MODERN ICE SENSORS FOR UAVS.

technical white paper

Compliments of
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An overview of unmanned aerial vehicle hazards due to ice-induced tailplane stall, its causes, effects and detection before landing.

The perverse thing about ice on the tailplane of a general aviation aircraft is that the pilot sits and looks forward, but the tailplane is aft. You can't see it from the cockpit.

One sign there's ice on the tailplane of a GA aircraft in flight is when the controls become "mushy". That's a tactile clue, but when there's no human being with hands on the controls, it's a compound problem for unmanned aerial vehicles.

As for ice on the wings etc, GA pilots are trained to "look for ice". Again, without a human being in direct control, it's a double problem for UAVs. But even so, how do you see clear ice? How do you see white ice on a white wing? How do you see ice at night?

Clearly, ice sensors are de rigueur for UAVs.

UAVs can fly at great heights, and for long periods of time. But in order to get up there, they have to transit through the hazardous ice-formation zone below 20,000 feet; that's where ice forms.

Above that altitude, it's generally too cold for ice to form on the airframe. Because the temperature lapse rate of our atmosphere is -3.5 deg F per 1000 feet, H_2O molecules in the air up there may already be in their solid phase, and they just bounce off.

It's when liquid water molecules (clouds) impinge on the airframe and freeze in place -- that's the danger.

Ice forms on thicker members of an airframe *later* (windshields and wings). That's because thicker cross-sectional members compress more H_2O molecules, and their cumulative ram-air heating effect is greater than it is on thinner cross-sectional members (horizontal stabilizers and rudders of the tailplane empennage). Less compressional heating means the tailplane remains colder, and ices up *earlier,* before the wings do.

So, the perversity of ice on an aircraft tailplane is that ice is more likely to form there than on the wings; the tailplane can't be seen, and the deleterious effects of ice on the horizontal stabilizer can be greater than ice on the wings, especially on landing.

Wing ice on the leading edges and upper surfaces is bad enough. It destroys lift, and the weight of it (90% that of water) not only burdens the powerplant, but is mostly forward of the center of gravity, inducing the nose to point down, toward the ground.

Figure 1 — Optical aviation ice sensor is a commercial, off-the-shelf, in-flight ice sensor that monitors the optical characteristics of whatever substance is in contact with the optical surfaces of the probe, either air (NO ICE) or water ice (ICE ALERT). Ambient wind blows standing water away, but ICE sticks. Made of nonconductive delrin and acrylic plastics, probe is electromagnetically compatible with its host aircraft radio environment, and can be installed in close proximity to radio antennas.

On landing, the effect of ice on the horizontal stabilizer is definitely worse than on the wing. An aircraft's horizontal stabilizer is actually a small wing, mounted upside-down. It creates downward "lift", forcing the tail down, and the nose up.

If the horizontal stabilizer stalls on landing, the nose can pitch down very abruptly and violently. Ice-induced tailplane stall on landing is really bad, because there may not be enough altitude remaining in which to recover.

In-flight situational awareness is even more critical in a UAV than in a manned aircraft, because of the absence of tactile feedback to a human pilot.

Bristling with GPS and other gear

Most large air transport and military aircraft are normally equipped with pneumatic de-icing boots made of rubber. These boots have been around since the 1940s and earlier; they can be activated manually by the pilot, or automatically, by an on-board ice sensor.

Since the advent of rubber boots, more recent developments for aircraft de-icing include hot bleed air from the engine's exhaust, electrical heaters, ethylene glycol weeping wings, capacitive discharge loops that literally blast ice off the leading edges, and others. Historically by default, most automatic de-icing schemes use ice-sensing technology based on a vibrating reed, from the 1980s.

Vibrating-reed ice sensors protrude from the fuselage of an aircraft into the ambient airstream and resonate in free air at 40 KHz. When ice forms on the probe, its mass reduces the frequency of vibration.

The sensor housing contains a circuit board that translates that change in frequency to an equivalent mass on the probe. Then a another circuit board translates that equivalent mass to a theoretical thickness of ice, which, if it exceeds a threshold of typically 0.020 inch, the unit reports ice alert. This signal then activates pneumatic boots which expand and crack the ice away from the wing's leading edge.

