OMG It's ICE!

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I was a newly minted pilot on that February afternoon, armed with only the basic experience that comes with few hours and an excess of ego. Flying was a new adventure and even though tiny butterflies fluttered in my stomach they did not override the logic between go and no go. I was naïve. I was green. I was inexperienced. Oh, I was instrument rated all right and my Mooney was fashionably instrument equipped; but my risk assessment ability was definitely overrated and under-deserved.

Flying through the ragged clouds on that cold winter's day for a 200-mile journey, I had the "Weeping wings" weeping Glycol, yet at 8,000 feet, the view of the grey clouds ahead seemed to get "fixed" with the mosaic of a frosty windshield. And then there was panic!

I was lucky. I very shortly flew out of the clouds. The only remnant of the encounter was a one-inch ice-horn that formed on the leading edge of the light covers, a cool chill down the back of my spine and an untimely tremor in my mental peace with words emblazoned in my mind in neon like "Never Again."

So what makes clouds cover a perfectly fine beautiful airplane with ice?

Clouds
Clouds form from moisture in saturated air when the temperature and dew point meet. The moisture may come in lifted unstable air, or it may already exist in a stable air mass.

Micro-droplets
What is interesting about the clouds is that they represent a suspension of very tiny droplets of moisture. These droplets are 10-40 microns or less than half the thickness of human hair (Human hair 100 microns and 1 micron = 0.001mm). In the cumulus clouds they can range to 200 microns. Tiny by all standards collide and coalesce with their counterparts and in so doing get larger. The largest ones are present at the top-most layer of the clouds. Here due to gravitational pull and lack of any further development based on the limits of the atmospheric dynamics these micro-droplets float carrying their precious cargo of water. Imagine a snowball gathering more snowy mass as it rolls down the mountain, only here it's in reverse; the droplet gets larger as they climb in the clouds.

So from a practical point of view the most rime icing one can get would be in the top crust of a stratus layer. Above is bright sunshine and below warmer temps and smaller droplets.

As the droplets are lifted into colder and colder temperatures they become super-cooled when the temperature reaches -20 degrees Celsius. Above -20 degrees Celsius the droplets freeze and as they fall into the warming temps below they turn into super-cooled droplets (SLD).

Before that frozen state, however, and having no further climb left, the micro-droplet reaches a critical mass of 200-500 microns and, with gravity's help, falls down towards the earth as a freezing drizzle. In a cumulus cloud these droplets can range as large as 2 micrometers and even up to 6 micrometers but beyond that size it is mechanically impossible to sustain togetherness due to the physics of surface tension, so they fall in the form of rain.

Interestingly, Popular Science (October 2010) reported that an aluminum aircraft flying through a cold cloud and agitating the micro-droplets, causing them to collide and coalesce will, by this shearing force, cause stratus clouds to spit out a brief spill of snow to the ground.

But what happens to the aircraft?

Certain conditions are necessary for structural icing in flight: (1) the aircraft must be flying through visible moisture such as rain or cloud droplets, and (2) temperature at the point where the moisture strikes the aircraft must be 0° C or colder. Aerodynamic cooling can lower temperature of an airfoil to 0° C even though the ambient temperature is a few degrees warmer. So now imagine flying through this thick layer of clouds with the temperatures between +5 to -20 degrees Celsius. As the super-cooled micro-droplets hit the surface of the cold aluminum or even a cold composite, the friction from this contact results in latent heat generation which raises the temperature of the micro-droplet above 0 degrees Celsius, hence a very small portion of the droplet sticks to the leading edge of the aircraft while the remainder wanders over the surface if the droplet is large or dissipates if it is small. It is the constancy of the cloud moisture content and the size of the droplets that dictate the form and intensity of icing on the aircraft skin.

Raindrops versus Micro-droplets: Size and Volume

The suspended moisture in the clouds cannot sustain the droplet size past 100-200 microns. Once they achieve that size the droplets start to fall as drizzle due to the tug of gravity. If the clouds are cumulus type then in their journey toward the earth, the droplets merge with others and grow like snowballs. These raindrops can reach sizes of 2 micrometers and sometimes 6 micrometers.

Aircraft Ice Accretion

So here we are flying though the clouds and those droplets are hitting the surface constantly causing friction, raising the temperature of the colliding molecules of aluminum and water. Slowly and in incremental steps the super-cooled droplets hit and lay themselves down as Rime ice. Most of the Rime ice forms on the leading edges. Research of steady-state icing done by NASA on a Twin Otter shows a constant increase in the angle of attack at the rate of 1.2 degrees per 300 seconds in cruise mode and 1.6 degrees in a holding pattern. It is therefore a matter of time before the angle of attack is exceeded and the aircraft stalls if nothing is done to prevent it.

Rime, Mixed and Clear Ice

Mixed or Clear ice is nothing more than abundant moisture and larger droplets. Imagine the droplets getting turgid from coalescing with each other and getting heavier. Finally when they reach the critical mass they get a call from gravity and start falling. Reaching a boundary layer of colder temperature as they fall (especially in cases of a warm front over-riding a cold front) the droplets get super-cooled turning into "Freezing Rain" and upon striking the cold surface of the aircraft, instantly freeze and get glued to the surface. Since these are larger droplets they can and do hit the airfoil (wing) at a point past the leading edges thus disrupting and detaching airflow over the upper surface of the wing and destroying lift. Being larger droplets, they form clear ice or with a mixture of small and large droplets a mixed version of the same.

