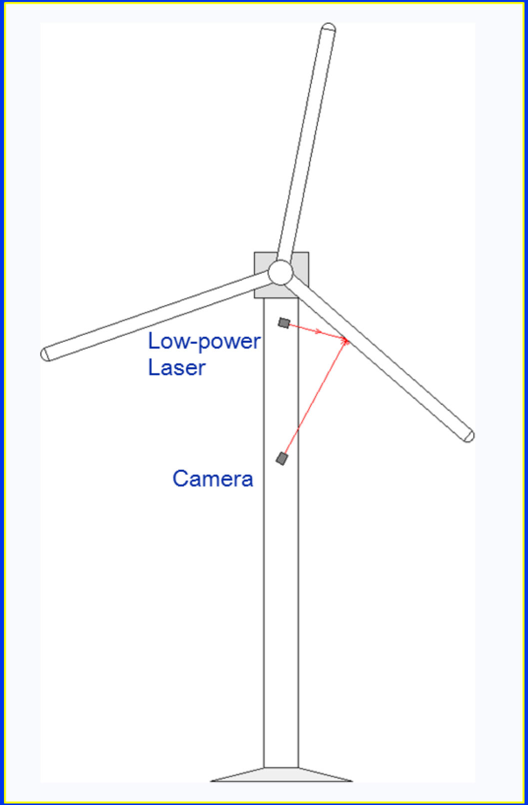

A Remote Ice Detection System Suitable for Detecting Icing on Wind Turbines

Robert Gagnon
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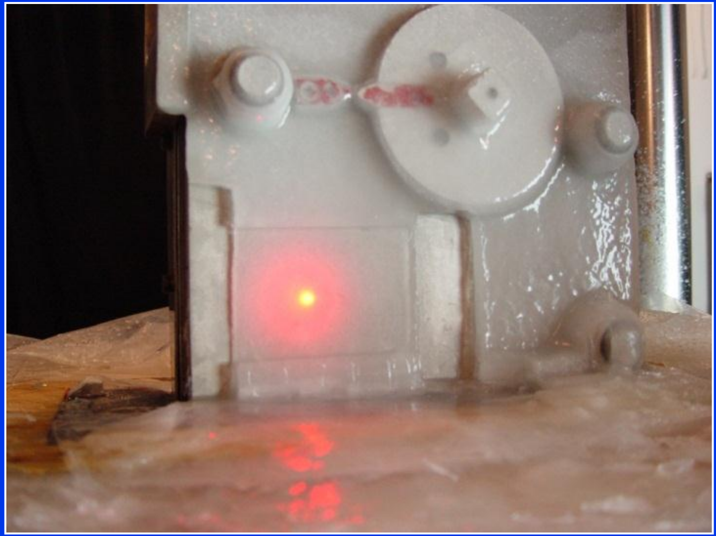

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Examples of Applications for Ice Detectors

Energy

To initiate mitigation strategies.

To warn of power interruptions and initiate mitigation strategies.

Aerospace

To warn of degradation of wing performance.

To avoid hazards of inflight falling icing accumulations.

Marine

To warn of icing encumbrance of safety and communications equipment.

To control heaters for de-icing stairs and walkways.

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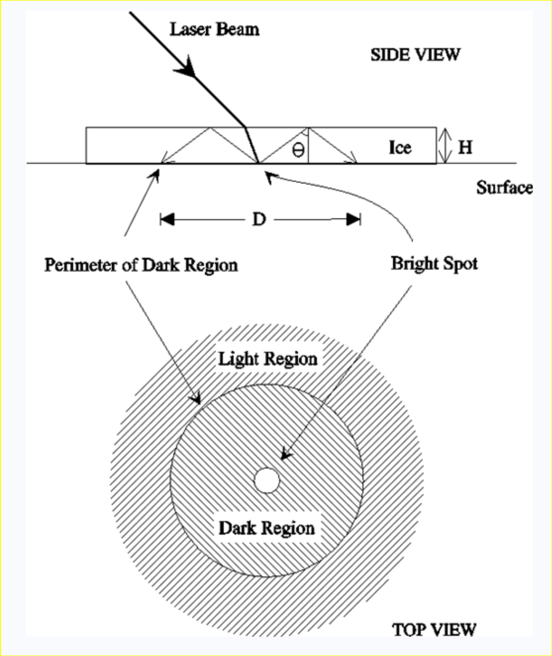
Technical Description of the Current Remote Ice Detection Prototype

