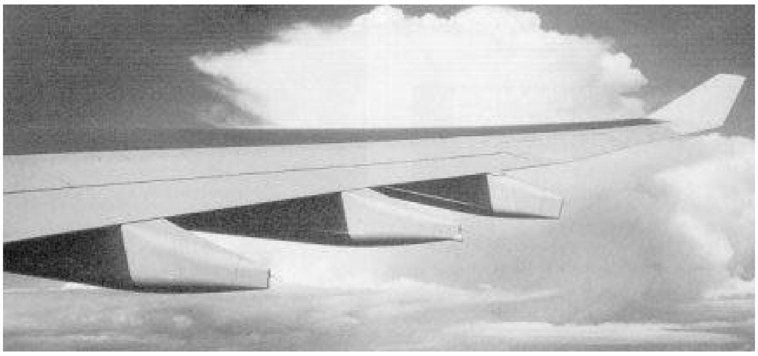
UNDERSTANDING THE PROCESS OF ICE ACCRETION

Original idea from Claudius La Burthe



Fuel reserves for ETOPS have to be based on an assumed diversion leg of up to three hours, flown at or above 300 kt and possibly flown at a flight level of 10,000 feet (FL100). It is true that flying at FL100 in North Atlantic winter weather can be terrifying in a light aircraft.

The icing accident record in the region for these aircraft is well known and heavy. With this experience, a standard icing policy was applied by authorities to all aircraft, and aircraft manufacturers complied. This required provisions to sustain continuous icing over a 1000 nm straight flight leg.

The resulting fuel penalty was enormous and the feeling was that the icing threat had been over-estimated. Therefore, Airbus and Boeing jointly decided to investigate the case. Many different studies were launched, all aimed at achieving more realistic rules, including:

- better definition of the icing threat (meteorological approach)
- study of ice accretion at high speeds (speed effect approach) .

In 1990 it was jointly decided to support a study at Penn State University, called *"Assessment of aircraft icing potential using satellite data"*, being conducted by Dr. J. Curry. That study clearly established the possibility of predicting (short term) reasonably accurate water content by data fusion between satellite infra-red imaging and computer meteorological models. Some side results mentioned in the report supported the idea that areas in which icing occurred would be very limited in size. Although the study only covered a one month period and was called a "pilot study", subsequent events confirmed the result. Through contact with specialists, it was then discovered that the Canadian Government was funding an icing research exercise called CASP II (Canadian Atlantic Storms Program).

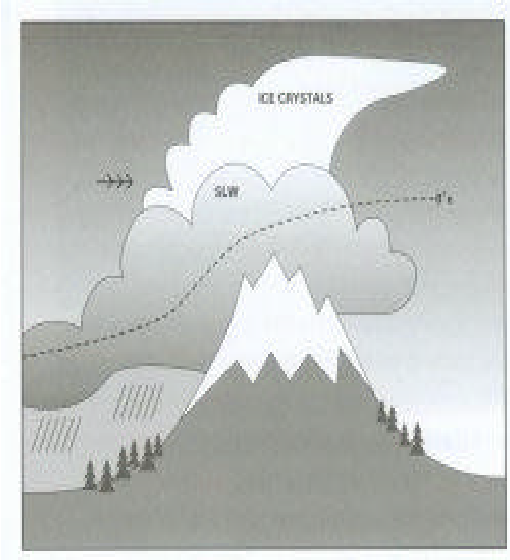
Following an earlier CASP I campaign, that research was initiated by the need to protect the Canadian cod fishing fleet from the risk of blizzard. The problem is that those small ships operate off the coast of Newfoundland in mixed hot/cold waters due to oceanic streams. In winter they can encounter extreme icing conditions, up to the point of being capsized by the very heavy weight of ice accumulated on the superstructure in a very short time. Airbus and Boeing asked if they could participate in this program and were made very welcome by the Canadian government.

CASP II took place from January to March 1992 in St John's Newfoundland. The program involved about a hundred people including many high level scientists, two research aircraft fully equipped for icing measurements, and very significant support by Canadian weather services, particularly in the field of satellite coverage. During the process of accruing a total of more than 200 flight hours, about a hundred icing encounters were recorded.

The results are of extreme interest in all fields related to icing; they not only confirmed that the icing threat in ETOPS had been initially over-estimated, but also considerably augmented current knowledge about icing.

JUST A LITTLE BIT OF SCIENCE

What is an icing atmosphere?
An atmosphere which is susceptible to the production of icing is necessarily at sub-zero OC temperature and must also contain droplets of liquid water. That water is called Supercooled Liquid Water (SLW) and analysts refer to the SL W content(SLWC). This phenomenon only happens when the atmosphere is disturbed, due to meteorological reasons possibly aggravated by the effect of mountains (orographical effect). An icing atmosphere is localised and unstable, and therefore does not last very long.



