ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN
ANN ARBOR

ICING DETECTORS

By

EDMOND BRUN

(Les Détecteurs de givrage
Bulletin du G.R.A., No. 3)

Translated By

G. H. BEGUIN

MYRON TRIBUS

Project M992-4

WRIGHT AIR DEVELOPMENT CENTER, U. S. AIR FORCE
CONTRACT AF 18(600)-51, E. O. NO. 462 Br-1

March, 1953

ICING DETECTORS

I. General Remarks

In icing detection the following problems are encountered: (1) to detect icing as soon as it starts, it is necessary to have an "icing-warner"; (2) to know the intensity of the instantaneous icing, it is necessary to have an indicator of the rate of icing; (3) to know beforehand whether or not there is a possibility of icing, it is necessary to have a "forewarner" of icing; (4) to detect the amount of ice accretion which is likely to occur, it is necessary to have an anticipator of the rate of icing.

The sequence in which the above problems are listed seems to correspond to the order of increasing usefulness, for, on the one hand, it is better to anticipate than to be faced with the fact, and, on the other hand, a quantitative indication is preferable to a qualitative observation.

Besides, as we shall see later, it is not true that the complexity of the apparatus increases at the same rate as the value of the observations it supplies. One can imagine, for instance, forewarners more simple than some warners described in the literature.

II. Terminology

Before going into a brief description of different types of devices, we shall define the terminology which we propose.

A. Detectors

Icing Detector: Any instrument capable of detecting icing clouds (even at some distance) or of making measurements on the ice being formed or likely to be formed.

1) Detectors of Instantaneous Icing: devices able to indicate icing at its beginning or to measure the ice being formed. These devices would include the following two instruments:

a) Warners of Instantaneous Icing: devices which detect icing as soon as it starts.

b) Indicators of Rate of Instantaneous Icing: devices which measure the rate of icing.

2) Predetectors of Icing: devices capable of determining at a distance whether or not a cloudy zone, through which aircraft must pass, will cause icing; or devices capable of measuring the intensity of the phenomenon which will take place.

These devices would include among others:

a) Forewarners of Icing: devices capable of disclosing at some distance the existence of a cloudy formation which will cause icing on a plane.

b) Preindicators of Rate of Icing: devices which will measure an ice-producing zone at a distance and permit the determination of the intensity of the phenomenon which may occur.

This classification may be represented in the following table:

TABLE I

ICING DETECTORS

Detectors of Instantaneous Icing		Forewarners of Icing	
warners of instantaneous icing.	indicators of rate of instantaneous icing.	forewarners of icing	preindicators of icing rate

B. Relationship between Detectors and Protection Devices

1) Anti-icing: operation which prevents formation of ice.

2) Safety Interval: interval of time between the signal given by a forewarner of icing and the first deposit of ice.

3) Thermal Anti-Icing Time: time required to produce the anti-icing temperature in a part which must be protected from icing.

4) Indicator of Anti-Icing Thermal Power: instrument yielding a reading proportional to the thermal power required to achieve anti-icing.

5) De-Icing: operation which removes the ice previously formed.

III. Warners of Instantaneous Icing

The monitors of icing should satisfy the following conditions: (a) they must be sensitive, i.e., detect the formation of ice at its beginning; (b) they must react to ice only and not to wind-blown snow or dust; (c) they must quickly de-ice so that they may operate again after a first warning.

Numerous alarm devices have already been described. They are based on various principles:

A. A simple observation may indicate the ice deposit.

For instance, in a patent of the Seguin Brothers, a beam of light crosses a glass subjected to icing. The ice layer is not entirely transparant, and the light absorption can be estimated with the eye or with the help of a photoelectric cell connected to a microammeter.

In a German patent (731,905 of March 9, 1935, published February 17, 1943), the same principle is used.

The condition of sensitivity seems not to be easy to realize with this type of warning device.

B. Ice, when dry, is an electric insulator. The American device, Holzapfel (Flugsport, v. 24, p. 465, 1941), makes use of this property. A rotating brush rubs on a plain metallic surface set on the leading edge of the wing; when ice forms on the surface, the electrical contact between the surface and the brush is cut off, and a signal lamp is lighted showing "icing". The brush is put in motion automatically when the temperature as measured by the wall thermometer sinks below +2°C. A signal lamp may be lighted at the time the brush starts to rotate.