Optical Method 1



$$H = \frac{D}{4 * Tan(\Theta)}$$

$$\Theta = \sin^{-1}\left(\frac{1}{n}\right)$$

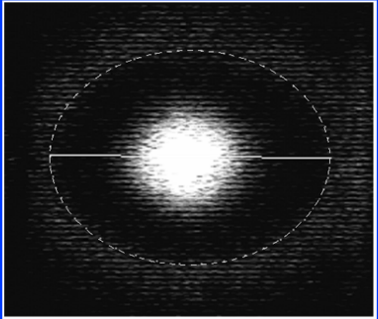
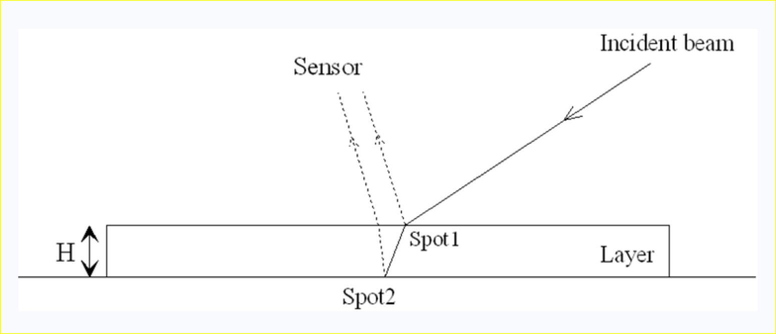


Illustration of the remote thickness measurement technique, optical method 1, used for clear solid or liquid layers. (From *Gagnon, R., Groves, J., Pearson, W., 2012. Remote Ice Detection Equipment – RIDE. Cold Regions Science and Technology 72, 7-16.*)

Image from an ice layer measurement showing the elliptical fit at the light/dark boundary and the major axis of the ellipse. The iced surface was tilted relative to the view direction, hence the pattern of illumination is elliptical rather than circular. (From Gagnon et al., 2012)

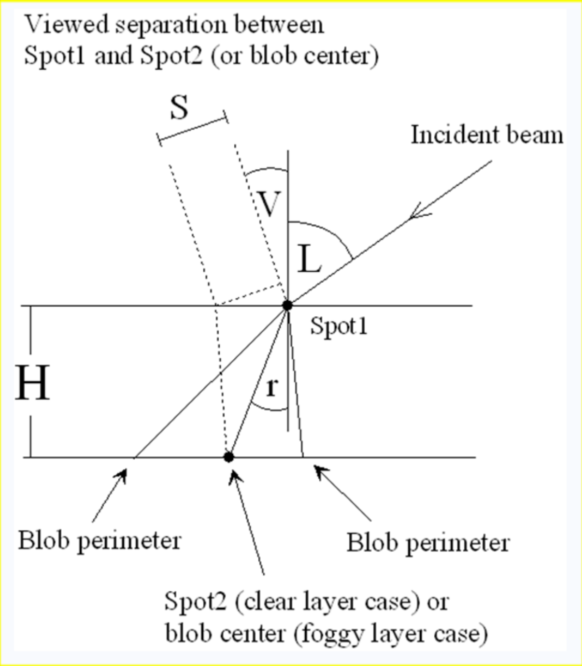
Technical Description

Optical Method 2



The basic operation of the second technique, optical method 2. The method can be used for clear or foggy layers of solids or liquids. (From Gagnon et al., 2012)

$$H = S / [(\tan(\sin^{-1}(\sin(V)/n)) + \tan(\sin^{-1}(\sin(L)/n)))\ \cos(V)]$$



Detailed schematic for optical method 2. Note that the blob 'perimeter' is not a well-defined line but rather, for descriptive purposes in discussing the figure, it refers to an ellipse defined by a line of arbitrary equal brightness. (From Gagnon et al., 2012)