Does an icing atmosphere always lead to ice accretion on aircraft?

Absolutely not! Aircraft pick up ice much less often than they meet icing conditions, which are predicted by weather services on their meteorological charts almost every other day over the North Atlantic! In fact, the icing mechanism is rather complicated. Detailed study shows that a problem of energy is raised. It is very likely that if a group of different aircraft flew into the same icing cloud, most of them would not collect ice and only a few would suffer from significant icing.

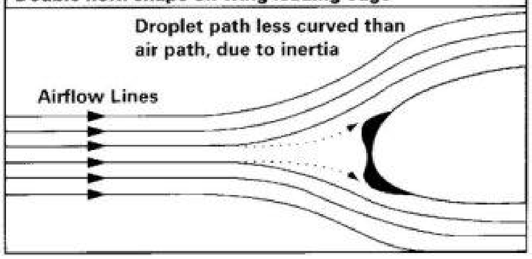
Does speed have an effect on ice accretion?

Absolutely yes! In very simple terms, the effect of speed is illustrated here:

DESCRIPTION OF ICE ACCRETION MECHANISM

A wing leading edge flying into icing air is supposed to be exactly at ambient air temperature (negative °C). That air is loaded with water droplets, but many touching it (continuity of airflow). However, water droplets are much heavier than air particles and they do not pass round so easily. Some of them therefore impact on the leading edge (figure 1).

Figure 1
Double horn shape on wing leading edge



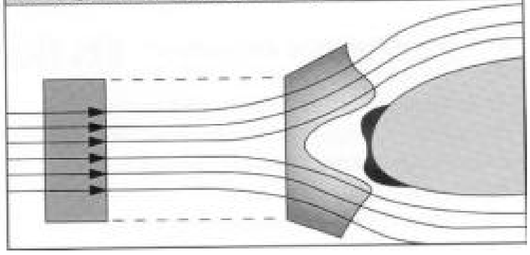
Also, it is a rule of supercooled water that it is unstable, and supercooled liquid water freezes immediately after the impact. Ice accretion results from the continuation of this process.

Double Horn Shape

- *Why the double horn shape?*

The above process leads to an uneven distribution of water droplet impacts on the leading edge (figure 1). It is easily conceivable that those which are right in the middle would not be deflected very much and would impact instead on the upper and lower sides of the leading edge.

Figure 2
Development of double horn shape



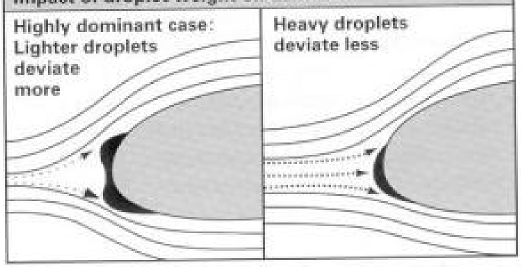
This starts the double horn shape, which is a divergent process and which is further enhanced by ram effect (figure 2). But if the droplets are very heavy, as in the case of freezing rain, deflection is limited, and ice accretion takes place in an arc shape (figure 3).

Ram Effect

The impact mechanism generates energy both in the air and in the water which generates a rise in temperature. Aircraft leading edges are heated by the friction of high speed air, this temperature rise being highly dependent on speed (figure 4).

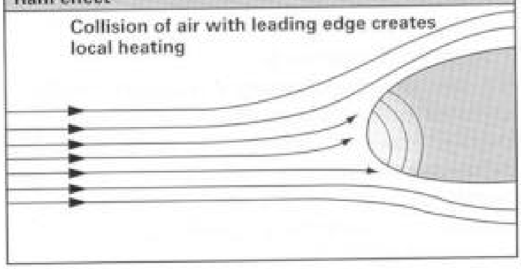
For air only, the temperature rise is +40°C at 150 kt and +16 °C at 300 kt at FL100. It is very important to take this temperature rise into account for the assessment of ice accretion.

Figure 3
Impact of droplet weight on deflection



Significant icing is not possible if the speed is such that the ram effect brings the leading edge temperature above zero! For example, no significant ice accretion is possible in air above –16°C if aircraft speed is maintained at 300 kt.

