CHAPTER 12

AIRFRAME ICING

Photo courtesy of Kelly Paterson

Airframe icing is a thorn in the side of many an aviator—but for pilots in the northern tier of the States or Alaska, it's part of doing business. Even small accumulations of airframe icing can wreak havoc, so pilots must know its inherent perils. ***Airframe*** or structural icing can be subdivided into ***ground icing*** and ***in-flight icing.***

This chapter will discuss both. We also lightly delve into ***induction icing***, which affects reciprocating engines.

WATER DROPLETS OR ICE CRYSTALS?

If there is a cloud deck based at 1,500 feet and the surface temperature is well below freezing, what are the clouds composed of? Most people would guess ice crystals. One of the biggest assumptions made about clouds is that cloud droplets freeze to ice crystals quickly once the temperature reaches a few degrees below zero Celsius. After all, when ice crystals are warmed above freezing, they immediately melt. But when water droplets are cooled to below freezing they are happy to remain in the liquid phase until very cold sub-zero temperatures are reached. However, zero degrees Celsius does mark the temperature below which water droplets become ***supercooled*** and are ***capable*** of freezing. While some droplets freeze spontaneously just below 0°C, most persist in a liquid state at much lower temperatures.

Most meteorologists I know are more comfortable with the term "melting level" instead of freezing level which is more common in the aviation weather world. That's because we know water in the solid state must melt when the temperature is above 0°C, but doesn't necessary have to freeze at a temperature below 0°C. But I doubt the FAA will ever use anything but freezing level.

Why don't ice and aircraft wings mix? Flight is achieved by air flowing ***smoothly*** over a wing (the smooth movement of the fluid in parallel layers, with no disruption between the layers, is called ***laminar flow***). When ice contaminates an aircraft's wings, laminar flow is disrupted, which in turn causes lift to decrease and wing performance to suffer. Many people assume ice on airfoils is dangerous solely because of the additional weight, but it's the loss of lift from the disruption in laminar flow and increase in drag that causes most problems associated with airframe (structural) icing.

An aircraft can lose 30% of its lift with just a small accumulation of ice the thickness of sandpaper. The stall speed will increase with drag potentially increasing 40% or higher.

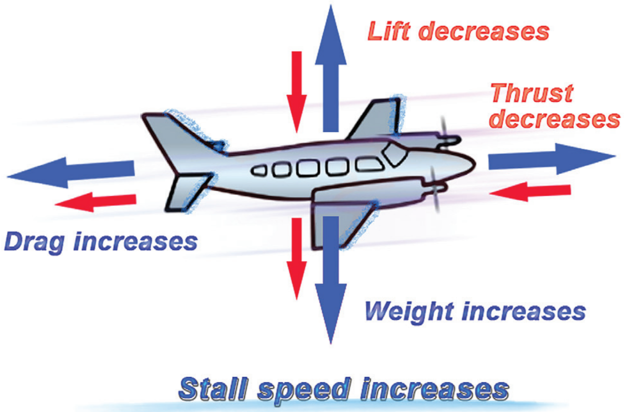


Figure 12-1: shows the forces of flight affected by icing. As drag, weight and stall speed increase, and lift and thrust decrease; the end result is an unsafe scenario.

The Many Hazards of Icing

1. **Reduced Lift:** This is the most dangerous result of icing. Like ailerons, flaps, spoilers, elevators, and rudders, flight controls become less effective when ice accumulates. Some aircraft will exhibit a tendency to enter a spin in this scenario. During the flare, you may find your elevator unresponsive due to ice build-up.

***1.** During my Navajo days, the procedure was to wiggle the elevator on short final to shake off any ice and ensure that it was operating jam-free. **2.** On one approach into Calgary, Alberta in freezing fog on the Airbus A320, my flare didn't really happen. I'm certain ice accumulation on the non-deiced tail played a part. At least that is my excuse for a hard landing.*

2. **Increased Parasitic Drag:** Smaller aircraft are not as streamlined as most passenger airliners. Protuberances like the struts and wheels of fixed landing gear, and wing struts can cause ice build-up. This increased drag will require higher throttle power/thrust settings and result in higher fuel burns.
3. **Increased Weight:** Although most books downplay the effect of increased weight from ice build-up, it can certainly become an issue in the overall picture. If the aircraft is near maximum weight, an engine malfunction during takeoff could be catastrophic.
4. **Increased Stall Speed:** This is an important factor to consider during operations with high angles of attack, including takeoff, approach to land, landing. Many operating procedures recommend increasing the approach speed when landing with accumulated ice; this is called flying the approach ***hot.*** The airplane may stall at much higher speeds and lower angles of attack than normal. It can roll or pitch uncontrollably, and recovery may be impossible.
5. **Flaps/Slats Selection:** Difficulty in selecting flaps/slats can result from ice on the wings, as these components may become jammed. Some company procedures require that you DO NOT set your flaps/slats until fully ready for takeoff.
6. **Blocked Pitot/Static Systems:** Ice blocking pitot tubes and static ports will cause problems with the airspeed indicator, altimeter and vertical speed indicator. A blocked pitot tube and drain hole affects the airspeed indicator, causing it to over-read in a climb and under-read in a descent. (A partially blocked system may not be so discernable). Readings will drop to zero if the drain hole is open. A blocked static port affects more instruments: altimeter, vertical speed indicator, and airspeed indicator. Erroneous readouts on the airspeed indicator can be difficult to diagnose; icing tends to cause decreased airspeed readings in a climb and increased readings in the descent. Most aircraft have an alternate static source, found in the flight deck, which can be used to verify that your instruments are in working order and provide static pressure to the instruments. A blocked pitot/static source on airliners will affect computer-driven instruments. In 2009, an Air France Flight 447 flying an Airbus A330 in heavy convective cloud succumbed to ice-induced faulty (and faulty pilot technique) readings due to a high ice water content (high concentration of ice crystals).
7. **Effect of Ice on Stall Warning Devices:** Ice on the wing will increase the stall speed (and stall angle of attack) and therefore the stall warning device may or may not activate to provide a

timely warning to the pilot. Margins between the coefficient of lift and the stall angle of attack at takeoff are normally small and the reduction of the stall angle due to surface contamination reduces the margin even further with no warning.

Know these discrepancies and their effects on the pitot-static system, as they are asked on many commercial/instrument/ATPL exams.

8. **Increased Fuel Consumption:** Fuel consumption can double under airframe icing conditions. For some aircraft, this can be equivalent to flying with the landing gear down. For more advanced aircraft, extra fuel will be burned to operate the deicing/anti-ice systems.
9. **Obscuring Windscreens:** Under severe conditions, vision can be restricted to the point of complete obscuration. Many light aircraft do not have windshield heating.

