

ENGINEERING RESEARCH INSTITUTE
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THE THERMOMETRIC ICE WARNING INDICATOR

W. FINDEISEN
(Das thermometrische Vereisungswarngerät)
(Deutsche Luftfahrtforschung, Untersuchungen und Mitteilungen, No. 691)

TRANSLATED FROM CENTRAL AIR DOCUMENTS OFFICE FILE ATI 55569

BY

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MYRON TRIBUS

Project M992B

WRIGHT AIR DEVELOPMENT CENTER
CONTRACT AF 18(600)-51, E. O. No. 462-BR-1

August, 1952

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I. REVIEW OF THE DEVELOPMENT

During a conference called by the Lilienthal Society in May 1938 on the subject "Icing," it was brought out that there was an operational need for an ice warning indicator. There were several ice warning devices known at that time; however, these devices could not be used operationally. Almost all of them indicated the total amount of ice accretion on the airplane parts up to any one time, but they failed to indicate whether the amount of ice was increasing or decreasing. Major Helm pointed out at the meeting that operationally it is of prime importance to have an ice warning indicator which permits one to determine the "icing condition," i.e., the time variation of the ice accretion. The indicator must, above all, show how quickly the ice accretion is occurring in the cloud layer through which the airplane is flying, so that the pilot can take the necessary measure for the prevention of further icing hazards (change in altitude, change in course, or monitoring of the equipment for the prevention of icing). Only such an apparatus deserves to be called a true warning device. Other

indicators, which show the ice accretion only after the operation of the airplane has been impaired, are of small use in practice.

Major Helm's remarks, based on his great experience in practical flying, induced me in the years following to search for a method of measurement which can fulfill the stated requirements. First, I investigated whether information obtained from my research on electrical characteristics of icing, which are related to the precipitation-static problem¹ could be utilized to obtain a serviceable ice warning indicator. During the formation of ice on an airplane part, there are liberated measurable electrical charges which can be used for the activation of an ice warning indicator. Until now I have not been successful in establishing the above-mentioned type of apparatus in a simple and serviceable form such as would be required for an indicator for practical use.

Experience with systematic temperature measurements from aircraft, undertaken to determine with precision the difference between the icing layer and the zero-degree isotherm,² gave me the idea in 1941 to measure the temperature of icing. If a thermometer bulb is exposed to icing, its temperature will be increased considerably due to the liberated heat of fusion of the water, thus changing the temperature indication. The temperature increase continues as long as icing continues. The amount of the temperature rise depends upon the rate of ice accretion. By means of measurements of the temperature increase of a thermometer exposed to icing, we can determine the icing condition (the icing differential).

It was apparent that the temperature rise of the iced thermometer could be compared with another thermometer whose measuring bulb was likewise exposed to the air stream but was not influenced by icing. This can be achieved by proper arrangement of the thermometer bulbs. We must, however, consider the heating which occurs on the thermometer bulbs due to compression and friction in the flowing air, for this heating is not the same on the differently exposed thermometer bulbs. Through the different effects of pressure and friction on the two thermometer bulbs there can occur temperature differences which are of the same order of magnitude as those which can be produced by different rates of icing. On the basis of knowledge obtained from numerous flight investigations, carried out by the Cloud Investigation Institute in Prague, we have succeeded in eliminating this source of error. We also succeeded in doing away with other sources of errors, which will be discussed later. We now have an ice warning indicator that records almost without error, the icing condition in units of "millimeters of ice per minute." It further records the disappearance of ice by

¹W. Findeisen, Met. Zeitsch., 1940, p. 201.

²Cf. D. (Luft) 1209. Our measurements are in complete agreement with those given in D. (Luft) 1209.

sublimation or evaporation, for in this case the two thermometer bulbs indicate a temperature difference in the opposite direction.

The device was developed at the Cloud Investigation Institute of the Government Office for Meteorology (Air Force) in Prague, where there existed close coordination between laboratory work and practical flight testing. Government Consultant Walliser, and particularly Diploma Engineer Dr. Maass played an important part in this development.

II. EQUIPMENT

Just like an electrical airplane thermometer, the ice warning indicator consists of a transmitter, which is mounted on the outside of the airplane, and an indicator, which is mounted on the instrument panel. They are electrically wired to one another and connected with the airplane electrical system.