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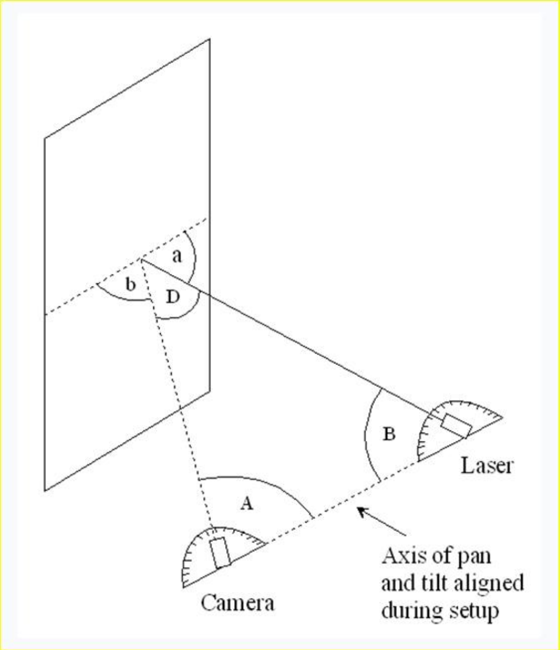
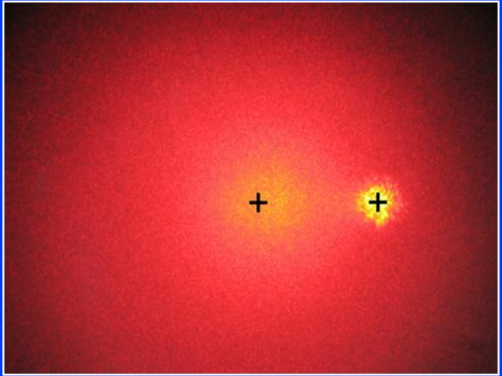
Technical Description

Optical Method 2



Schematic of the system setup where a measurement is made on a surface that is tilted relative to the plane defined by the camera, the laser and the measurement point location. Relevant angles used in the calculations are shown. (From Gagnon et al., 2012)



An image captured by the device during a test program where the thickness of a foggy ice layer on a metallic surface was determined. The bright spot at the right corresponds to the location where the low-power laser beam impinges on the top surface of the ice. The large and more diffuse illuminated region taking up the majority of the image corresponds to the light blob on the underlying surface caused by scattering of the laser beam by the tiny air bubbles in the ice as it propagates through the layer. (From Gagnon et al., 2012)

Technical Description

Optical Method 2

$$H(thickness) = \frac{S(spot\ separation)}{\sin(b)\cos(RV)\tan(AV)\left[1 + \frac{\cos(RL)\tan(AL)}{\cos(RV)\tan(AV)}\right]}$$

where: RL = $\tan^{-1}$(tan(a)sin(T)); RV = $\tan^{-1}$(tan(b)sin(T)); AL = $\sin^{-1}$(sin(L)/n); and AV = $\sin^{-1}$(sin(V)/n).

where: *T is the angle of tilt of the surface relative to the device*

$$L = 90 - \tan^{-1}\left[\frac{\tan(a)\cos(T)}{\sqrt{1+\left(\tan(a)\sin(T)\right)^2}}\right] - (a - \tan^{-1}(\tan(a)))$$

$$V = 90 - \tan^{-1}\left[\frac{\tan(b)\cos(T)}{\sqrt{1+\left(\tan(b)\sin(T)\right)^2}}\right] - (b - \tan^{-1}(\tan(b)))$$

Current System Hardware Components

The two main system components situated on their respective tripods. The laser tripod is on the right. Also visible in the photo are the Lexan™ weather housings resting at the bases of the tripods. (From Gagnon et al., 2012)

