in the freezing process, allowing part of it to flow rearwards before it solidifies. The slower the freezing process, the greater the flow-back before it freezes. The result is a sheet of clear ice with very little trapped air. It has a high density and is correspondingly heavy and tenacious, characteristics that make it difficult to shed any significant accumulation.

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Clear ice is dangerous for many reasons. As mentioned, it can spread back over a large area to parts of the aircraft that do not have ice protection – this can cause a rapid increase in weight. It can be difficult to detect (particularly at night) because it is transparent and tends to follow the contours of the aircraft's surface. Initially, it may not adversely affect aerodynamic performance, and the accumulation may be undetected by the pilot. Clear ice is tenacious, and if allowed to flow back to the hinge line of a control surface, may render it unusable. It also tends to break off in large chunks when the aircraft encounters warmer air, possibly causing airframe damage.

Although not confined to cumulus developments, clear ice can be anticipated in cumulus cloud within the first 6000 to 8000 feet above the freezing level. This is largely due to convective movement producing high water content and consequent development of super-cooled droplets. Cumulus cloud formations (especially cumulonimbus) associated with frontal systems can be dangerous if the aircraft is flown along, or near to, the front line. Isolated clusters of cumulus cloud at this level, however, do not pose a serious icing threat, as the aircraft is only exposed to icing conditions for very short periods.

Super-cooled Large Water Droplets (SLDs) can, however, exist in stratiform clouds and, when this does occur, it often happens over a wide area. A number of aircraft have suffered upsets in these situations – usually while in a holding pattern in moderate to severe icing conditions arising from SLDs. In contrast to cumulus developments, icing layers in stratus formations are relatively shallow, and it is often possible to climb or descend out of the icing layer.

Rime Ice

Rime ice is rough and uneven in its appearance and fairly brittle in comparison to clear ice. This is due to rapid freezing that traps many pockets of air within its mass. Rime ice is usually the result of much smaller and colder (ie, below –15°C) super-cooled water droplets freezing almost instantaneously as they come into contact with the cold surface of the aircraft. The extent to which the droplets flow rearwards as latent heat is released is far more limited than it is with the larger super-cooled droplets that form clear ice. Thus the total surface area affected by ice is considerably reduced.

The large amount of air trapped within the ice gives it rough and crystalline characteristics. As it builds up on the leading edges of the wings and tail, it dramatically affects their aerodynamic qualities – accumulations around engine intakes can also have a detrimental effect on engine performance. The large increase in drag and loss of lift associated with rime ice build-up does not require elaboration, other than to stress the importance of clearing it quickly – there are numerous overseas examples of aircraft suffering tailplane stalling due to severe rime ice build-ups. Unlike clear ice, rime ice does not usually cause a significant increase in aircraft weight, and it can be readily cleared by the activation of de-ice equipment.

Rime ice is usually associated with stratiform cloud, where a lack of convective movement within the cloud means that large SLDs do not have time to form due to the reduced number of droplet collisions. The temperature range for the formation of rime ice is generally between 0° and –40°C, but is most commonly encountered within the range –10° to –20°C. If the flight takes place in temperatures colder than this, the ice particles may be so dry that they do not adhere to the aircraft skin. However, stratiform clouds associated with an active front,

Photograph courtesy of ATR.

Rime ice on the leading edge of an ATR wing. It is typically very brittle and frost-like in its appearance.

or with orographic lifting of a moist maritime airflow, increase the icing probability at lower-than-usual temperatures – continuous upward motion of air generally means a greater retention of moisture within the cloud.

Flight in stratiform cloud within the first 2000 to 3000 feet above the freezing level may produce SLD conditions conducive for moderate to severe clear ice formation. Stratiform cloud associated with a warm front often has embedded cumulus cloud. Care should be exercised in anticipating, and avoiding, the types of conditions that might be conducive to these icing combinations.

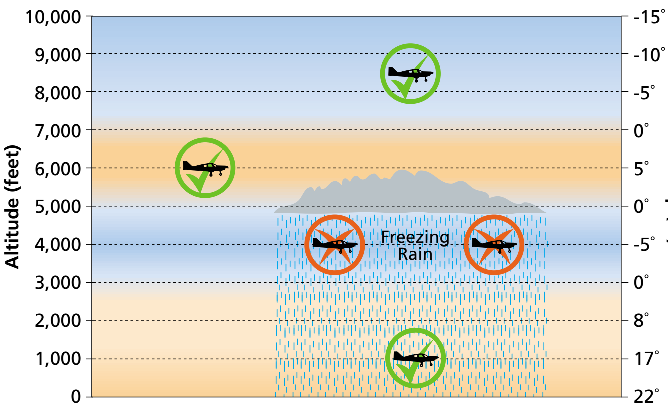
Freezing Rain

Freezing rain occurs when rain from a warm layer of cloud falls into an air mass that has a temperature below zero. If you happen to be flying through this area it is likely that your aircraft will be quickly enveloped in ice (usually clear ice) from the freezing rain.