(a) Description of the Transmitter and Principle of Its Operation

The essential parts of the transmitter are two thermometer bulbs in the form of circular flat discs, 2cm in diameter. The two thermometer bulbs are mounted, as shown in Figure 1, on a tubular cross in such a way that one is crosswise, and the other parallel to the direction of stream flow (forward-facing disc and side-facing disc). The two bulbs expose different cross sections to the stream and, on entry into icing conditions, are affected in a different manner by the ice formation.

On meeting icing conditions, an ice formation occurs on the leading edges of the wings, and simultaneously ice formations occur on the corresponding parts of the transmitter. Considerably more ice builds up on the forward-facing disc than on the sidewise-facing disc. The thickness of the ice increases more quickly on the narrow side of the disc, but the fact that the icing surface for the forward-facing disc is greater is important for the determination of the total amount of ice.

As is well known, during ice formation, the heat of fusion of the water is liberated with the result that considerable temperature increase occurs on the iced surface. The temperature of the iced thermometer bulbs

³Concerning the mechanism of ice formation, see L. Ritz, Jahrbuch 1938, Deutsche Luftfahrtforschung, Ergänzungsbd., p. 180

are similarly increased. They take on an average temperature which is between the temperature of the surrounding air and the temperature of an iced surface, and the greater the surface exposed to icing, the more the bulb temperature varies from the air temperature. The forward-facing disc has therefore, a much higher temperature during icing than the side-facing disc. The temperature difference between the discs can be used as an indication for the occurrence of icing.

Moreover, this temperature difference is not only a warning signal but an indication of the rate of icing.

The more ice is formed on a body the more its temperature must rise with respect to the surrounding air, since the temperature difference is brought about by the ice formations liberating the heat of fusion. If the release of the heat of fusion ceases, icing also stops. The quantity of ice formed is proportional to the heat of fusion liberated and subsequently diffused, and this in turn is proportional to the temperature difference between the body and the air, as follows from the law of heat transfer. The temperature difference is therefore proportional to the rate of icing. As can easily be seen, the same difference in temperature which occurs between two differently iced bodies, also occurs in the case of the two thermometer discs of the indicator. The temperature difference is equal to the ice accretion intensity (with respect to time and surface), multiplied by a constant factor. The icing rate is most appropriately given in units of millimeters of ice accretion per minute. The above-mentioned factor has a value of 1.3 mm of ice accretion per minute for a 1°C temperature difference in the sketch arrangement.

It is to be expected that the calibration factor is not strictly constant but has somewhat different values in different clouds, some of which contain preponderantly small drops, others chiefly large drops. This conclusion follows when one considers that the percentage of the drops which strike the surface depends upon their size and the cross section of the body.⁴ Accordingly, the relationship between ice masses on the two thermometer discs of the instrument must change, since they present different-sized cross sections to the air stream; likewise the measured temperature difference and the multiplying factor will change. Flight investigations have shown however that these variations are not important in a practical sense and can be neglected.

With the help of the measurement obtained from the instrument in millimeters of ice per minute, one can estimate the icing on the wings, on the tail surfaces, and on the other parts of the airplane. It is a fact that the amounts of ice which form on these different profiles differ in

⁴F. Albrecht, Phys. Zeitsch., vol. 32 (1931), p. 51; L. Ritz, l.c.

thickness. The thickest accretions occur on those parts of the airplane which have the smallest cross section exposed to the stream. Consequently, the ice accretion rate is considerably greater than, for example, on the wing surface; but it is approximately just as large as on the tail surfaces.

The temperature difference between the two discs of the transmitter remains constant as long as icing continues; i.e., as long as the ice is building up. The effect of the increasing ice thickness is virtually negligible since at its exposed surface the same heat exchange occurs that existed at the very beginning of the icing of the discs. During the ice build-up there continuously occurs on the surface of the ice mass a constant temperature of its outer surface. Consequently, the increased temperature difference occurs between the two discs in the same fashion as in the beginning of the icing process, when the discs were practically ice-free.