In a French instrument (Chabert) a concave-shaped finger with sharp edges (a hammer) periodically comes in contact with a cylinder (an anvil); the duration of the contact is of the order of one second; between times, the hammer is in a raised position; if in an icing wind the layer of ice which covers it prevents its contact with the anvil when it is lowered; an alarm device enters into action. A rubber strip through which the hammer passes, insures the imperviousness of this alarm device, which has an ovoid-shaped body.

After it has functioned, the detector, which is of small dimensions, can be rapidly de-iced by retracting it into a heated chamber.

C. Many alarm devices are based on the closing of grids, or of small apertures, by the ice. The Mirles device has a circular grid made of 0.4-mm wires with a spacing of 1 mm. Downstream of the grid there is a piston which the dynamic pressure, kept at equilibrium by a spring, maintains in such a position that an electric contact assures the functioning of a green lamp. When the grid is covered with ice the dynamic pressure decreases, the spring pushes the piston forward, and a contact causes a red light to shine. Heating coils fixed in front of the grid permit the de-icing.

In a German patent (701,884 of April 27, 1938, published January 25, 1941), the grid lies at the exit of a Venturi tube. An inverted Pitot tube, which usually shows quite a low pressure, indicates a higher pressure when the grid ices and may even show an excess pressure.

The Billon apparatus (French patent 860,974 of July 17, 1939, published January 29, 1941), is made of parallel laminae (similar to those of a variable condenser), with their sections toward the wind. An intake for dynamic pressure is set downward of the laminae, while another one of larger diameter is put above the laminae. The pressure difference as indicated by the two intakes depends on the degree of closure of the laminae spacing by ice.

The instrument described in the Swiss patent No. 213-362, published May 1, 1941, is composed of two intakes of dynamic pressure, with different diameters, inserted at the throat of a Venturi. When icing takes place, the small apparatus ices before the large one and the pressure difference between the two intakes acts through a pressure gage on a signal light and causes the de-icing of the intakes, which then can give a new signal.

The Seguin Brothers, in their patent, propose simply to arrange a cavity on the leading edge of the wing connected with the outside by a small opening. An electric resistance installed in the cavity is periodically heated under tension; if the ice closes the aperture, pressure variations take place. The heating causes the de-icing of the aperture at the same time.

On the whole, all these devices do not seem to show any great sensitivity; in particular, the icing of the front of the grid wires does not initially impede the flow of air. Moreover, these instruments work when it snows. Finally, for some of these devices (such as Mirles) the indications are related to the speed of the plane.

Instead of using the variations of dynamic pressure due to icing, one may make use of the variations of mechanical torque.

For this purpose, let us assume (see B.S.T. No. 95) a wind-vane device consisting of a profile protecting against icing by an interior electric heating and a wire laid parallel to the profile. When the wire ices, its aerodynamic resistance increases and the vane is deflected. The deviation hardly varies with the speed of the plane, since the law of variation of aerodynamic resistance with speed is, in a relatively small range, practically the same for the wire and the profile. De-icing is ensured by an electric circuit through the wire.

In one of the Seguin Brothers' patents two small profiles are mounted on an axle parallel to the wind: one is protected against icing by electric heating, while in the other the ice deposit modifies its weight and its lift, which produce a deviation regulated by a spring. The deviation is transmitted to the pilot by a pressure device.

The lack of sensitivity of such instruments is obvious. M. Idrac has recently proposed an icing alarm device which makes use of the blocking by the ice and which will be described in a coming publication of the G.R.A. It consists essentially of an axle having mounted on one of its extremeties a small blade that moves periodically by magnetic attraction on the top of surface on which icing control is desired. If, due to the presence of ice the blade is blocked, an electric current is released which may control a signal or anti-icing devices. This device is very sensitive.