Freezing rain is normally associated with the cold sector directly under the slope of a warm front, or in the cold sector just behind a cold front. Sometimes it can occur where there is a strong temperature inversion and rain falls from warmer air at altitude into cooler air just above the freezing level.

If flight is continued in the freezing rain environment, it is likely that anti-icing or de-icing systems will not be able to cope and aerodynamic performance will be quickly degraded. If these conditions are encountered, it is essential to vacate them as soon as possible.

Freezing rain associated with a frontal system inversion layer



This graph shows how a temperature inversion at altitude can produce conditions conducive to freezing rain.

Summary

- New Zealand's mid-latitude location, relatively warm oceans, and orographic lifting all combine to make a meteorological environment that is conducive to icing at altitude.
- Most of our light to medium weight IFR traffic cruises at medium-level altitudes (ie, generally between 8000 to 20,000 feet), which is where the main risk of airframe icing in New Zealand exists.
- Over reliance on de-icing and anti-icing equipment should be avoided.
- Ice destroys the smooth flow of air over the wing diminishing its ability to generate lift and dramatically increases drag and weight.
- Tail icing can lead to tailplane stalling and nose-down pitching particularly when landing flap is selected on final.
- Disruptions to the airflow around the ailerons and wingtips by ice can induce roll upsets.
- The effects of ice on aircraft pressure instruments are numerous and should never be underestimated.
- Clear ice normally occurs between 0° and –15°C. It can quickly build up undetected, dramatically increasing the aircraft weight and stall speed. Clear ice build-ups can freeze up control surfaces and is often difficult to get rid of. It is most commonly encountered in cumulus cloud within the first 6000 to 8000 feet above the freezing level.
- Rime ice can affect the aerodynamic qualities of the aircraft (because of its uneven crystalline nature) by degrading the laminar airflow over the wings and tailplane. Rime ice build-ups can cause unexpected stalling and degraded control effectiveness. Rime ice is most commonly encountered within the temperature range –10° to –20°C and is usually associated with stratiform cloud.
- Freezing rain occurs when rain from a warm layer of cloud falls into an air mass that has a temperature below zero. It can envelop the entire aircraft with clear ice in a matter of minutes to the point where de-icing equipment is unable to cope. Freezing rain is normally associated with the cold sector directly under the slope of a warm front, or in the cold sector just behind a cold front.

Watch out for the next article in this series where we will look at other types of airframe icing, identification and avoidance of icing conditions, aircraft icing certification levels, and company Standard Operating Procedures. ■

References

Meteorology for Professional Pilots by Walter J. Wagtendonk

The Aircraft Icing Handbook published by the Civil Aviation Authority of New Zealand.

Are Helmets a Good Investment?

You Bet They Are!

From issue 2/2000 of Transport Canada's aviation safety magazine Vortex.

All hazards were identified in a thorough reconnaissance of the job site prior to landing, and the identified hazards were again reviewed on the ground before starting the work. The sky was clear, wind calm, temperature 12 degrees, and humidity 32 percent.

The spray job was in a rectangular 40-acre field with a power line on the west side running north and south and a row of mature trees on the north and south sides running east and west. A barbed wire fence surrounded the entire field.

The field was seeded to corn and the crop was about three inches high. The circumference of the field was bordered by a 30 to 40-foot strip of barley. The chemical used that day was WPA, and we were using an ultra-low-volume application. All equipment was tested before starting the work, and both the helicopter (a Robinson R22) and spray gear were operating as expected.

> ***There is no doubt in my mind that my helmet saved me from serious injury and quite probably death.***

I flew one orientation pass from south to north (the longest side of the rectangular field), noting the power line, which was about 50 feet away on my left. I turned right, away from the power line, and started to apply the product to the field. I had made three passes when I realised that I did not have enough product to do another full pass.

Because of the trees at either end of the field, I decided to spray a headland pass to give me more room to pull up at the treed end of the field. I figured I had enough product remaining to do one headland pass before heading back to refill.

I pulled up and flew out of the field to determine how best to approach the headland pass. Flying to the west would bring me too close to the power line at a high rate of speed, so I decided to fly away from the power line. I manoeuvred into position with the power line behind me. I had settled into what I thought was a stable hover but, as I moved slowly forward,

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