Interestingly as the super-cooled droplets and the frozen snow fall from colder atmosphere to relatively warmer temperatures the electric charges of the droplets reverse on the precipitate surfaces. The friction between the "colder and warmer temperature precipitates" become negative and positive electrical charged particles respectively, which can create thunder snow with lightening in the winter and of course our trusty thunderstorms in the summer months, replete with microburst, rain shafts and anvils. The concept remains the same just the variation in temperatures and build-up of clouds makes the difference in outcome. You can get icing in the clouds in the middle of summer at altitude as you can near the surface in the winter.

GA and the Carriers

Icing is not only a concern for general aviation aircraft. Icing was cited as the cause of an American Eagle ATR turboprop crash during a holding pattern over Illinois. Another ice-related accident involved an Air Florida Boeing 737-200 at Washington, DC, in 1982. And as recently as 2008 a British Airways, Boeing 777-236ER was brought down short of the runway in London by contaminated fuel icing in its huge engines with resultant power failure. The meek and the mighty are both vulnerable to nature's fury.

Here are all the total effects of aircraft icing:

1.A loss of aerodynamic efficiency due to an increase in weight, a reduction in lift, a decrease in thrust, and an increase in drag.

2. A loss of engine power; "Ice frequently forms in the air intake of an engine robbing the engine of air to support combustion. This type of icing occurs with both piston and jet engines, and almost everyone in the aviation community is familiar with carburetor icing. The downward moving piston in a piston engine or the compressor in a jet engine forms a partial vacuum in the intake. Adiabatic expansion in the partial vacuum cools the air. Ice forms when the temperature drops below freezing and sufficient moisture is present for sublimation. In piston engines, fuel evaporation produces additional cooling. Induction icing always lowers engine performance and can even reduce intake flow below that necessary for the engine to operate."

3. A loss of proper operation of control surfaces, brakes, and landing gear.
4. A loss of pilot's outside vision.
5. False flight instrument indications; "Icing of the pitot tube reduces ram air

pressure on the airspeed indicator and renders the instrument unreliable. Most modern aircraft also have an outside static pressure port as part of the pitot-static system. Icing of the static pressure port reduces reliability of all instruments on the system--the airspeed, rate-of-climb, and altimeter."

6. A loss of radio communication: "Ice forming on the radio antenna distorts its shape, increases drag, and imposes vibrations that may result in failure in the communications system of the aircraft."

Knowing this will alert you to the remedies needed and required if you encounter icing and what necessary mitigation strategies you need to have to arrive safely on terra firma. Also the Icing Forecasts are to be taken with a grain of understanding. A Boeing encountering mild to moderate icing would be a "Blizzard" for a GA pilot. So Pireps from equivalent GA aircraft have more validity. Also the location where icing is reported does not stay static, it moves as weather moves therefore the playing field becomes wide open from a single pilot encounter.

And how to get out of the icing encounter:

1. Never knowingly fly into known icing conditions even if equipped with anti-icing equipment. The freezing drizzle and or rain can quickly overwhelm all anti-icing functions.
2. If you encounter rime icing and the accumulation exceeds your comfort zone of a thin layer to less than one-inch accumulation, ask for a deviation in altitude of up or down 2000 feet from your current altitude.
3. If accumulation is moderate to heavy, change altitude, declare an emergency and ask ATC for help in locating VFR conditions.
4. If the horizontal stabilizer is iced fly the aircraft manually to determine the change in control surface function and the required input to determine the degree of lift destruction. The concept is to detect the loss of elevator effectiveness.
5. On approach to a landing with structural icing do not extend flaps for change in the camber and loss of lift generation. Ice accumulation on the horizontal stabilizer is a potentially hazardous condition particularly during approach and landing. Extension of the flaps can increase the "downwash" that can seriously reduce tail-plane stall margin.
6. React before drastic action has to be taken. In mixed or clear icing conditions even the hint would require you to take immediate action. Such as a deviation to reach warmer temperatures aloft (Warm front over-riding a cold front). Ninety percent of pilots gather information through visual cues, which are not reliable in during icing encounters. In an experiment, 89 percent of pilots in simulator training wrongly predicted the stall state of the aircraft in icing conditions.
7. Always fly manually in icing conditions since aircraft stall and elevator saturation can occur when the autopilot is engaged in altitude hold state. This altitude hold state with a roll command can overcome the vertical component of lift and lead to a stall in a turn.
8. Once the ambient temperatures are below -20 degrees Celsius and the moisture falls as snow, flying is at best, bumpy. The snowflakes are deflected from the airframe and do not accumulate.

9. It is better to see snow and especially freezing rain from the comforts of an armchair.

Always have an exit strategy, a Plan B, an alternate option, another choice. Be Safe.

References:

1. http://www.pilotoutlook.com/aviation_weather/icing

2. Cloud Dynamic Structure by Professor Steven Rutledge, University of Colorado, June 3, 2009.

3. Detection of the loss of elevator effectiveness due to aircraft icing. Robert H.Miller * William B. Ribbers, Department of Aerospace Engineering, The University of Michigan, Ann Arbor, MI 48109 AIAA-99-0637

4. European Aviation Safety Agency: British Airways, G-YMMM Boeing 777 236ER Accident.

5. Smart Icing Systems for Aircraft Icing Safety, Michael Bragg et al, Univ. of Illinois.

6. The Ohio State University American Institute of Aeronautics & Astronautics 27/01/2009

6. TP 185 - Aviation Safety Letter http://www.tc.gc.ca/CivilAviation/publications/tp185/1-07/Feature.htm

7. Aircraft Icing handbook, Version 1, Civil Aviation Authority New Zealand.

Additional Resource:

NASA Icing reference: http://aircrafticing.grc.nasa.gov/index.html

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