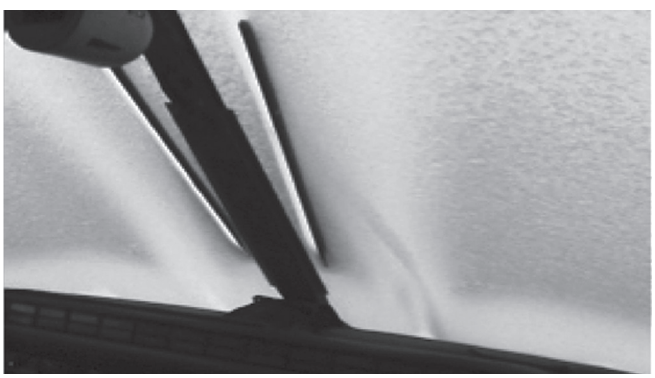
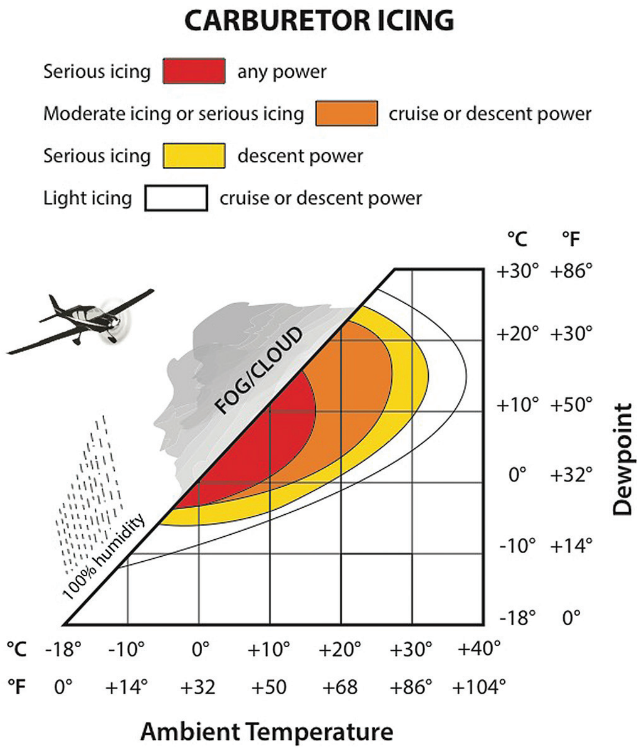


Figure 12-2: Windscreen severely iced up with no deicing capability (or unserviceable). This picture belongs to a student Doug taught weather to. This was taken during his first job, flying a King Air in the Canadian North. (Photo courtesy of David Lewis.)

An operator I flew for years ago used to supply windshield scrapers to use while in flight! In the Navajo, it was possible to reach out of a small side window to scrape the front window. Looking back on this, I sure am thankful everything worked out.

10. **Ice in Landing Gear Wells:** When this happens, it can cause difficulties in retraction/extension. Icing of brakes during taxi can be an issue, and some procedures recommend that you leave the gear extended a little longer after takeoff to allow ice to break away from the brakes.
11. **Ice on Aerials:** Iced-over aerials can cause static and poor communication; sometimes, aerials have even been known to break off mid-flight, due to vibration or the heavy weight amassed. Ice may impede radar altimeter aerials, causing erroneous readouts.
12. **Propeller Vibration:** Propellers can quickly become out of balance due to unequal shedding or ice build-up—factors which can also cause engine roughness. Ice will form first on the spinner and then spread to the blades. Ice breaking off and hitting the fuselage, engines running rough, and the fuselage shaking are all experiences that can be disconcerting to the pilots and passengers. One way to alleviate ice build-up on constant-speed propellers is to increase the RPM. This will increase the centrifugal force and decrease the angle of attack of the blades. Helicopter rotors are very susceptible to icing; the blade tips whirl near the speed of sound, and any vibration due to ice build-up can be catastrophic.
13. **Carburetor:** Icing in the carburetor can obstruct the intake of air, but this phenomenon (***induction icing***) can happen at temperatures well above zero, since air cools as it undergoes a slight drop in pressure. This, combined with the evaporation of fuel, will create enough cooling to form carburetor icing (fuel vaporization and throttle ice). The first indication will be a drop-in RPM in fixed pitch propellers and a drop in manifold pressure with constant speed propellers. Carburetor icing can cause an engine to run roughly or quit. Recall, however, that to encounter airframe icing, one must be in cloud (or below cloud in freezing precipitation), with temperatures at or below freezing. These conditions do not have to be met for induction icing to occur. If you are near cloud (visible moisture and high humidity), think possible carburetor icing. Check your temperature/dewpoint spread chart for the likelihood of icing for most months.

14. Watch your temperature/dewpoint spreads even during the winter months.



15. **Air Intakes:** Clogging of air intakes may starve an engine of air or cause overheating. This is called impact icing.
16. **Fan Blade Damage:** Jet engines can be very susceptible to icing, but they are equipped with hot air bled from the engines to help alleviate this problem. However, during a long taxi or at idle speeds, fan blades can be seriously damaged. Rear-mounted engines may ingest ice that breaks off from the fuselage.
17. **Antennae:** When a communication or navigation antenna mast begins to accrete ice it will vibrate. If the vibration becomes significant enough, it may break and depart the aircraft leaving the pilot in a nasty icing situation with a potential loss of communication with ATC and navigation guidance.

Figure 12-3A: Jet engine fan blades laden with ice.

Figure 12-3B: Maintenance or ramp attendants apply heat to the blades. (Photos courtesy of Kelly Paterson.)

When a pilot goes through primary training they are taught how to avoid airframe ice. However, if in the future you decide to purchase an aircraft that has a certified ice protection system (IPS), understand that flying within icing conditions is a different beast altogether. It's best to take the time to receive advanced weather training on how to safely fly through regions that may cause airframe ice.

As mentioned, cloud droplets can exist in a liquid state well below the freezing mark. Droplets in this state are called ***supercooled.*** In fact, they can remain in a liquid state to as low as –40°C (coincidently it is –40°F as well). Colder than that, even the most pristine water droplets in the air freeze; this phenomenon is known as homogeneous (spontaneous) freezing of water or ***homogeneous nucleation.*** Liquid water cannot exist below this theoretical temperature.

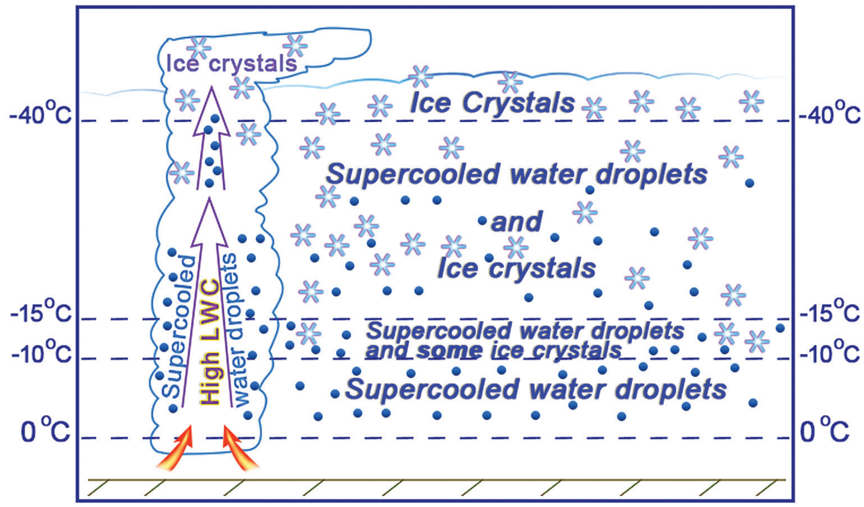


Figure 12-4: From zero to -12°C, H_2O exists mostly in the form of supercooled water droplets. At -12°C, more ice crystals begin to develop. At -15°C and below, the percentage of ice crystals increases substantially; at -40°C, all water exists in the form of ice crystals. Also note that supercooled water droplets can be carried to great heights in convective cloud.

Many airlines adopt the policy that engine anti-ice systems can be switched off when flying at temperatures of −40°C or below, as icing conditions are deemed nonexistent at these temperatures.

According to icing expert and meteorologist, Ben Bernstein, Environment Canada flew a research and instrumented aircraft into a thunderstorm and found supercooled liquid water at −37.5°C. That's cold! It's not unusual to see water in the liquid state down to −30C within deep, moist convection.

When water droplets and ice crystals coexist, the water droplets evaporate, causing the newly formed water vapor to deposit (in what's known as a ***deposition process)*** onto the ice crystals. A snowflake is born! As mentioned in Chapter 5, IFR pilots know that when it is snowing inside a cloud, icing will typically be at a minimum because ice crystals are growing at the expense of the supercooled water droplets. Note that some environments like snow or rain showers (showery precipitation is rooted in a convective process) can still dish out some nasty (even severe) air frame icing.