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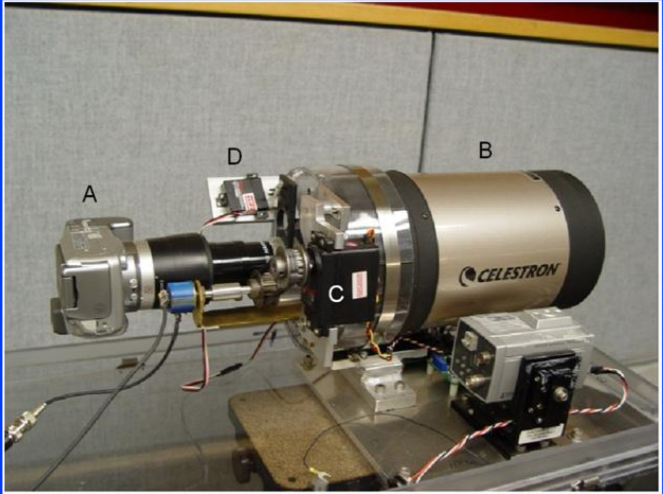
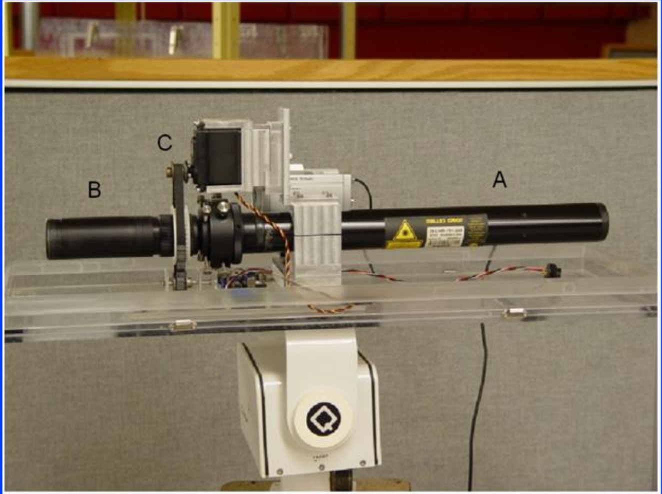
Current System Hardware Components



Digital camera (A) and telescope (B). The telescope's focusing knob is controlled by a servomotor (C). A filter, for use in bright sunlight conditions, can be deployed by a second servomotor (D). (From Gagnon et al., 2012)



HeNe laser (A) and optic (B) for beam expansion and focusing. The optic is controlled by a servomotor (C). (From Gagnon et al., 2012)

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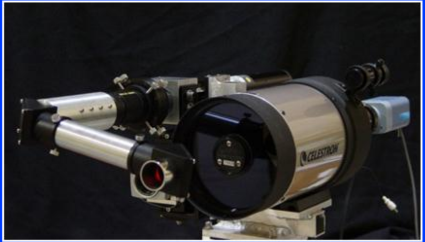
Test Programs

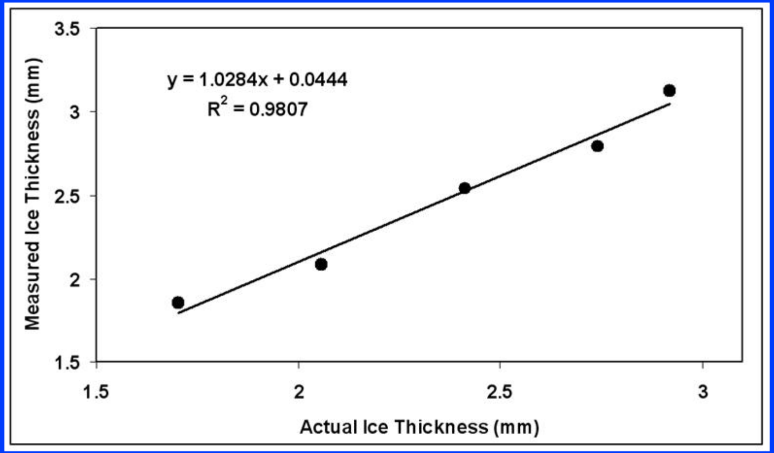


Tests Using an Earlier Version of the Remote Ice Detector

(Suitable for thickness measurements of clear ice layer accumulations)