H2O phase change

Even for aircraft that do not employ pneumatic de-icing boots, vibrating ice detectors have been the default ice sensors for 30 years, providing advisory ice alerts to pilots, advising them to take some corrective action -- climb up out of the clouds to clean air, descend below the clouds to warmer air, or turn around and go back.

All this is well and good, but when it comes to modern unmanned aerial vehicles, mechanically vibrating ice sensors are less than an optimum solution. In a major breakthrough in ice sensor technology development, today's newest and most up-to-date ice sensors are available on the open market for subsonic aircraft.

Modern UAVs are used as airborne platforms for surveillance, mapping, communications, fire fighting, agriculture, search & rescue, and other radio-intense applications. Compared with traditional general aviation aircraft, modern UAVs tend to be smaller and lighter, with less powerful engines, a lower energy budget, and bristling with GPS and other radio gear.

Just as any other radio antennas, transmitting and receiving antennas on UAVs require a sphere of elbow room in which to propagate and receive electromagnetic signals correctly, without interference from nearby electrically-conductive structures that might distort and corrupt their frail, low-level satellite and terrestrial radio signals.

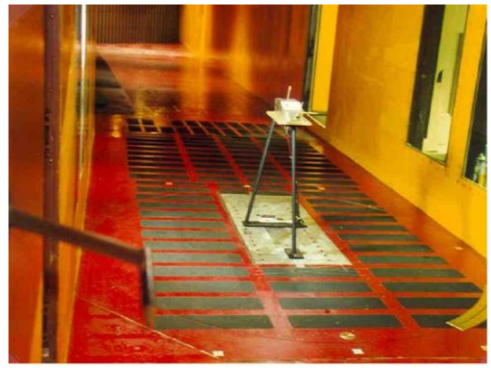

Figure 2 -- Test program conducted at NASA Glenn's Icing Research Tunnel demonstrates sensor conformity with defacto standard SAE AS 5498 ¶5.2.1.1.1 minimum operational performance for in-flight icing detection systems. Also listed in SAE AIR 4367 ¶ 4.11. (Note NASA Pitot tube in left foreground, rotating deck for adjusting wind tunnel icing angle-of-attack).

The limited surface area for ice sensor probes on a small UAV can complicate the location and installation of any kind of metal ice sensor vis-a-vis the aircraft's sensitive radio antennas.

Solving this problem, the external sensing probe of modern aviation ice sensors is fabricated of non-conductive PLASTIC that is transparent to radio signals, and poses no radio interference problem for the host UAV.

Modern optical ice sensors generally consist of a unitized plastic probe with an air gap, circuit board, housing, and cable. The probe is a delrin plastic cantilever that holds two optical windows and a reflecting wall below the wing, out into the airstream. In operation, optical ice sensors detect the H2O phase-change between liquid water and solid ice. Producing the maximum possible sensitivity, in-flight ice molecules form directly on the probe's optical surfaces.

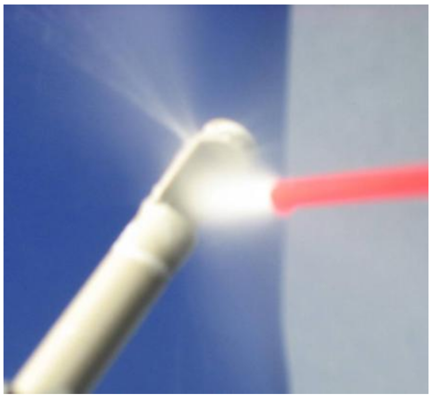

Figure 3 -- Simple field test procedure sprays tetrafluoroethane component cooler on air gap optical surfaces, freezes ice out of ambient moisture, tests rate-of-accumulation ICE ALERT, MORE ICE, SATURATION.

An optical sensor-excitation signal is created and received by the interface board. The earliest formation of ice molecules on the optical surfaces perturbs the sensor's excitation signal, on a molecular level. The board interprets and outputs transducer signal variations on three discrete logic wires as no ice (000), ice alert (001), more ice (011), or saturation ice (111).