*You may encounter the **ram effect**—snow sticking to the leading edge of the wings—in the above conditions (snowing inside or outside a cloud), but it's usually non-threatening.*

For a supercooled water droplet to freeze, it needs something to stick to, like an ice nucleus. When a suspended supercooled water droplet impacts an aircraft, the droplet freezes by releasing its latent (hidden) heat held within. How these droplets freeze and accumulate is dependent on nearly ***thirty*** parameters, including aerodynamic factors as well as meteorological conditions.

Here are a few of those parameters…

1. **LWC (Liquid Water Content):** Liquid water content is the amount of liquid water in a given amount of cloud or air. It's dependent on the size and number of droplets: the higher the LWC, the more intense the icing. Generally, the amount of supercooled water in a cloud increases with height when the temperature is just below 0°C. This scenario can be conducive to a high LWC near the tops of the clouds (if they are not too cold). However, when the temperature is well below freezing, LWC **decreases** with altitude inside a cloud, as more droplets freeze into ice crystals.

   Bouncing (flying) on the top of clouds is a no-no for two reasons. First, it can be rough, and you'll often hear IFR pilots asking for a level change to find smoother air. Plus, the threat of ice accretion is highest at this level in some cloud types, as the updrafts carry high LWC toward the tops as air continues to expand, cool and condense. When flying over areas of open water one can pick up lots of ice from moisture-laden stratocumulus clouds that formed over the water. Flying low in and around the Great Lakes during winter, you will encounter these conditions. Strong vertical currents can keep large droplets from falling from a cloud. Well developed Cu, Tcu and Cb clouds are laden with large supercooled droplets. Air that moves up a hillside or mountain, or along the lee side of a mountain in waves, also supports a high LWC. A warm front in the wintertime is also conducive to unusually high LWC in freezing rain and ice pellets. The East Coast supports a high LWC in the winter due to onshore flow from open waters. Just east of the Appalachian Mountains from Charlottesville, Virginia to Charlotte, North Carolina you will find the highest occurrence of freezing precipitation in the country.

In 1985, a DC-8 carrying American soldiers crashed in Gander, Newfoundland due to freezing drizzle. For years, you could see the scar remnants left on the departure end of runway 22. A monument has been erected in remembrance of the 256 that perished.

Cloud Type	LWC g/m3
Cirrus	.03
Fog	.05
Stratus	.25–.30
Cumulus	.25–.30
Stratocumulus	.45
Cumulonimbus/towering cumulus	1.0–3.0

Figure 12-6: shows typical LWC values for various clouds. A cumulonimbus cloud contains 100 times more LWC than cirrus.

Icing conditions tend to be less severe in layered clouds. Icing areas are more likely to be greater in the horizontal extent, and more limited vertically. Therefore, an altitude change of 3,000 feet could be enough to alleviate icing. Icing is extremely transient, meaning that icing conditions can change within minutes. Several factors affect this variability, including the interaction between cloud droplets and ice crystals. Descriptions of icing types and accumulation can be very subjective, just like descriptions of turbulence: different pilots flying the same weather may report different icing conditions. A change in altitude of a few thousand feet can make the difference.

2. **Ambient Temperatures at or Below Freezing:** Prime temperature range is 0° to –15°C.
3. **Aircraft Skin Temperature at or Below Freezing:** As the aircraft moves through the air, kinetic heating (due to adiabatic compression and friction) causes warming along the **immediate** leading edge. Ice will not form if the skin temperature is above 0°C. (although don't be surprised to see ice accrete when temperature readings are on the plus side, indicating that the temperature probes, typically immersion thermometers, are not always accurate, especially when they get wet or have accreted ice). And remember: your aircraft skin temperature varies, and will typically be warmer on the immediate leading edge and cooler further after of the immediate leading edge.

   Airliners use TAT (Total Air Temperature) and SAT (Static or Ambient Air Temperature) measurements. The ambient temperature may

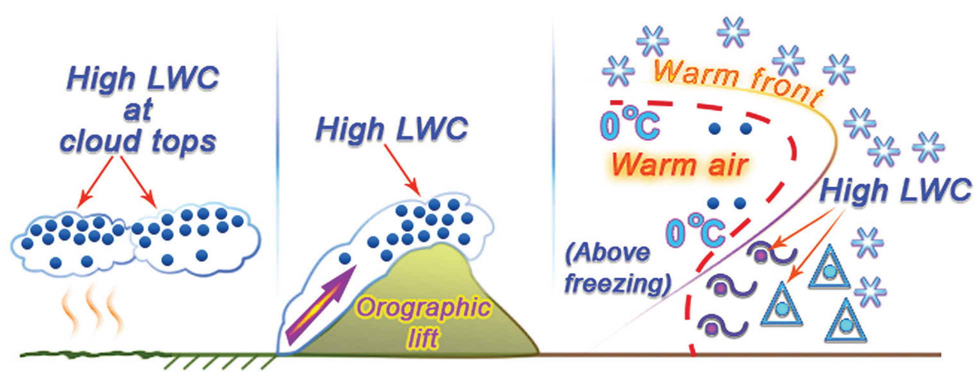


Figure 12-5: shows high LWC located in cloud tops, high LWC due to ascent over terrain, and high LWC in freezing rain and ice pellets associated with a warm front in the wintertime.

be –10°C, but due to the speed of the aircraft, the TAT may be +10°C. In theory, no airframe ice will form under these conditions. Many airlines use +10°C coupled with visible moisture as the rule of thumb to expect potential icing. One must remember that air over the wing is rapidly cooled due to lower pressure, thereby enhancing icing conditions on larger aircraft. This effect isn't as great with lighter (and slower) aircraft.

4. **Collection Efficiency (Rate of Catch):**
    - A. **Droplet Size:** Small droplets tend to follow the airflow over the boundary layer of the wing, whereas large droplets tend to strike the wing head-on and may penetrate the boundary layer behind protected surfaces. Also, the larger droplet tends to spread farther causing run back icing.
    - B. **Aircraft Speed:** The faster you fly, the higher the accretion rate.
    - C. **Shape of Wing:** Likelihood of icing is inversely proportional to the shape of the collecting surface; a thicker wing collects less ice than a thin wing. Items with a small curvature radius, like antennas, probes and thin wings, will collect more ice than canopies and thick wings. Ice may form on the outside air temperature probe first. A fast-moving jet fighter will collect more ice per unit area than a slower-moving turboprop.

Types of Icing:

Rime: As an aircraft impacts **small supercooled** water droplets, the water droplets give up heat to the environment and freeze. They accumulate along the leading edge and freeze relatively quickly. Ice made from these small fast-freezing droplets looks greyish or milky white, and is brittle and granular. Examples of rime ice can be found along the walls of a (non-frost-free!) refrigerator. Rime tends to form in temperatures from 0° to –20°C, with a range of –10° to –20°C being most likely. Due to its brittle nature, rime ice can be ***eliminated*** easily on airplanes equipped with deicing equipment such as pneumatic boots along the leading edges of the wings. Usually, small supercooled water droplets are found in ***stable layered (stratiform) clouds*** (research indicates that icing is greatest at the tops of these clouds) with rime icing occurring ***75%*** of the time.

Rime icing is more extensive horizontally than vertically. Stratus, altostratus, nimbostratus, stratocumulus and altocumulus clouds all support these small, supercooled water droplets.