Clear Ice Layer on Space Shuttle Foam

Thickness Measurements at a Distance of ~15 m

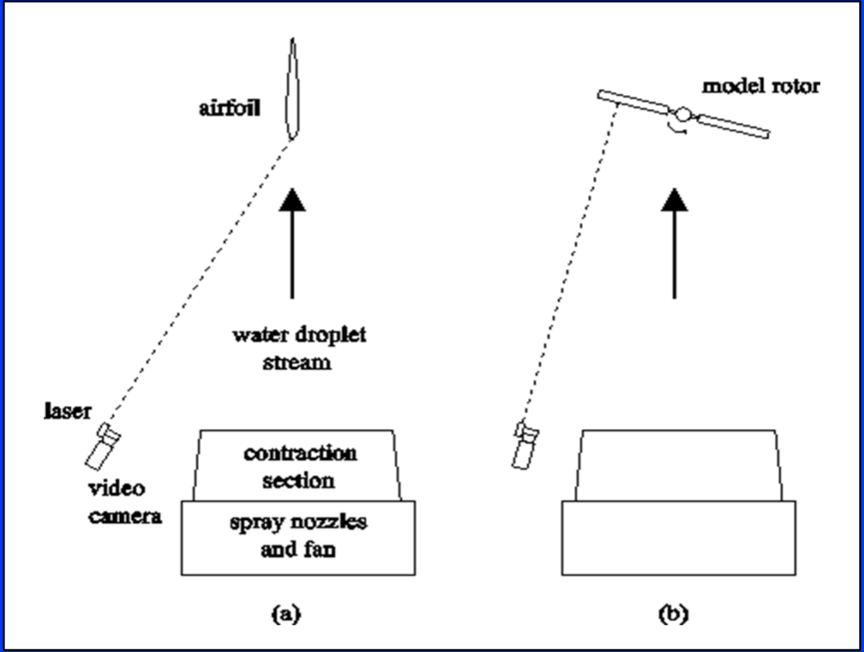


The technology was used at the US Army TARDEC Facility in Warren, Michigan to determine clear ice layer thicknesses, utilizing Optical Method 1, on foam samples of the type covering the Space Shuttle external fuel tank. The tests were conducted with the assistance of Dr. Tom Meitzler and his group at TARDEC. (From Gagnon et al., 2012)

Test Programs

Other Earlier Test Programs

Icing on an Airfoil and Model Rotor (IAR/NRC Facility)