Figure 4
Ram effect

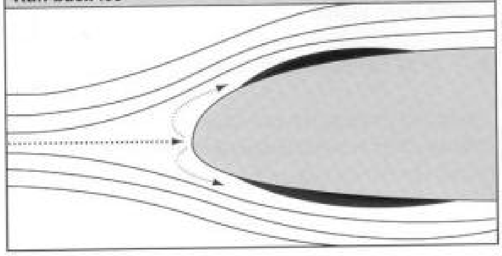


Run-back Ice And Shear Forces

- *What happens when an aircraft is flying in icing conditions where leading edge temperature is positive?*

Due to ram energy, water droplets do not freeze on impact, but explode into numerous little globules which are blown by the airflow along the wing surfaces. But wing surfaces aft of the area heated by ram energy are at a negative temperature and cool the water down. It often happens that the cooling is quicker than the blowing off and water freezes on the spot. This process is called *"runback ice"* (figure 5).

Figure 5
Run back ice



Efficiency of the blowing off process depends on the shear forces present in the boundary layer. The faster the aircraft, the cleaner the wing.

Sublimation

- *What happens to an iced wing once the aircraft is out of the cloud?*

The situation is hardly ever considered. Ice will not stay as it is because of sublimation, which is the direct change of water from solid state to vapor. Once out of cloud, ice thickness will necessarily decrease. The sublimation rate depends on relative air humidity and may reach a rate of one millimeter per ten minutes. This is quite an impressive figure, which is worth considering for flights of long duration.

CASP II CONCLUSION

Although numerous icing events (about 1 00) were encountered during the CASP II experiment, very few were of significant importance for aircraft flying at FL100, and none at all if the speed was assumed to have been 300 kt. This surprising outcome resulted from a number of factors unfavorable to the formation of icing.

North Atlantic Climatology Related To Icing

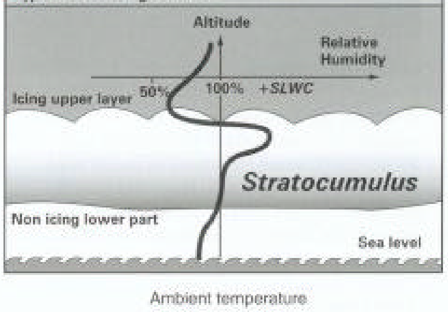
It was found that North Atlantic winter weather conforms to its legendary severity mainly at lower altitude. The absence of Orographic effects lets the frontal systems develop in a classical "horizontal" manner. Weather moves East rapidly. Precipitation of multiple types is heavy on the ground, but water content at altitude remains moderate. Cumulonimbus clouds are rare, very small and with moderate activity. Stratiform clouds dominate and carry most of the Supercooled Liquid Water (SLW) which is far from evenly distributed in them. ***Most of the SLW lies in the upper few hundred feet of the layers.*** Due to ever-present micro convection, water content is extremely irregular. If peak values can be impressive, average figures remain moderate and so does the ice accretion. By definition, a temperature inversion layer sits on top of every stratus cloud layer (figure 6).

The consequences for aircraft are of prime importance:

- if icing is encountered, a small altitude change (a few hundred feet) may relieve the threat. This is not conventional, but atmospheric physics are in operation !
- flying close to the top of a stratiform layer probably involves the greatest risk of icing. Flying above the layer is much smoother and the atmosphere is much drier, thus making it prone to active sublimation.

Figure 6

Typical CASP icing conditions



Size Of Icing Clouds

Typical icing clouds are hardly ever extensive horizontally, even taking the worst case which would be to fly along a cold front. It is difficult to quote a figure before all CASP results are available, but it is clear that an ***aircraft flying at 300 kt would never remain** in **icing cloud for more than a few minutes (and would have no ice accretion, due to speed).*** Repetitive encounters are possible in an area where a complex weather system sits, but not all would be a real threat. It has also been found that no definite correlation exists between cloud size and droplet size.

Effects Of Speed And Sublimation

It has been shown above that speed protects aircraft from icing due to ram effect. The CASP II results confirmed that neither of the aircraft involved ever experienced ice accretion at their maximum speeds, 230 and 250 kt respectively. It had been considered that ram effect might produce run-back ice, but it was found that the increased level of shear forces encountered at high speeds reduced runback ice to negligible proportions. If, in spite of everything an aircraft iced up during an ETOPS diversion, ***sublimation would significantly decrease the drag penalty during the rest of the leg.***

These results can be expanded to include oceanic areas other than the North Atlantic of similar latitudes. Note that icing risks are necessarily aggravated by the proximity of mountains and that ice accretion on jet airliners at medium flight levels differs from the icing encountered by light aircraft flying at lower levels and speeds. This research does not attempt to address the experience of icing gained by the thousands of magnificent men and women who have crossed the Atlantic in their light flying machines.