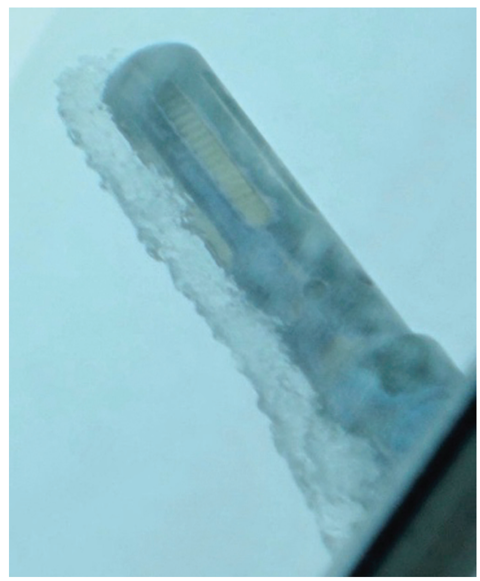


Figure 12-8: Airbus ice detection probe between the front windscreens. Older Airbus models do not illuminate the probe with a light, but a good ole flashlight or map light pointed outside does the trick. Some aircraft, like the Embraer, have a more elaborate detection system. Years ago, while Doug was flying the archaic British-made BAe 146, he relied on a relatively sophisticated exterior detector that took readings based on torque imposed from the ice accretion.

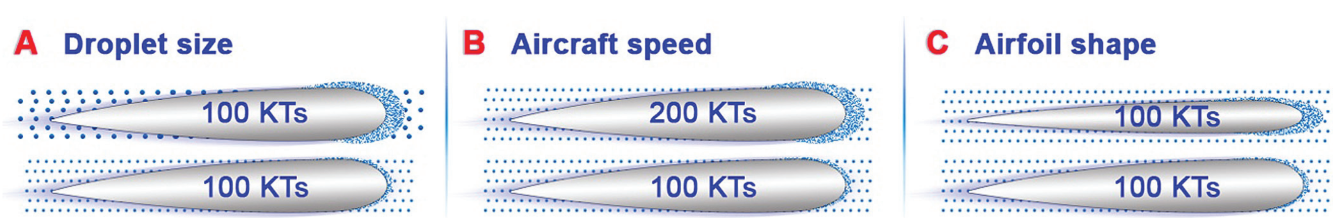


Figure 12-7: shows how droplet size, airspeed and wing shape affect the collection efficiency of airframe icing.

Most deicing systems are located on the leading edges given that rime ice is the most common and it's where rime icing mostly occurs.

Clear: As an aircraft impacts **large supercooled** water droplets, the droplets freeze on impact, but at a slower rate. As a consequence, they freeze further back from the leading edge, both on top and below the wing, away from the deice equipment. Because these water droplets freeze more slowly, the ice that results is smooth, clear and hard. A solid sheet of ice can form with no embedded air bubbles to weaken the integrity. This ice is similar to the kind found in icicles or ice cubes and occurs about ***10%*** of the time with temperatures from 0° to –10°C. Two places where large supercooled water droplets exist are in convective cloud (Tcu, Acc, Cb) and in freezing rain that can be mixed with ice pellets. In Chapter 5, we learned that it takes a million cloud droplets to make one rain droplet, so you can appreciate that severe clear icing can quickly form in freezing rain or freezing drizzle.

*Rime ice tends to form in **layered/stable** cloud with **small** supercooled water droplets, whereas clear ice forms from **large** supercooled water droplets in **unstable cumuliform** clouds (or in freezing rain/drizzle).*

Mixed: (A combination of rime and clear). Both the formation of mixed ice and, indeed, its very existence is a subject of debate in many weather books. Many books shy away from discussions of mixed ice, claiming that large and small supercooled water droplets can't coexist. From experience, Doug can tell you it certainly forms with freezing drizzle. Drizzle droplets are much smaller than raindrops, but much bigger than cloud droplets. Mixed icing occurs about ***15%*** of the time in a temperature range from –10° to –15°C.

Mixed icing often occurs when traversing regions where the temperature profile, liquid water content or droplet size may vary such as climbing or descending through a cloud deck. As the environment changes, so does the icing type.

Reporting the type of any icing can be challenging; many pilots report "mixed" as a default.

Frost: As moist air comes in contact with an aircraft's skin, a process of ***deposition***, in which water changes phase directly from a vapor to a solid, depositing a white, crystalline frost. Many people use the term ***sublimation*** instead of deposition for this process. In either case, it is describing water vapor going directly to ice without passing through a liquid form.

Be leery of an aircraft parked overnight under clear skies (typically under a high pressure system), as the upper surfaces of the airplane may have chilled by radiation cooling. The weather office starts forecasting the risk of frost at +5°C or less. Just because the official temperature is above zero doesn't mean frost (called hoar frost) is not present. Test data indicate that frost, ice or snow formations with a thickness and surface roughness similar to that of medium/coarse sandpaper on the leading edge and upper surface of a wing can reduce wing lift by as much as 30% and increase drag by 40%. A heavy coat of hard frost will cause a 5 to 10 percent increase in stall speed. Even a small amount of frost on airfoils may prevent an aircraft from becoming airborne at normal takeoff speed.

Never depart with surfaces contaminated with snow or frost. Snow falling on a somewhat warm wing while taxiing will freeze to the surface and will not just blow off in the airflow during the takeoff roll—don't ask me how I know that.

There have been many documented cases where the pilot shrugged off the peril of frost on the wings. Frost disrupts the boundary layer over the wing, so if a tight turn or large angle of attack is required on takeoff, there may be surprises.

For a new or VFR pilot, frost is the type of icing you will most likely contend with since in-flight icing usually occurs in IFR conditions such as in cloud (IFR), or flying beneath cloud in freezing rain, or ice pellets. Frost must be removed! You may have the luxury of moving the aircraft into a warm hangar or blowing warm air over the aircraft from a heater (Herman Nelson). Some operators may keep bottles of glycol handy or simply wait until the sun (hopefully) melts the frost away. However you do it, you have to make sure it is removed…it's the law! Caution: One wing may be clear because it is directly in the sun, whereas the other may be coated in frost!

On a layover in San Francisco, our Airbus 320 sat in a morning shadow from the terminal with frost forming on the wing's spoilers. KSFO has very little in deice support, so we pushed the aircraft into the sun and let Mother Nature take over. The process took about 20 minutes and I made an announcement pointing out to my passengers how green California was regarding deicing.

Frozen Dew: may condense on cold aircraft skin and then freeze as the aircraft's skin dips below 0°C. Dew tends to be clear, whereas frost tends to appear crystalline and white. No matter what the contaminant, get rid of it before you even think of going flying.

Blue ice? Some aircraft lavatories use a 'donut' type seal for servicing. Sometimes the seal leaks a little and freezes up at altitude. On rare occasions, the ice lets go—and on three documented instances, it has fallen through people's roofs. On flights to Tokyo, procedures recommend that pilots extend the landing gear before reaching the shoreline. By doing this, any potential ice in the wheel well won't fall on populated areas.

Supercooled Large Droplet (SLD) Icing: No discussion of icing would be complete without covering SLD. Many pilots seem to think this stands for supercooled **liquid** droplet icing. That interpretation would be completely missing the point. Yes, these are liquid droplets, but the "L" stands for **LARGE**, not liquid.

As we have mentioned, droplet size is one of the critical meteorological factors of airframe icing. The larger the droplets, the more likely they will impinge on air aircraft surfaces making airframe icing more likely. Moreover, these droplets take longer to freeze and will tend to run back, sometimes beyond the protected surfaces (such as boots, which we'll discuss in a bit).

SLD occurs in well-developed cumuliform clouds, especially at the tops. Some of the worst SLD in clouds can be encountered when flying through deep, moist convection (thunderstorms). SLD also can occur in freezing rain (FZRA) and especially freezing drizzle (FZDZ).

Figure 12-9: Here is a scaled down version of a wing model being tested at NASA's Icing Research Tunnel (IRT). You might be surprised to know that the IRT cannot test freezing drizzle or freezing rain conditions. Even with high wind speeds in the tunnel, many of the larger droplets would succumb to gravity and fall down before reaching the model in the test section. The largest Median Volumetric Diameter (MVD) size capability in the IRT is 50 microns which is the lower end of the supercooled large droplet (SLD) icing spectrum. So essentially the IRT is only designed for icing certification standards contained in 14 CFR (Code of Federal Regulations) Part 25, Appendix C, also known as small droplet icing.