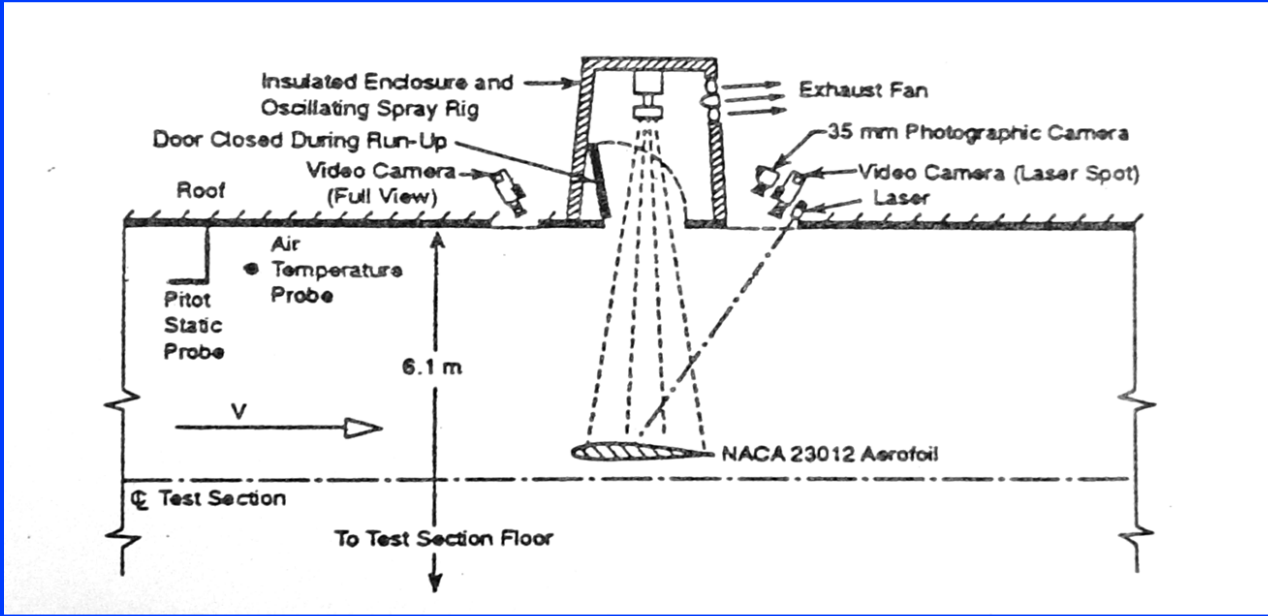


Gagnon, R.E., Marcotte. D.L., 1995. Icing Thickness Measurements from an Airfoil and Model Helicopter Rotor Using a New Remote Technique. Proceedings of the American Helicopter Society International Icing Symposium `95, Montreal, Canada, September, 1995, 417-428.

Test Programs

Another Earlier Test Program

Wing Performance in the Presence of Contaminated Fluid (IAR/NRC Facility)



Oleskiw, M.M., Penna, P.J., Crabbe, R.S., Beyers, M.E., 1995. Full-Scale Wind-Tunnel Simulation of Takeoff Performance Degradation with Contaminated Fluid Runback. Proceedings of the American Helicopter Society International Icing Symposium `95, Montreal, Canada, September, 1995, 179-190.

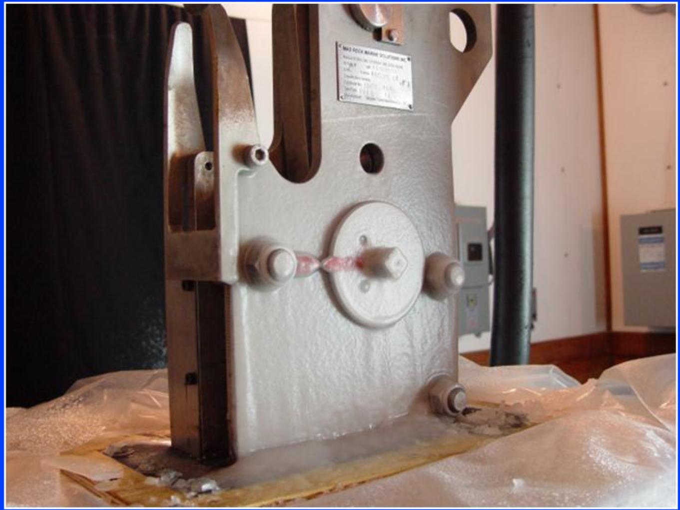
Test Programs

(most recent)

Remote Ice Detection Tests on a Lifeboat Hook Using the Current Prototype

OCRE/NRC Cold Room with Windows

Lifeboat Hook with Icing Accumulation

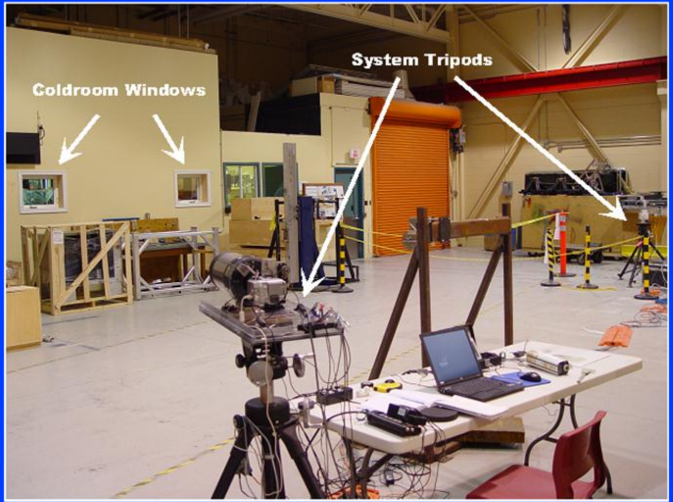


These tests were conducted in the Model Preparation Area and Cold Room of OCRE/NRC. A lifeboat hook (right) had previously been installed in the Cold Room (left) to investigate the effects of icing on its performance, so this provided an opportunity to also test the ice detection technology. The Cold Room was equipped with two windows to provide optical access for the technology.