However, the temperature relation between the discs changes gradually with a heavy ice build-up, and this change causes a diminution in the sensitivity of the instrument. When the instrument is covered with a thick ice layer, it yields approximately 50 per cent too low a measurement of the icing rate. This phenomenon is related to the geometrical relations between the ice masses and the discs and to the resulting heat-transfer properties of the ice-covered discs. The error decreases when in place of the discs of 2-cm diameter, larger and thicker discs are used, which affect the collection efficiency of the ice, even in heavy icing conditions, less adversely. Since in the operational use of the ice warning device, it is less a question of the exact measurement of the icing rate than of the time variation of the icing process, and since only an approximate determination of the intensity is desired, one can almost ignore the diminution of the sensitivity at very high icing rates. Ordinarily, no flying takes place with very thick icing layers, and furthermore, through intelligent use of the ice warning apparatus, these thick ice accretions can be avoided. Therefore, it is not normally necessary to provide the transmitter with larger discs, which, naturally, when compared with smaller ones, have the disadvantage of a higher drag; this must be guarded against in the actual use of this equipment. In the development of the apparatus, 3.5-cm discs were used in addition to those of 2-cm diameter. Their use would be advantageous in all cases in which the icing rate, even after an icing of long duration, is no longer to be determined qualitatively but rather quantitatively.

When icing ceases, the temperature difference between the thermometer discs disappears. This occurs as rapidly as the thermal capacity of the ice-covered discs permits; practically anywhere between 5 and 10 seconds. The temperature difference, however, does not simply return to zero but takes on a high negative value.

This phenomenon depends primarily upon the changed meteorological conditions. Icing occurs normally in subcooled water clouds, and in these

clouds there exists a relative humidity of virtually 100 per cent. Above or near the clouds, the relative humidity is usually considerably less. There ice accretion not only ceases but the ice begins to evaporate. For this process, which results in a gradually decreasing quantity of ice, much heat is required, which results in a corresponding temperature decrease on the layers. The temperature disturbance is greater on the forward-facing disc than on the side-facing disc, so that the transmitter reports an inverted temperature difference and therefore a negative reading. Again the magnitude of the reading of the indicator is proportional to the change of the ice. Large negative readings mean a rapid decrease in the ice accretion.

The diminution of ice is, furthermore, not only dependent upon the relative humidity of the air through which the airplane is flying, but also upon the flight velocity, since at high speeds in cloud-free air there is a considerable decrease in the relative humidity around the airplane.⁵ For this reason, there is often a diminution in the ice accretion, and the instrument shows this through a negative reading.

Negative values occur even to a greater extent than with evaporation of the ice mass, if the ice melts as a result of an increase in the air temperature, for example, during descent. This process is easily understood, since in melting, heat is required. The heat requirement is in this case very large because melting occurs usually much more rapidly than evaporation.

Negative values occur not only during the disappearance of previously present ice masses, but to a smaller degree at times even for ice-free transmitters. In the evaluation of the dependability of the indicator the following observation is pertinent: these negative measurements occur only in flight through clouds where an ice accretion would melt, for example, in flight in water clouds above the freezing temperature. The impinging water drops do not freeze in this case and therefore do not give up a heat of fusion. On the contrary, they have a temperature which is lower than the surrounding air. The air which arrives at the disc at free-air speed is warmed through compression and friction due to the conversion of kinetic energy, as the air is intercepted. Warming of the air is somewhat less during flight through clouds due to the action of the water vapor at the surface of the body (wet adiabatic), but it is still considerably greater than the warming of the impinging drops. The conversion of kinetic energy associated with the drops produces only about one-half as great a heating, since the specific heat of the water has a higher value than that of air. Under these circumstances a body which is exposed to the impingement of many drops of water must be colder than a body which is not so much wetted,

⁵W. Findeisen, Forschungs-u. Erfahrungsberichte des Reichswetterdienstes, Series A, No. 11, Berlin, 1941.

and the relative temperature diminution of the forward-facing disc of the transmitter can then be explained and the negative value understood. This phenomenon is more pronounced in thick clouds and at high velocity. The negative values remain after the cloud has been left behind, that is, as long as the thermal elements, especially the forward-facing disc, are still wet. The temperature difference is usually even greater than it was in flight through clouds. It disappears however much quicker than, for example, in the sublimation of the ice, and for this reason it is unimportant for practical purposes. At any rate, the negative values indicate the absence of icing danger.

(b) Sources of Error

In the consideration of the principles of operation of the transmitter, we must not overlook two sources of error, which may result in both positive and negative temperature differences between the thermometer discs even without icing, melting, or evaporation taking place at the transmitter. One of these two phenomena may be improperly indicated by the instrument. During the development and the technical perfection of the ice warning device, both these errors had to be considered.