A large droplet environment is defined as one where the Median Volume Diameter (MVD) of the droplet exceeds 50 microns. To find the MVD you would line up all of the droplets according to size within some volume of air and find the droplet size that is at the median. If the median is greater than 50 microns, it's considered SLD. In reality, there will be a mixture of droplets with some smaller and some larger than 50 microns. Pilots can't calculate this directly so it must be inferred by the meteorological environment present (e.g., freezing rain/drizzle, presence of a SIGMET, AIRMET or PIREP). By the way, research aircraft are instrumented with equipment than can measure the MVD.

For those who are micron-challenged, 1,000 microns is equal to one millimeter. To put this into perspective, the average human hair is 100 microns in diameter. So, once the MVD reaches half the size of a human hair, it's considered a large droplet environment. The point is that no aircraft has certification to fly into an SLD environment. Certified ice protections systems (discussed later) are only certified into MVD environments smaller than 40 microns! As of this writing, the FAA is looking to allow some aircraft to fly in some specific SLD environments.

Icing Intensity

Trace: (Not every book includes this as an intensity.) "Trace" refers to the situation in which ice is barely perceptible. The rate of accretion is slightly greater than the rate of sublimation. It's not hazardous, even on a small aircraft not certified for flight into known icing conditions. However, if your aircraft is not certified to fly in icing conditions, you better ask yourself why that ice is forming. And if you are a VFR pilot, eyebrows will be raised, because you shouldn't be in the clouds.

Light: This rate of accretion may create a problem if you are in it for more than an hour. Light icing does not require a change in altitude or direction, but it will affect fuel burn. Plus, you don't know if it will intensify, either in cruise, descent or in a climb. It doesn't present an immediate problem as long as the deicing/anti-icing equipment is in use. ***A light accretion rate is about 1/4 inch (6 mm) or less per hour.***

Often the first thing you may notice when you begin to accrete ice is the loss of airspeed. Even with light or trace icing you may notice a 5 to 10 knot decrease in airspeed in most light aircraft. Often you may see this before you see any ice accumulations on the leading edges of the wings, especially if the wing is white.

Moderate: A moderate rate of accretion is such that the deicing/anti-icing equipment has to be on continually and you'd better be thinking about plan B. If you are flying twin-engine ***props,*** you may be feeling vibration and hearing loud noises as pieces of ice break off and hit the fuselage. Your heart rate is starting to escalate. ***Moderate accretion is about 1/4 inch to 1 inch (0.6 to 2.5 cm) per hour.*** You are getting a good ***jag*** (protrusion of ice) on, and this isn't good!

The FAA introduced a heavy intensity during one update to the Aeronautical Information Manual (AIM), but rescinded it on the next update. You can reference the icing categories in the AIM: 7-1-21.

If you look at the side of the fuselage abeam (at a right angle) the propeller on a twin-engine airplane, you will see tell-tale signs of ice that has broken off from the propeller and hit the side of the aircraft. There will be chips in the paint, and some aircraft will even have reinforced plates on the exterior walls.

Severe: This is bad. Really bad! The rate of accretion is such that the deicing equipment is not keeping up. ***A representative accretion rate for "severe" is more than 3 inches (7.5 cm) per hour!*** You are accreting ice like a glacier! You are not having a good day. Immediate diversion is imperative. No aircraft is legally allowed to fly into known severe icing conditions which is typically announced by pilot weather reports (PIREPS) or a SIGMET for airframe icing. Just by its definition…it's meteorological suicide.

Eliminating ice on the ground and in the air

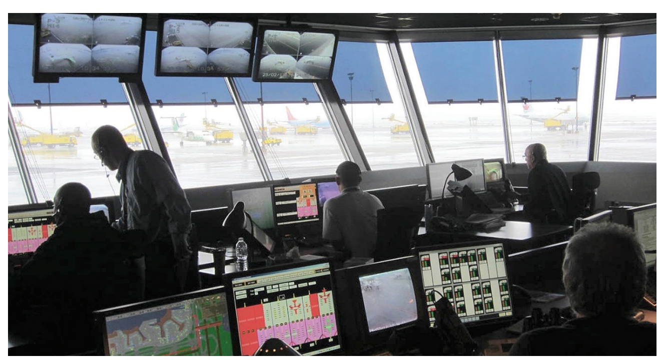


Figure 12-11: Inside the Ice House at Toronto's Central Deicing Facility (CDF).

Figure 12-10: Deicing vehicles at Toronto Pearson's CDF (Central Deicing Facility)—the world's largest. The deice truck in the middle is for the mammoth Airbus A380. (Photo courtesy of the CDF.)

You may hear some pilots boast that their airplane can "carry" a load of ice with little or no substantial loss of control. That very well may be true for some aircraft in some weather environments, but there's no guarantee. To that end, I was speaking with Paul Pellicano about icing certifications. Paul is an aerospace engineer for the FAA's Small Airplane Directorate who specializes in icing certification. He made a very sobering statement: "Airplanes that are not certified into known icing conditions are not tested for inadvertent icing encounters." Essentially, if the aircraft is not certified for flight into known icing conditions, there's no way to anticipate how it will react when it accretes even a tiny amount of ice.

There are several devices designed to prevent ice from forming (anti-icing) or dislodging the ice once it has accumulated (deicing). Some methods of dealing with aircraft ice: fluids, membranes and heating (either electrical or from engine-bleed air). Keep in mind that in order to fly into known icing conditions, the aircraft must have a certified Ice Protection System (IPS) installed and must be operational and the pilot in command may also have to go through some kind of certification training on an annual basis. It's also important to understand that these systems are only certified into what are known as "small droplet" icing environments. When the droplet sizes increase and/or the liquid water content increases, even these certified systems may not be sufficient to protect the aircraft.

A. **Fluids:** Some aircraft implement ethylene glycol-based deice fluids (such as TKS®) that excrete from tiny holes in laser-drilled titanium panels affixed to the leading edge of the wing. The system also employs a slinger ring to protect the propellers and a spray bar to coat the windscreen. It's designed to work as a freezing point depressant that mixes with the supercooled liquid water to lower the freezing point below –76°F (–60°C). This is not the same as rain repellent, which is used to alleviate visibility issues in heavy rain. Fluids inhibit ice accretion, so they would be deemed primarily as anti-ice products, but will be somewhat effective at removing icing already accreted on the airframe. In other words, it's best to have the system primed and activated before entering into an environment that is conducive to icing. However, if you allow ice to accrete on the leading edges, the antifreeze solution will chemically break down the bond between the ice and airframe, allowing the aerodynamic forces on the ice to eventually carry it away.

B. **Membranes (Boots):** Pneumatic rubber boots are attached along the leading edge of the wing and tail and sometimes on the leading edge of the vertical fin. They are made under the umbrella of Goodyear, Goodrich and other tire companies. These boots inflate by pumping air into them, thereby breaking off the ice due to the expansion of the leading edge. Ice sometimes does not break off uniformly, especially if a boot only partially inflates. Because this deice system works along the leading edge, it is possible for clear and mixed icing to escape the deicing boot, referred to as "runback", by working its way under and on top of the wing. Hence the danger. You may read about ***bridging*** of the boots; this refers to a situation that used to arise years ago, where one had to wait until enough ice formed before ***blowing (inflating) the boots.*** This has now been rectified, and boot activation can be done anytime the pilot sees fit. Having said this, you may find yourself flying a relic on which bridging is still an issue. Of course, in this case, you will consult your POH (Pilot Operating Handbook), AOM (Aircraft Operating Manual) or AFM (Aircraft Flight Manual) to read about boot operation, because every aircraft procedure is different!

