FLUKE®

Fluke thermal imagers show the way to safer flying

Application Note

Testing Functions

Case Study

> **"We had some statements that had survived in the industry for a long time, like 'You never get frost after sunrise.' Not true."**

Tools: Fluke Ti25 Industrial Commercial Thermal Imager

Operator: John Horrigan, owner and airline safety expert at Ops House Consulting of Ottawa

Applications: Analyze frost on airplane wings

An airplane accident in 1989 changed how people in aviation dealt with snow. The "clean wing" concept replaced the old notion that takeoff with "a little snow" or ice sticking to the wings was somehow OK. Now the wing had to be free of snow, but sometimes pilots were still taking off with wings that had frost on them because frost represented a threat that was more difficult to detect and evaluate. That's because frost occurs most often in excellent weather—when skies are clear and winds are light—and because frost can form even when the air temperature is above freezing.

Airline safety expert Captain John Horrigan, who helped implement the lessons learned from the 1989 crash, has set the job of detecting and evaluating the dangers of winter flying for himself and his company, Ops House Consulting of Ottawa. A veteran pilot and former inspector for the Civil Aviation Branch of Transport Canada (the Canadian equivalent of the US Federal Aviation Administration), Horrigan has been in the cockpit and has made the difficult and complex decisions that pilots must make when flight schedules press and weather goes bad.

"When pilots identify a threat, they deal with it," Horrigan said. "Nobody wants to go to work and not come home." But in the past, the true threats from many winter conditions were not well understood.

The challenge of optimized design

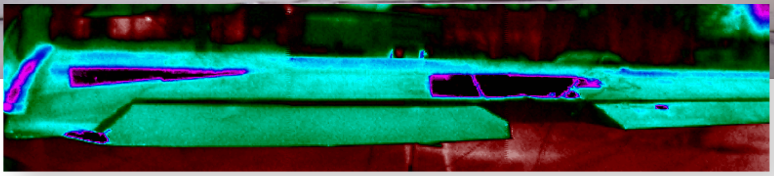
Today's swept-wing airliners are optimized for efficient flight at the high speeds and altitudes where they spend most of their time, Horrigan said. But at low speeds, swept wings respond very differently from straight wings. They need help. Most of them have leading-edge slats and trailing-edge flaps that pilots deploy to adjust the airfoil shape, enhance air flow, and provide extra wing area and lift for takeoff and landing.

It's easy to see that a layer of ice or snow on the wing could mean trouble. But frost, too, can interfere with the flow of air along the all-important "boundary layer," where air must move swiftly over the wing's upper surface to generate lift.

"The top surface of the wing still has to be pristine to allow that airflow to go over," said Horrigan. "If you have roughness on the upper surface of the wing—picture 20-grit sandpaper—that's enough to wipe out 30 percent of the lift. Contamination defeats the design assumptions of that wing. And if the wing isn't doing what the manufacturer designed, all bets are off."

Frosty facts

"For many years, when we were talking about ground icing, we couldn't actually verify some of these assumptions," Horrigan said.



This merged image started the ball rolling. The resolution of the thermal imager is low (use of the imager had started that day), but it delivered a new perspective. Even though the focus was variable across the merged field, good post-processing capabilities helped in handling the data.

"Before 1989, most of the research that we now rely on hadn't been done. There were a lot of assumptions and myths about what an aircraft needed to have done, what it could and could not do."

Horrigan has learned a lot about frost and how it forms. "The big hazard with frost of any kind is underestimating its rate of formation, and what it's doing to your wing," he said. Frost formation can be complex, influenced by air temperature, humidity, sun and cloud conditions, wing finish, and even the content of the fuel tanks. That makes frost tricky for pilots and ground crews to understand.

A better way to see

Aircraft wings generally don't have temperature sensors, so Horrigan relied on temperature probes to check and record surface temperatures. "I was doing a lot of research with heat, but with direct temperature probes on the surface," he said. "I began to realize that although these direct probes worked well, they had a very limited field. I needed something that was going to give me a good look at the entire wing, all at once."

So Horrigan added a Fluke Ti25 Thermal Imager to his toolbox.

"We took the approach that the imager would just be one more sensor, with our primary data still coming from the contact probes," he said. "What the imager did was augment the contact probes with over 19,000 sampling points. As a result, I hoped to be able to either verify our model or maybe see areas of the wing that didn't behave as expected. My expectations from the imager were low. After all, we were just starting to use it."

What happened next was surprising. "In the very first session, the data that changed the entire direction of my research came from an imaged area where we had never placed probes before. What we saw in the image was nothing close to what we had assumed would be there." The first response was that the image had to be an error resulting from inexperience with the device. But instead of an error, the imager had, in fact, captured a missing piece of the frost formation puzzle.