IV. Indicators of Rate of Icing

It is very useful to know the rate at which the layer of ice thickens, for this rate generally determines the seriousness of the phenomenon. In fact, it often happens that the plane can stand a long period of icing when the icing is very slow. The pilot can then safely keep his course while checking from time to time that the icing intensity does not increase. In other cases, on the contrary, the deposit is very large after a few minutes; the pilot must then adopt the flight tactics which seem to him most efficient for escaping the danger (ascend in order to get out of the cloud, turn back, etc.) The usefulness of an indicator of icing rate is thus beyond doubt.

A. Some icing alarm devices can be transformed into indicators of average rate of icing. Part of the apparatus ices during a given interval, of the order of thirty seconds; the thickness of the ice is then measured; an electrothermal device causes the de-icing of the apparatus, which is then ready to operate again.

Such apparatuses give only average values, and a sudden increase in the intensity of the phenomenon has no direct influence on the apparatus. Besides, they do not function continuously.

B. Two instruments, Brun-Vassy, described in B.S.T. No. 95 of the "Ministère de l'Air" permit a continuous measurement of the icing rate. These devices consist essentially of a plate rotating slowly and uniformly about an axis perpendicular to the icing wind. The upstream portion ices, while the sector on the generator which passes forward allows an evaluation of the rate of deposit of ice for a constant velocity of rotation of the instrument.

1) In the first optical instrument the rotating element is a circular cylinder the axis of which is perpendicular to the wind. The ice deposited upstream obstructs, depending on its thickness, a beam of light which, in the absence of ice, is flush with the surface. Since the beam strikes a photoelectric cell connected to a microammeter, the indications of this meter are directly related to the thickness of the ice upstream. The cylinder is de-iced downstream by means of a heating system inside the cylinder.

In fact, the transfer of heat by the thermal conduction of the cylinder wall cannot be sufficiently reduced to ensure a satisfactory operation in large ranges of speed and of outside temperatures. It is advisable to substitute for the cylinder an endless flexible element (such as a wire or belt) driven by a system of pulleys. The thickness of the ice is always measured by the obstruction of a beam of light, which can be achieved either by unrolling the flexible element flush with the beam or by having the beam cross the metallic element with a small angle of incidence. In this last case one should obtain a good sensitivity (which one can, moreover, regulate by modifying the angle of incidence) for the deposits on each wire combine to reduce the section of the beam of light. After its passage into the detecting beam, the flexible element is de-iced mechanically in passing over the pulleys; the use of a complementary thermal de-icing apparatus could also be considered.

2) The operation of an electric instrument is based on the fact that the dielectric constant of ice is larger than that of air. For a frequency higher than 50 kc per sec, this constant is independant of temperature and of frequency in a large domain. Hence, a condenser, the plates of which ice, increases in capacity and the impedance of the circuit which contains it also increases.

In the indicator of the rate of icing, the plates of the condenser are slightly conical and the icing wind blows between the two plates. When the plates rotate, their front section ices while the back section is de-iced by heating.

C. M. Idrac has proposed an indicator of icing rate based on the obstruction of a beam of light by the deposit of ice. This optical instrument differs from the Brun-Vassy device in the following ways:

1) There exist two beams of light emitted by the same lamp and received by two distinct photoelectric cells: only one of the beams is intercepted by the ice so that the indication obtained in measuring the difference of light flux received by the cells is nearly independant of the light flux emitted by the lamp.

2) An electric amplifier system enables one to obtain the derivative of the thickness of ice with respect to time.

3) The instrument is designed to yield at the same time the value of the total thickness of ice deposited since the beginning of the operation up to a maximum thickness, corresponding to the entire obstruction of the beam of light.

4) Thus, during the corresponding interval one can read in a continuous manner both the values of the thickness and its rate of increase.

When the thickness reaches the maximum value provided for, the apparatus should be de-iced in order to permit a new reading.

D. MM. Moraux and Idrac have proposed indicators of anti-icing thermal power derived from M. Idrac's icing warner.

In these devices the stopping of the blade immediately causes the electric de-icing of the surface on which they are placed.

The current is cut off as soon as the de-icing is accomplished (when the blade is free), and a new cycle starts.

The instruments constitute electric devices which relate the quantity of heat provided to the time during which it has been furnished (derivative, with respect to time, of the integral of the current provided).

E. Forewarners of Icing.

Icing can occur on a wall only if its temperature is below 0°C. Icing is thus to be expected when:

1) the plane flies in a cloud of water, and

2) the temperature of its walls, while perhaps above 0°C, is still close to it.