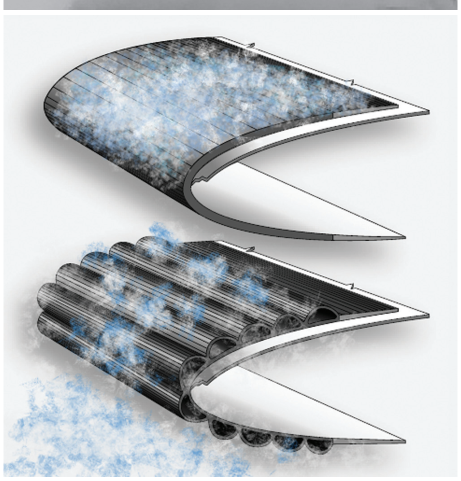


Figure 12-12A: King Air wing with black deice boots along the leading edge. Light icing is accreting and soon the pilot will blow the boots. Boots, because they are rubber and black, allow for easier sighting of ice. (Courtesy of Doug's ex-student David Lewis.) **Figure 12-12B:** Deice boots adhering to the leading edge of the wing with the second diagram showing full inflation.

C. **Heating Devices (Electric):** There is electrical heating for: windscreens, pitot tubes, static and alternate static ports, propellers, stall warning and the fuel vent system. There are also some leading edge installations (such as Thermawing™) that do an effective job keeping ice from building on some of these surfaces. This is an electrically conductive, graphite foil technology that delivers heat to areas that freely collect ice. These systems automatically go through heating and cooling cycles called shedding cycles. The immediate leading edge (called the impingement area) is kept warm enough to continually melt any ice in that area. The area just aft of this impingement area, known as the shedding zone, is kept below freezing causing any "run back" water to freeze and collect as ice (you can get a lot of run back in environments containing high liquid water content and/or large supercooled droplets). During a shedding cycle the temperature is increased just aft of the shedding zone, breaking down the bond between the ice and the laminate thus shedding the ice via aerodynamic force. Heat is then removed from the shedding zones allowing supercooled liquid water to freeze once again until the next shedding cycle.

Deice boots would not work on propellers and rotors and nor do they work on fast-flying jets. Icing can cause serious problems for helicopters. The rotor is thin and moves fast, which is conducive to high ice accretion. Just small amounts of ice shedding can cause the rotor to get out of balance and self-destruct. Most helicopters are not ice qualified. For small aircraft, like a Cessna 172, the only true anti-icing/deicing equipment available is pitot heat and maybe some defrost for the windscreen and carburetor heat for induction system icing, thus, avoidance is imperative.

D. **Bleed Air Heating Devices (Hot Air):** Hot air is bled from the engines and is piped along the leading edges of the wings and sometimes the tail. Bleed air requires the engines to work a little harder, which may restrict takeoff performance in icing conditions. Hot air is also bled to the intakes of turboprop and jet engines. When the switch is activated, continuous auto-ignition to the engines is initiated. The goal of these systems is to literally vaporize the supercooled liquid droplets before they impact the aircraft surface and are therefore anti-icing systems. Bleed air can also be used for brake deice.

These are some of the systems incorporated into aircraft to help pilots deal with icing. They all have their limitations, and you will learn their intricacies with each aircraft type you fly.

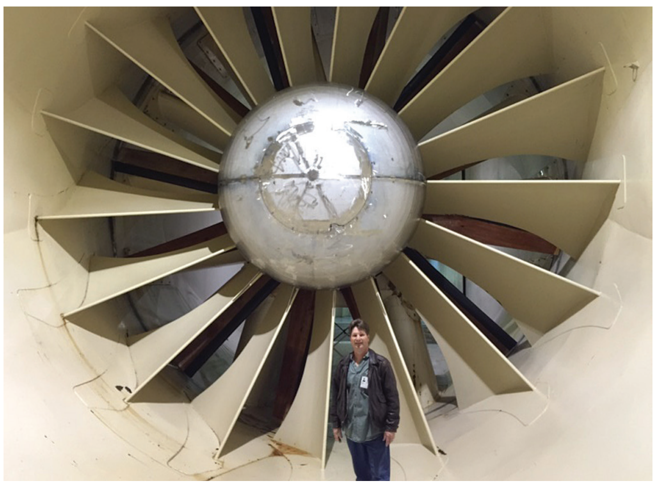


Figure 12-13: NASA's Ice House. The NASA Glenn Icing Research Tunnel (IRT) in Cleveland, Ohio is one of a kind. It was built before the U.S. entered World War II. The icing research tunnel is a closed loop with a 5,000-hp fan containing wooden blades made of spruce that can generate winds approaching 400 miles per hour. Air in the tunnel can also be chilled to a frigid temperature of −40°C which is plenty cold enough to test all temperature ranges for potential icing. Yes, that's Scott in the picture on his visit to the IRT. You might think it's pretty dangerous standing in this tunnel next to that huge set of blades … what happens if someone accidently turns it on? Well, turns out that the key needed to turn on the fan is the same one that is needed to open the door into the tunnel. Just hoping this kind of thinking came from forethought and not from a previous oops!

Some things to think about…
The Do's and Don'ts

As soon as you encounter ice, immediately start working to get out of it. Start querying ATC, ask for pilot reports (PIREPS) regarding the intensity, cloud tops, freezing level, etc. Request weather info; whatever it takes. ***Icing may not require immediate action, but it does require a pilot to be proactive.*** When flying small, slower aircraft restricted to low altitudes, you will be ***in it*** much longer than a fast-flying jet capable of climbing above the cloud and into much colder temperatures where icing is less likely. Your first job may be flying a light twin-engine aircraft restricted to 10,000 feet, or a single pilot, single engine turboprop like a Cessna Caravan. These craft are known for their chilling ***story after story*** icing encounters. Here is one scenario: If you were in level cruise flight, how would you know your static system is iced up? See chapter 21 on Altimetry.

1. Icing is mostly an IFR issue, because other than being in freezing precipitation, you have to be in cloud to get it. So make sure you are armed with PIREPS (pilot weather reports), the latest G-AIRMETS and SIGMETS and a clear plan B, which can range from a solid alternate, to turning back, to delaying departure or remaining safely on the ground.
2. Watch for airspeed changes. A change, such as a drop in indicated airspeed is a sure sign something is up. If your instruments start to go a little wonky, suspect ice!
3. Do a thorough walk-around before takeoff. Never depart with ice-contaminated surfaces.
4. Watch out for puddles during taxi. Ice on brakes has been known to induce surprises.
5. While climbing through icing conditions, climb at a higher speed and a lower deck angle (pitch). You don't want to get ice under the wing and belly and it will help you maintain a comfortable air speed to avoid a stall.
6. In a layered cloud, you can usually get out of the ice by changing altitude. Rime icing can be very extensive horizontally, but tends to be narrow vertically. Typically, a change of 3,000 feet may decrease or eliminate ice accretion.
7. If you are flying near a warm front in the winter, sometimes it is best to climb to find the warmer air. There could be an extensive above-freezing layer aloft which will quickly melt the ice. Do your homework before you depart.

8. Do not use the autopilot when in heavy icing conditions. It masks the aerodynamic effects of the ice and may bring the aircraft into a stall or cause control problems. Sometimes the pilot is the last to know of the urgency of icing.

The crash of a Dash-8 Q400 owned by Colgan Air has been attributed to a tailplane stall within the pilot community. In talking with Kurt Blankenship who is a research pilot and deputy of aircraft operations at the Glenn Research Center, the Colgan Air accident had little to do with icing. In fact, on March 25, 2009, NTSB investigators indicated that icing probably did not contribute greatly to the accident. Kurt said that, "the plane basically trimmed itself to a stall. It had a stick pusher on it which he [the captain] fought against and pulled back and held it until the plane finally went over and it was too late." Could it be that the captain thought he was experiencing an ice-contaminated tailplane stall even though he said nothing on the tape? In Kurt's opinion he thinks "the pilot simply panicked." Kurt further commented that "he was low to the ground and it [pulling back on the controls] was a natural reaction." Other mistakes were made such as the co-pilot retracting flaps without it being called and not having a sterile cockpit during the approach to land. From Kurt's view, this accident "was a low-speed awareness issue and that should be the focus of the training and recognizing when you are in the backside of the power curve regime. They were slow; it was a wing stall, clearly."