One of these errors depends upon the thermal capacity of the thermal elements. If the thermal capacity of the two elements is not the same, then during high rates of temperature change of the air which is flowing by (for example, during a dive), a temperature difference between the two discs may occur. As a matter of fact, the thermal time constants of the two discs are not equal as a result of their different placement in the air stream. The disc which is placed in parallel flow to the air stream is better ventilated and can therefore adjust to surrounding temperature changes more quickly. In order to eliminate this source of error, one might make this disc somewhat thicker. Technically simpler is the method of diminishing its effective surface through the addition of a heat-insulating material. In this way the time constants can be easily equalized.

The other source of error results from an unequal warming of the thermometer discs in the air stream. The thermal elements perpendicular to the air stream is heated to a greater extent through the compression of the oncoming stream on its windward side than the disc parallel to the stream is heated through the friction of the air stream. As a result there appears, for example, at 300 km/hr velocity, a temperature difference of approximately 0.5°C. The effect increases in proportion to the square of the flight velocity and must be taken into account at especially high velocities. This effect is cancelled, just as in the case of the thermal-capacity effect, through a partial covering of the surface of the disc with a heat-insulating material. This is possible since the discs are exposed on their opposite sides to different amounts of warming through friction and compression. For the forward-

facing disc, there occurs a greater warming on the windward side than on the lee side. On the sidewise-facing disc, the upper surface, which is attached to the bracket, is warmed less than the lower surface. If the warmer side of a disc is covered, then the average temperature of the disc is decreased, since then the heat transfer on the cold side has a proportionally much greater influence.

The covering of the discs can be done in such a way that both sources of error can be diminished at the same time. Especially effective is the covering of the upper surface of the parallel-placed disc. However, it becomes evident that for complete elimination of the velocity effect, the windward side of the forward-facing disc should also be partially covered.

(c) Mounting of the Instrument on the Airplane

The indicator must naturally be so located on the airplane that it is subject to the same icing as the leading edges of the wings and tail surfaces. It is immaterial whether it is mounted on a wing or on the fuselage, but care should be taken that it is not exposed to the exhaust from the engines.

The thermometer discs should not be exposed to the direct rays of the sun, since significant erroneous readings can be obtained in spite of the very high air velocity around the airplane. Though these errors do not occur during flight through clouds, in which we are primarily interested, they might diminish the confidence of the flight personnel in the ice warning indicator. For this reason the indicator should be covered with a radiation shield.

The indicator should not be mounted too far back on the fuselage or wing surfaces. If the thermal elements extend into the boundary layer, in which, as is well known, there exists a decrease in velocity, then one can not expect error-free operation of the indicator. It must also be noticed that, in the air which is flowing in the neighborhood of the fuselage or the wing surfaces, there are considerably fewer drops than outside the boundary layer. For this reason, the support for the indicator should not be too short in relation to the boundary-layer thickness; otherwise the indicator will give too small a reading for the ice-accretion rate.

(d) Electrical Arrangement

The temperature difference between the two thermal elements which are characteristic of any icing condition can be converted into electrical signals and transmitted to an indicator by known electrical techniques.

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For this purpose the temperature dependence of electrical resistance of the thermal elements is used. To obtain the maximum electrical effect, which can be recorded with sturdy electrical equipment, it is desirable to use as the temperature element a material with a larger coefficient of resistance. To this end semiconductors are much better than, for example, platinum; semiconductors, furthermore, can be used in the much simpler shapes, such as are necessary in the case of the thermal elements of the indicator, e.g., they do not require the winding of coils.

To compare the electrical resistance of the two thermal elements one can use either opposing coils or a bridge circuit. The opposing coils have the drawback of high voltage requirements and must have a relatively high current flow through the thermometer elements which can upset the energy balance. The bridge circuits have a lower current requirement.

The bridge circuit of the ice warning device is shown in Figure 2. The resistances of the bridge elements, R_1 and R_2 , are of such magnitude that, when the thermal discs are at the same temperature, no bridge current flows. In this case, the mechanical and electrical zero point of the bridge galvanometer agree, and drifting of the zero point as a result of changes in the bridge circuit is eliminated. Through this arrangement, the instrument is insensitive to the voltage fluctuations which necessarily occur in flight. At the most, only moderate percentage-wise errors in the measurement of the ice accretion rate can be caused, which, however, are not normally important. The bridge circuit is adjusted through resistor R_2 . This also regulates the current through the thermal elements and therefore the sensitivity of the arrangement.