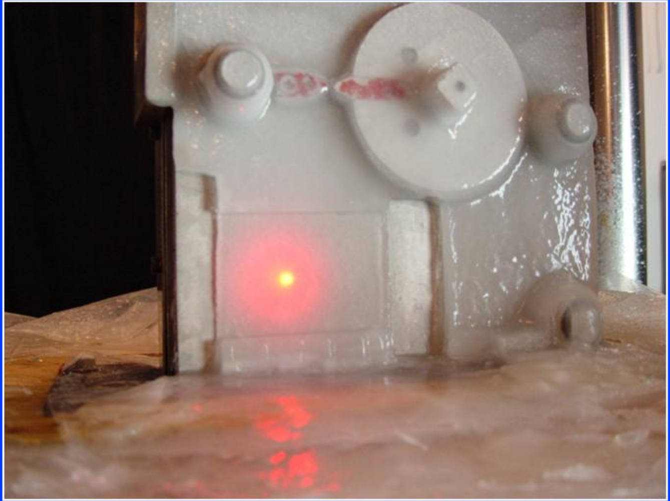
Test Programs

Remote Ice Detection Tests on a Lifeboat Hook

Ice Detector Prototype Setup



Lifeboat Hook with Icing Accumulation and Laser Beam Impinging on the Surface

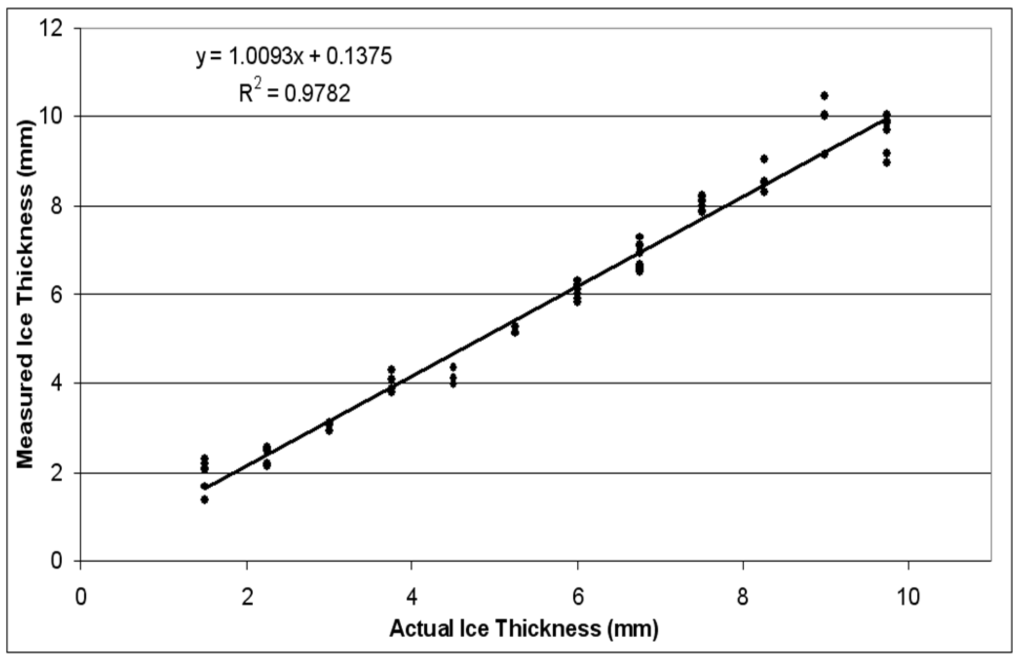


The camera and laser tripods (left) were located in the Model Preparation Area at ~14 m and ~12 m respectively from the iced metal surface (right) that was located in the Cold Room. There was an angle of about 51° between the laser beam and the camera viewing direction.