9. Try to avoid cumuliform clouds. If you're not avoiding them for the turbulence, definitely avoid them for the icing!
10. When you are iced up, use more power, especially in turns, and avoid abrupt maneuvers.
11. Tell others about your experience. ***Submit a pilot report—help your fellow pilots!***

If you look at the reports contained in the Aviation Safety Reporting System (ASRS) database managed by NASA, you'll discover a fair number of alarming statistics. For example, there are dozens of reports from professional flight crews flying Embraer EMB-120 aircraft having significant issues with just a light amount ice. Here's one such report. "On October 16, 1994, near Elko, Nevada, an EMB-120 stabilized at 160 KIAS at 13,000 feet. Both pilots checked for ice on the wings and spinner, but they did not see a significant amount. With the aircraft on autopilot, the flight crew initiated a heading change to the right, and the aircraft began a right wing down (RWD) roll attitude. During the turn, at about 20° RWD, the stick shaker and pusher activated almost simultaneously. The aircraft rolled nearly 90° to the right and pitched over. The pilot took manual control of the airplane and recovered. Post-flight inspection of the aircraft revealed clear ice on the wing leading edge and propeller spinners. The deice boots were not activated during the flight because the crew did not believe the ice was of sufficient thickness to cause concern. Data from the FDR was extracted by the air carrier and forwarded to the FAA and Embraer. Analysis showed a minimum airspeed of 138 KIAS before the stick shaker activated. The stick shaker activated about 10 knots above the calculated accelerated stick shaker speed." (This incident was described in ASRS report 286127).

Even More Words of Wisdom!

1. Cumulus clouds with sharp, well-defined edges tend to be ***younger clouds*** with a higher LWC, especially near the tops.
2. When you're flying above a cloud layer and you see your aircraft shadow inside a rainbow of rings (called a glory), there is liquid water present in the top of the cloud. And if the temperature is below freezing, it'll be likely supercooled liquid water.
3. After taxiing in snow and slush, don't leave the parking brake set. The warm brakes will melt the snow and ice, but after they cool, ice will reform and lock the brakes. There has been many a pilot who found out about this the hard way.

One story mentioned to me... An unlucky U.S. pilot parked his airplane in front of the terminal in Detroit, Michigan on a cold New Year's Day. It snowed all day. Later, he loaded everyone into the plane, deiced on the spot, and powered up—only to go nowhere fast while the entire terminal watched. He was red in the face; the brakes were frozen.

Figure 12-14A: Doug's Airbus shadow silhouetting upon a cloud deck. This is called a glory or sometimes pilot glory. It means there are liquid droplets in the tops of the clouds below. To see a glory, you must have the sun behind you (just like with a rainbow on the ground), and be close to the cloud top. The brighter the glory the higher the LWC.
Figure 12-14B: Doug's current airplane the B787 Dreamliner with a glory in tow. (Brian Losito's photo.)

4. Most airplanes have pitot covers, but not static covers. BLSN (blowing snow) impacting the plane from the side can clog the static ports and give irregular readings.
5. Don't trust TAFs blindly. Check current METARs and make sure they agree with the TAF. If they don't, find out why. It will help determine the confidence level in the forecast for your destination and your alternate.
6. Know your typical airspeed, pitch attitudes and thrust settings so that you can compare them to your readings in icing conditions. If your airspeed doesn't seem quite right or your attitude is not where it should be, something is wrong. The fate of Air France's Flight 447 drove home the message that pilots ***MUST*** know their procedures for unreliable airspeed. Another recommendation we can take from this accident is to know how to handle a stall. We learned from initial training that recovery warranted thrust application with minimum altitude loss. The new recovery procedure is AoA (Angle of Attack) first! Get your nose down, ensure the wings are level, and once you're out of the stall, increase thrust. Worry about altitude loss later.

Airframe Icing (Advanced)

At 4:01 p.m. on January 13, 1982, Air Florida flight 90 crashed into the ice-filled Potomac River just 30 seconds after takeoff from Washington, D.C National Airport. Seventy-eight individuals died in the crash, including four people who were in cars on the 14th Street Bridge over the Potomac. The story of what happened on that January day is one of tragic human error in the face of extreme weather conditions.

The crash of a Fokker 28 passenger jet in Dryden, Ontario, in 1989 brought the perils of airframe ice to the forefront of Canadian aviation awareness. Shortly thereafter, the ***Clean Aircraft Concept*** became law in Canada, with the U.S following suit. The ***Clean Aircraft Concept,*** prohibit persons from conducting or attempting to conduct a takeoff in an aircraft with frost, ice or snow adhering to any of its critical surfaces, such as wings and propellers. Dry snow lying overtop a cold wing, or 1/8 inch of frost on the lower wing surfaces from the front to rear spar, are the exceptions if in accordance with the aircraft manufacturer's instructions.

As mentioned earlier in this chapter, some aircraft may "carry" ice fairly well, but there may be some other complications that can ruin your day. Here's one

such example. A pilot of a Piper Twin Comanche collected a significant amount of ice while on route to Greeley, Colorado. After successfully executing an instrument approach in low IFR conditions the pilot attempted to lower the landing gear. However, the landing gear wouldn't budge. The pilot circled the airport (at 400 feet AGL) and unsuccessfully attempted to manually lower the gear. In the end, the pilot safely landed with the gear tucked neatly into their bays. The NTSB discovered that the gear was working just fine and reported that the bay doors for the gear were frozen shut!

Definitions

Critical Surfaces: The critical surfaces of an aircraft are the wings, control surfaces, rotors, propellers, horizontal stabilizers, vertical stabilizers and any other stabilizing surface on an aircraft. In the case of an aircraft that has rear-mounted engines, the upper surface of the fuselage is also considered a critical surface, as ice can break off and be ingested into the engines.

Critical Surface Inspection (CSI): This is a mandatory inspection of the aircraft's critical surfaces. It's basically a technical term for a "walk around."

Pre-takeoff Contamination Inspection (PCI): This is an inspection of the aircraft's representative surface by the pilot. This is done when holdover times are exceeded, or during heavy snowfall, ice pellets, or when the cabin crew reports contamination.

Representative Surface: An aircraft's representative surface is a portion of the aircraft that can be readily and clearly observed by flight crew from inside the aircraft and is used to judge whether or not the surface is contaminated. For most airliners, it is the root of the left wing. The representative surface of an Airbus can be found inside the cabin, with a one-inch black triangle over the window. This is the go-to spot for a pilot to check when doing a PCI.

Tactile Inspection: A tactile inspection requires a person to physically touch specific aircraft surfaces. This may mean getting up on a ladder or atop a truck. Sometimes it is very difficult to tell if ice is present under certain circumstances, so a tactile inspection may be the only way of confirming that the critical surfaces of an aircraft are not contaminated. For some aircraft, tactile inspections are mandatory. Many airlines forbid the pilot from performing a tactile inspection.

During my Navajo days, I remember sticking my arm out of the side window to see if the freezing rain was actually freezing on my parka sleeve. Not a smart tactile inspection.

Post Deice Inspection (PDI): Some companies make it mandatory to go back in the cabin and look at the wings when only one deice truck is used OR if the deicing occurred outside of North America. Of course, you can always perform a PDI if anything seems suspicious.

Deicing: This is the process of getting rid of snow, ice or frost. It will include the use of deice fluid, heating of the wing, sweeping, scraping, or pulling the aircraft into a warm hangar.