"Up until that point, nobody we knew of had quantified the radiating power of this wing to the sky. We all knew about radiation cooling, but we didn't actually have quantitative knowledge. We began to realize that the surface temperature probes were not telling us the whole story. Areas that we previously thought would develop frost were not developing it as quickly as others."

The data Horrigan gathered with his thermal imager began to change industry thinking about frost. "We could finally see which assumptions were right and which ones weren't," he said. "In the past, operators would check one or two aircraft in a line, and say 'We aren't going to have any frost tonight.' And then we'd have all sorts of frost and it wasn't treated properly. And I began to realize it was because we were measuring the wrong things. We were looking at temperature, we were looking at dew point, making some assumptions on wind, but we were missing a large component of thermodynamics and heat transfer."

Among the frost factors

Cold-soak frost

At cruising altitude, a plane flies through air well below -40 °C. As the hours pass, conduction through the wing surfaces can chill fuel in the wing tanks to as low as -39 °C. "The air cools the fuel, and then the fuel stays cold," Horrigan said. "As the aircraft descends into warmer and more humid air, the cold fuel causes condensation and can cause freezing on the wing. It's not harmful in flight, but on the ground it's a threat." Even with ambient air at 15 °C, cold-soak frost can form. "People are walking around in shirt sleeves, but you've got frost forming on the wing," Horrigan said.

Open skies

If you've seen frost form on your car roof in the evening, even with air temperatures above freezing, you've seen the effects of radiation heat exchange. "It may be 10 °C outside but even in the summertime, at night, on the thermal scale the sky looks like it's -40 °C to -70 °C," Horrigan said. "Frost will happen on a clear night, with light winds, and high pressure. Sometimes the frost will take hours to form. Other times it will form in seconds."

Wing finish and shape

Bare aluminum generally radiates heat more slowly than painted surfaces, so painted wings tend to cool and develop frost first. Various areas of the wing may also radiate heat at different rates based on their curvature and the direction they face.

Looking for trouble

"From there I decided to go looking for trouble with our current models," Horrigan recalled. "We had some statements that had survived in the industry for a long time, like 'You never get frost after sunrise.' Not true. And we believed that you never get frost when taxiing. That turned out to be false as well." The imager helped debunk such old ways of thinking, and allowed Horrigan to see errors in his own assumptions.

"It was great," he said. "I could go and see that I should be getting frost now. I could see the difference in the temperature and see how it was responding. I could see the areas that needed surface probes, instead of making an educated guess." The surface probes still served a primary role by correlating the data that the imager was getting. They also helped deal with problems such as the variable emissivity across the wing surface. "We understood from the outset that the imager gathered energy, not temperature. The contact probes anchored the imager data, but only the imager could help us visualize the radiation heat transfer."

The result, Horrigan said, has been a fundamental shift in the aviation industry's understanding of how, when, and why frost forms—and how to respond. "The pilots' situational awareness is key," he said. "If they perceive a threat, they will take steps to avoid it. This will raise pilot awareness."

Horrigan hasn't been the only one to learn from the thermal images he has captured. He has used the images for training airline ground crews to recognize how and where frost forms, so they know when to respond with the required de-icing procedures. And when Horrigan spoke to a gathering of SAE International—the professional engineering organization devoted to building and operating not just cars, but all self-propelled vehicles used on land or sea, in air or space—the images helped bridge the language and communication differences among audience members.

"The presentation shows the model of cooling, and it also shows the images of it actually taking place," he recalled. "People aren't just looking at a plot of data and a line chart. They're looking at an image of data. At SAE, I'm in a room with probably 150 people there that speak a bucketful of languages, but they can all see the same thing. You look around the room and everybody's nodding and saying 'I see now.'"

A little help

Fluke thermal imagers delivered the insights Horrigan needed to change the way the world understands frost. Fluke thermography software and staff support have also played a key role. Horrigan downloads data from his imager into Fluke SmartView® Software, then exports the results into a database program for further manipulation (he once worked as a programmer in the petroleum industry). He reached out early to Fluke thermography experts for help understanding thermography and interpreting the information he was collecting.

"It certainly for me has been a game changer," Horrigan said. "The imager is good, the software is good, but what I didn't expect, and what really made a big difference, is that I bought a Fluke system that goes far beyond the hardware and software. When I can call a manufacturer's rep in Toronto with kind of a wrinkle in how I want to use this, and instead of being told it's not supposed to be used that way, instead I get plugged into a product development team like this—look at the impact it's had!

"In response to what we have learned, both the US FAA and Transport Canada have just published new guidance for frost conditions, effective immediately. These guidelines affect airlines and aviation companies all over North America. From its very first use, this humble little imager has improved the safety of millions of passengers. Not a bad debut, all things considered."

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