The indicator for the bridge circuit is used to indicate the icing condition through proper calibration of the scale. Indication takes place in the manner discussed in section II-a. No difficulties of any sort are expected.

It may be desirable, even with slow ice accretions, during which there is only a small deflection of the instrument, to have a clearly visible warning signal. For this purpose the bridge circuit is connected to a relay which lights a warning lamp whenever a small positive temperature difference occurs on the instrument.

III. DETAILED DESIGN

The detailed design of the above-discussed apparatus offered no difficulties. The two parts of the thermometric ice warning indicator, the transmitter and the indicator, can be built with relatively simple means.

The aim of the development was to make a device of a form suitable for flight use. The specific requirements were: dependable operation, insensitivity to mechanical loads, small space need, small air resistance, easy mountability, and little use of current.

Figure 3 shows the individual parts of the ice warning device the transmitter and radiation shield being disassembled. Figure 4 shows the transmitter as it is mounted on the outside of the plane. The details are given below:

(a) Transmitter

The tubular cross shown schematically in Figure 1 is welded to a base plate. At the ends of the tubes are the thermometer discs, each mounted with one screw; hard-rubber discs serve as insulators. The tubes carry the electrical wires which lead to the thermometer discs.

We used "Urdox"-resistors, produced by the firm Osram, in Berlin, as thermometer discs. They are made of the semiconductor magnesium-titanium "spinell"* pressed into a mechanically firm molding compound. They are shaped in the form of a ring of 20 mm outer and 11 mm inner diameter, approximately 1.5 mm thick. On either side of the discs, wire is welded to form a circular terminal.

The electrical resistance of the discs, as with all semiconductors, decreases logarithmically with increasing temperature. In the temperature region under consideration, the change amounts to approximately 300 ohms, and the temperature coefficient of the resistor is approximately 4 per cent per degree, which is somewhat more than 10 times that of platinum.

Experience has shown that the discs can be manufactured only with rather large tolerances, i.e., the resistance and temperature coefficients vary considerably from sample to sample. For the ice warning device, however, it is necessary that the two discs of a transmitter have practically the same temperature coefficients, since otherwise the normal temperature variations may cause an unbalance in the bridge (for example, following altitude changes in flight), which could lead to erroneous deflections of the indicator gage. For each transmitter, therefore, a pair of discs must be found that have comparable temperature coefficients. It is not necessary that the resistance of both discs be the same, since an inequality of resistance can easily be taken care of through an appropriate selection of the compensating resistors (R_1 and R_2 in Figure 2). Also, the temperature

*Spinell is a type of alloy composed of a bivalent and a trivalent element and having a characteristic crystal structure--Translator's note.

coefficients of the pair of discs in different transmitters may be different, for this results only in a change in the sensitivity of the transmitter, which can be compensated for without difficulty through proper adjustment of the calibrating resistor (R_V in Figure 2). As a matter of fact, due to the irregularities of the Urdox-discs, the set of resistors, R_1 , R_2 , and R_V , must be separately adjusted for every pair of discs.

The selection of the pair of discs is made on the basis of a calibration in a cold bath. The calibration curves appear as straight lines on a logarithmic plot and therefore can be easily established. The slope gives necessary information on the temperature coefficient for the selection of the discs.

In the transmitter the discs will carry between 2 and 4 milliamperes. This small current causes a heating of the discs less than 0.1°C . The measurement is not upset through this heating since the two discs are heated by the same amount.

The potential at the discs is of the order of one volt. In general, it is somewhat higher than the electrolytic polarization voltage, and therefore care should be taken that no electrolytic connections are made to the surfaces of the discs, which are often covered with a water film, for in this way erroneous readings may be obtained. The discs were therefore covered with an insulating layer of lacquer; "Konstantol 706" made by the firm of Tebas, in Prague, served this purpose. The lacquer dries at 150°C and gives a good protective coating.