Anti-icing: This process stops ice, snow, or freezing precipitation from adhering to the aircraft. It offers you some protection, but is only useful for getting the aircraft airborne; anti-icing fluids are designed to shear off at certain rotation speeds (Vr) during takeoff.

Figure 12-15: De Havilland Dash-8 Turboprop and its many anti-ice and deice features: heated propellers, heated windscreens, deice boots, pitot head/static port heaters, AoA vane heaters, ice detection posts at top of windshield wiper arms. (Picture courtesy of Kelly Paterson.)

Deicing/Anti-icing fluids

(All fluids are color-coded to identify the type and to aid with application).

Type I: Type one is orange and is a mixture of glycol and hot water (about 60°C to 80°C). It is applied with high pressure to get rid of ice, snow and contaminants and is predominantly used for deicing. It offers very little anti-icing capability.

Type II: This fluid is clear or straw colored and is more of an anti-icing fluid. It's typically used for airplanes with higher takeoff rotation (Vr) at speeds greater than 100 knots.

Type III: Type three is not widely available in North America. It is usually yellow and is formulated to shear off at rotation speeds below Vr 100 knots.

Type IV: This anti-icing fluid is dyed bright neon emerald green. Type IV is the most expensive and designed for aircraft with higher rotation speeds.

Holdover Time: What differentiates these types of fluids are the "holdover times." Holdover time is defined as the period from when spraying *starts* (*not when the spraying ends*) to the time one must be airborne. This, of course, is predicated on temperature, precipitation type and intensity. Holdover time tables must by consulted to obtain exact times.

All deice fluid sprayed on an aircraft is strictly used to get an airplane airborne. It is designed to shear off during rotation, which is why you will see lots of it on the runway. It will not help you contend with structural icing once you're airborne.

Apparently one American pilot visiting Toronto's CDF did not know this: his aircraft was contaminated with light frost, for which Type 1 fluid would have been ample, but he requested Type IV. When asked about his request by the CDF, he replied, "Toronto's ATIS (Automatic Terminal Information Service) states there is moderate icing at 10,000 feet." Ahem...

Cold-Soaked Wing: Clear ice on the upper wing can form on the ground whenever fog, drizzle, rain or wet snow contacts a wing surface that is below freezing. It is important to note that a wing containing sub-zero fuel can form clear ice at ambient temperatures up to +14°C!

A few winters back, while under a deck of stratus with temperatures of +7°C or so, we departed from Toronto to Montreal early in the morning not thinking about airframe ice. However, the aircraft had arrived in Toronto from an overnight red eye with cold-soaked fuel. We did not add much new fuel, which would have been much warmer. Once airborne, a flight attendant informed us that a passenger had noticed that a significant amount of ice had formed on the wings. I have never downplayed cold-soaked wings since!

Figure 12-16: An Airbus receiving Type I deice fluid in Toronto. If it is just a frost removal or there is no precipitation, then all that is needed is Type I. If some kind of precipitation is occurring, Type IV spray may be required. Deicing at designated areas tends to be "live" (engines running), and the aircraft must be "configured to spray," including having the brakes set. (Picture courtesy of Brian Losito.)

Figure 12-17: Right wing of Doug's Airbus 320 covered in ice (much of it previously broken off) due to a cold-fuel-soaked wing.

Approximate Holdover Times Under Various Weather Conditions (minutes)								
Outside Air Temperaure[2] (°C)	Freezing Fog or Ice Crystals	Snow, Snow Grains or Snow Pellets[3]			Freezing Drizzle	Light Freezing Rain	Rain on Cold Soaked Wing[5]	Other[6]
		Very Light[4]	Light[4]	Moderate				
-3 and above	11 – 17	18	11 – 18	6 – 11	Anti-Icing Required Use of Type I Fluid PROHIBITED			TAKEOFF NOT AUTHORIZED
below -3 to -6	8 – 13	14	8 – 14	5 – 8				
below -6 to -10	6 – 10	11	6 – 11	4 – 6				
below -10	5 – 9	7	4 – 7	2 – 4				

Figure 12-18: Holdover table for Type I (orange). For light snow at -3°C, the holdover time is only 11 minutes—18 minutes if you do a Pre-takeoff Contamination Inspection (PCI).

Outside Air Temperaure[1] (°C)	Type IV Fluid Concentration Neat Fluid/Water (Volume %/Volume %)	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)							
		Freezing Fog or Ice Crystals	Snow, Snow Grains or Snow Pellets[2]			Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing[5]	Other[6]
			Very Light[3]	Light[3]	Moderate				
-3 and above	100/0	2:05 – 3:10	2:00	1:20 – 2:00	0:40 – 1:20	1:10 – 2:00	0:50 – 1:15	0:20 – 2:00	A PCI is Mandatory when Operating in These Conditions
	75/25								
	50/50								
below -3 to -14	100/0	1:50 – 3:20	2:00	1:05 – 2:00	0:30 – 1:05	0:55 – 1:50[7]	0:45 – 1:10[7]		
	75/25								
below -14 to -27	100/0	0:30 – 1:05	0:40	0:30 – 0:40	0:15 – 0:30				

Figure 12-19: Holdover time for Type IV (green). For light snow at -3°C, the holdover time is now 1 hour and 20 minutes. If you're willing to do a PCI., you have up to 2 hours!

Figure 12-21: Toronto Pearson's DIIS (Deice Information System) located at the central deice facility.

Many airports are now using a Deicing Information System (DIIS) to replace holdover charts. DIIS is an automated system comprised of numerous sensors that measure weather conditions at an airport at ten minute intervals. The system computes a precise holdover time for any aircraft deicing and anti-icing fluid on the market. This information can be requested by flight crews and can be delivered electronically to the flight deck via datalink or on tablets or electronic message boards at the facility. In light snow at –3°C, the holdover time may be extended to 22 minutes instead of six minutes when using DIIS.

"There's an App for that!" *The preferred methods of obtaining holdover times for my airline is: DIIS, then the "app" found on our I-pad, with actual holdover tables ranking third in priority.*

THINGS YOU SHOULD KNOW...

- Water droplets exist as supercooled water at temperatures well below 0°C down to—40°C/F.
- The higher the LWC (liquid water content), the greater the intensity of icing.
- There are nearly thirty parameters that help determine why airframe icing forms. Some of the most important ones include high LWC, ambient temperatures below 0°C, aircraft skin temperature below freezing, size of droplets, speed of the aircraft, wing shape, etc.
- There are three types of airframe icing besides frost: rime, mixed and clear.
- Intensities of icing are: trace, light, moderate (heavy) and severe.
- Clear ice forms from large, slow-freezing supercooled droplets; rime ice forms from small, fast-freezing supercooled droplets.
- Collection efficiency is greater for sharp leading edges, high speeds and large water droplets.
- Icing in layered cloud is normally less serious, but extends through greater distances horizontally.
- General ranges for types of icing:
    - Clear: 0°C to –10°C
    - Mixed: –10°C to –15°C
    - Rime: –10°C to –20°C
- The worst icing conditions occur when an aircraft's airframe temperature is at or slightly below freezing, flying in cloud with a high LWC (liquid water content) containing large supercooled droplets.
- Effects of ice:
    - Reduced lift
    - Increased drag
    - Increased weight
    - Reduced thrust
    - Increased stalling speed
    - Difficulty in selecting flaps/slats
    - Iced-up stall warning system will not warn of an impending stall
    - Blocked pitot/static systems giving instrument errors
    - Increased fuel consumption
    - Obscured windscreens
    - Ice in landing gear wells can cause difficulties in retraction/extension
    - Ice on aerials can cause static and also cause them to break off
    - Ice can cause severe damage to engine fan blades
    - Ice on propellers may cause major vibration
    - Ice breaking off from propellers may damage the fuselage and the noise may be loud and disconcerting to pilots and passengers
    - Turn off the autopilot which may mask the signs of icing
- Get rid of ice—it's the law!