Test Programs

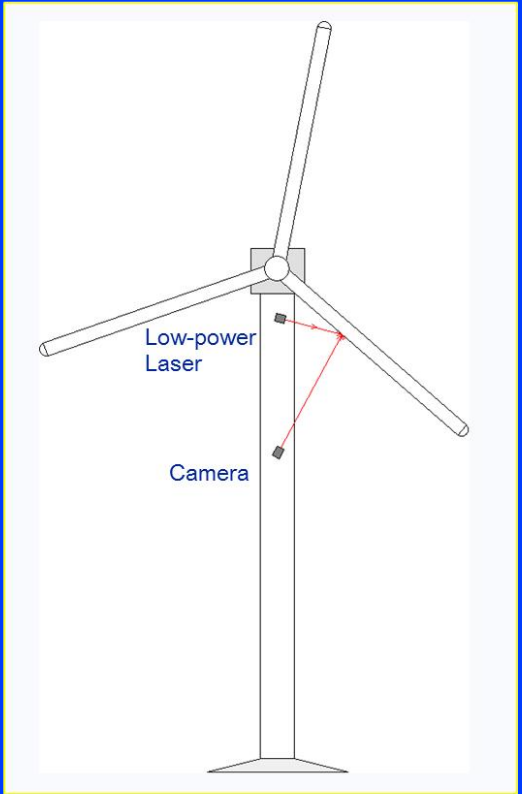
Remote Ice Detection Tests on a Lifeboat Hook

Automated Data Analysis from the Lifeboat Hook Experiments



Plot of detected ice thickness versus actual ice thickness for the tests conducted on the lifeboat hook that had a layer of foggy ice. The actual ice thickness was determined from controlled melting of an ice accumulation in a series of steps of 0.75 mm ±0.03 mm. The standard deviation for the fitted line is ~0.40 mm. (From Gagnon et al., 2012)

A Potential Deployment Configuration on a Wind Turbine



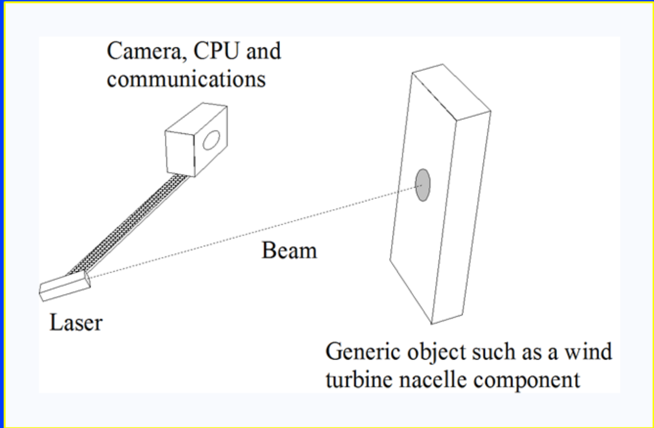
(Left) A schematic showing a potential configuration of the technology on a wind turbine tower. This configuration enables the monitoring of icing on the leading edges and downwind faces of the blades. (Right) Images of wind turbines that illustrate views of the blades that are accessible from the towers.

Conclusions

- A remote ice detection prototype device has been described that is capable of accurate thickness measurements of foggy or clear layers of ice or liquid on surfaces at distances in the range 6.5 - 30 m. The essential components of the prototype are a low-power laser with a long-distance focusing optic, a compact telescope and a digital camera.

- The system has many potential applications that include measuring the thickness of icing layers on blades and other components of wind turbines.

- Apart from long-distance icing measurements on the blades of a wind turbine the prototype could also be miniaturized for short-distance measurement applications such as on the nacelle, anemometer, rotor hub, blade stems and various locations on the tower.



A configuration for a miniaturized device.