The thermometer thus constitutes an excellent forewarner of icing. It is necessary to make some remarks on the conditions under which temperature should be measured.

1) What one should know is the wall temperature and not the true temperature of the atmosphere. It is known that these two temperatures are different especially at high speeds.[1]

Under flight conditions, one should measure the temperature of the coldest spot of all the walls liable to be covered with ice if one is to be informed of the possible occurrence of icing. However, it is not necessary to measure also the temperature at this spot by means of a wall thermometer; it is sufficient to place the thermometer in a well-determined position of the potential flow, then to establish once and for all the correspondence between the temperature as indicated by the thermometer and that of the coldest spot. One can even graduate the indicator dial of the thermometer in such a way that it gives at each instant the temperature at the coldest spot. A lamp could signal when the temperature of the coldest spot reaches +2°C, for instance.

2) When icing occurs, the thermometer must continue to give correct readings. To this end, it is necessary to prevent icing of the bulb, for the thermal phenomena which accompany the icing of the bulb depend essentially on the deposit and cannot be foreseen. To shelter the bulb behind a shield is out of the question, for the thermometer would indicate the temperature of the shield's wake, which is, for the reasons given above, poorly defined. The solution M. Caron and myself have devised is to place the thermometer bulb in the zone of free air, in potential flow, which exists in the neighborhood of certain parts of the plane (torpedo tube, upper surface of the wing), even when it flies in a fog.[2]

3) It may happen that the plane enters a water cloud, the temperature of which is lower than that of free air. Icing then occurs suddenly, without the convection thermometer being able to warn of the danger. In these conditions it would be preferable to use a radiation thermometer, which enables one

1. Edmond Brun, P.S.T. of the "Ministère de l'Air" No. 119 (1938).
2. E. Brun, R. Caron, N. Vasseur. Introduction à la Mécanique des suspensions, G.R.A. R.T. No. 15, 1945.

to know at a distance the temperature of the cloud in which the plane is going to fly. The principle of such instruments is well known. It would be desirable to adopt their construction to the particular problem to be solved. Let us note that, in the case where the plane flies inside a cloud, the radiation thermometer would also give the temperature of this cloud, so that it would replace advantageously the usual convection thermometer.

Here it is also necessary to establish the correspondence between the temperature as given by the radiation thermometer and that of the coldest spot likely to ice. But, in this case, the correspondence depend on the speed of the plane.

V. Remarks

A. It has been suggested several times that one could make a forewarner of icing by placing an icing alarm device in the throat of a Venturi tube; it has been said that the temperature of the cloud would be lower at the throat of Venturi and that icing would take place there earlier.

Indeed, the temperature of the icing part of the alarm device (which alone influences the phenomenon) is, under flight conditions, not modified by the presence of the Venturi. If, owing to the expansion, the cloud is colder, the thermal effect due to air friction on the apparatus is larger since the air velocity is higher and one nearly balances the other.

B. In 1942 M. Poincaré proposed to prevent icing effects for a few minutes by an anti-icing coating spread on the parts of the plane likely to ice. It is known that such a coating cannot work for long, but the interval during which the plane is protected could be sufficient to put to use all the means of icing prevention. Under these conditions a forewarner would be useless—an alarm device would suffice. The alarm device also could be mounted on a nonprotected part of the surface of the plane, properly chosen to be well visible for the pilot and to allow icing without any danger.

VI. Preindicators of Icing Rate

Since the thermometer indicates danger of icing, the problem is to know if one can foresee the importance of this danger.

When the plane flies in a cloud, it is obvious that the larger the product, C, (i.e., the collecting coefficient of a given body times the mass of liquid water in a unit volume of fog), the greater the danger (larger and more numerous drops). One has simply to mount on the plane a device capable of measuring easily the product, C. To this end a very simple instrument based on the comparison of convection in free air and in fog is being studied in our laboratory. The combination of the thermometer and this instrument would constitute a preindicator of the icing rate. It is obvious that this preindicator would not be appropriate in case of a flight in fog and would not enable one to foresee the icing intensity in a cloud into which the plane is about to enter.