The probe's inboard end mates with a small interface board buried in solid epoxy inside the housing, completely submersible in water. A lightweight blue cable connects the unit to its host system.

Optical ice sensors are small, lightweight, have no MHz clock, and no moving parts. They install from inside the wing, extending down, air gap facing forward into the air stream. The entire unit is fixed in place with a 5/16”-24 thread and nut, just as an ordinary outside air temperature gauge installs in a general aviation aircraft.

Optical ice sensors owe their high degree of sensitivity to the fact that they are pencil thin, and so create minimum ram-air heating effect on airborne H2O molecules. For this reason, they attract solid ice molecules before fatter, warmer airframe members, such as fuselage, wings and struts.

During NO-ICE conditions, ambient wind removes liquid water from the sensor optics, but ICE sticks to it and accumulates for detection.

NASA Glenn's Icing Research Tunnel, the world's largest such tunnel in Cleveland Ohio, has tested and documented optical ice sensors according to a matrix of temperature, humidity, altitude, air speed, liquid water content, drizzle drop diameter, and air pressure. Test tunnel matrix and report available upon request.

Shape-changer.

Ice formations on an exposed optical surface in an icing domain can be either clear ice or rime ice, depending upon atmospheric variables. But optically clear ice or opaque rime ice makes no difference to the sensor.

Optical ice sensors can change their shape according to the type of ice formation and report it. When shipped from the factory, optical ice sensors have one shape, but when installed in a UAV, flown aloft and faced with ice, they can change to a different shape.

Because they are completely solid and lightweight vs vibrating sensors, optical ice sensors are extremely robust vs shock and vibration. They create less aerodynamic drag than vibrating sensors, and they add lightness to any aircraft. One of the reasons for their lightness is they eliminate the weight of many-turns-of-fine-wire magnetic coils required for an electro-magnetically driven sensor probe.

Not only is the weight of the copper eliminated, but also the weight of the metal frame to contain and mount the vibrating assembly. Optical ice sensors employ very simple direct-sensing technology, have no moving parts, and are simple to manufacture and test. Manufacturing cost is much lower than vibrating sensors.

What's more, optical ice sensors substantially reduce the power budget of any aircraft. Simple to design into any UAV, they operate on just one single DC voltage anywhere between six and 30 volts. At standard 24 VDC input, they draw less than 100 mA; you can power it with a 5 Watt solar panel. Output logic levels for the three wires is zero volts to 3.3 volts DC.

Absence of installation-template restrictions affords optical sensors a great deal of flexibility. Probes can be separated from their electronic interface boards, and conveniently integrated directly with UAV running lights and Pitot tubes. Because they are potted solid with two-part epoxy, they are explosion-proof. Because system integration is so simple, sensors are shipped with their connecting wires simply stripped-and-tinned at the end. No requirement for MIL-SPEC connectors.

*Figure 4 -- Saturation ice on an Ice*Meister™ Model 9732 ice detecting sensor for aircraft*

Modern ice sensors are offered as commercial off-the-shelf (COTS) products. Because of an unfortunate absence of any published FAA TSO specification for in-flight ice-sensors, the aviation community relies upon defacto standard SAE aerospace specification AS-5498, core paragraph ¶5.2.1.1.1. Optical sensors are also listed in SAE aerospace information report AIR-4367 paragraph ¶ 4.11.

As unmanned aerial vehicles become more and more popular throughout the aviation community, modern ice sensors are becoming equally important to help operators of the aircraft avoid the hazards of ice-induced tailplane stall and other ice-related hazards. The recent advent of modern optical ice sensors to supplant primitive vibrating sensors promises to aid the state of the art.

For more information

on ice-induced tailplane stall, interested readers may wish to view a 23-minute NASA video entitled "TAILPLANE ICING" (NASA catalog # GRC-423) that excellently describes, illustrates and dramatizes the hazards of ice-induced tailplane stall, and its effects on aircraft safety while landing. For information, contact NASA Glenn at email grc-icing@lists.nasa.gov, or download from http://icebox.grc.nasa.gov/ext.

Also, a limited number of digital video disks are available directly from the New Avionics, email info@newavionics.com

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