The adjustment of the discs to equalize the thermal time constants and the heating in the air stream was obtained through a partial covering with hard-rubber rings. These were inserted on the appropriate sides of the discs, namely, on the windward side of the forward-facing disc and on the top side of the sidewise-facing disc between the mounting screws (or mounting tubes) and the discs. Since the thickness of the discs varies, a particular size of cover cannot be used with all the transmitters to give the same adjustment. The errors which occur as a result are quickly determined through tests in a fast air stream, and consequently the covers can be adjusted as required.

As is shown in the figures, the transmitter is provided with a radiation shield, which is mounted on the base plate of the tubular cross. In this way, the tubular cross and the discs are protected against great mechanical loads, as occur, for example, during flight operations. The indicator is mounted on the outside of the airplane along with the radiation shield. On all airplanes which do not have a motor located on the fuselage, it is advantageous to mount the indicator either below or on the side of the forward part of the fuselage because there the mounting can be carried out with least difficulty and the wires are shorter.

A three-strand cable connects the transmitter with the indicator. In a new variation of the transmitter the resistance coils of the bridge are mounted on the transmitter, namely in a small capsule which is located on the mounting plate of the tubular cross and extends into the outer skin of the airplane. With this arrangement a two-strand cable leads from the transmitter to the indicator and a second cable to the airplane electrical circuit.

(b) Indicator

For an indicator no special device is required. We may use a moving coil galvanometer, which has been developed for other purposes on a production scale and is mechanically suitable for use on an airplane instrument panel, without additional adaptation. The instrument must be contained in a standard housing. For the sake of space savings the small standard housing of 57 mm diameter was used.

Figures 3 and 4 show such a unit made by the firm of Hartmann and Braun, in Frankfurt am Main, called type "Hukka." It requires 0.37 milliamperes for full-scale deflection, and its resistance is 140 ohms. A similar unit of the same range and resistance is said to be manufactured by the firm of Philips, in Prague.

The divisioning and marking of the scale of the indicator is adjusted to the particular apparatus. Its purpose is to show the icing conditions at a glance.

As shown in Figure 5, the indicator has its zero point approximately one-third from the left of the scale. It maintains this position as long as the flight is through cloud-free air. During flight in rain or in water clouds without danger of icing, the indicator deflects to the left. These deflections, however, are relatively small and do not reach the left end of the scale. They indicate, as shown on the scale, "No icing." The indicator moves sharply towards the left when an ice accretion which has already built up on the airplane disappears in flight through ice-free layers, whether inside or outside a cloud, due to melting or evaporation. The indicator then moves to its left most position, and the scale therefore states "No icing. Ice disappearing."

The principal part of the scale to the right, which, to indicate danger, is inscribed in red, shows the icing rate in millimeters of ice accretion per minute. The sensitivity of the circuit is so adjusted that the deflection to the end of the scale at the right corresponds to an icing rate of 6 mm/min. As mentioned above (Section II a), this numerical value is correct only for thin profiles. On the parts of the wing near the fuselage the icing rate is considerably less. A 6-mm/min deflection indicates

very rapid icing. It can occur only in huge towering clouds where, however, occasionally the scale is overshoot. At today's flight speeds icing rates are normally approximately 2 to 3 mm/min. Depending on the icing sensitivity of the type of airplane, there is more or less time to change altitude or course to find a way out of the icing layer.⁶ The transition from a layer with icing danger to a layer without icing danger is very clearly seen on the icing indicator, since the pointer does not only return to its zero position but rather goes to the left. If new icing occurs, the indicator again goes to the corresponding position on the right.

The indicator device shown in Figures 3 and 4 has on its rearward part a capsule in which the resistors of the bridge circuits are located (see Figure 2). These resistors are small spools of approximately one centimeter, wound with coils of constantan wire. The two bridge resistors, R_1 and R_2 , have the same value of resistance as the thermometer elements, i.e., approximately 300 ohms. The calibrating resistor R_v has approximately 3000 ohms.

Since the resistance must be adjusted to the peculiarities of the pair of thermal discs, each set of resistors goes only with one pair of discs. Putting the resistance elements in the cockpit indicator has therefore the disadvantage that the indicator and the transmitter cannot be interchanged. This disadvantage is eliminated in the new arrangement of the ice warning device in which the set of resistors is located at the transmitter. The housing of the indicator is consequently somewhat smaller and it requires only a two-strand cable, which connects it with the transmitter. In the design considered first, two two-strand cables are necessary, one going to the indicator and the other to the airplane electrical supply.

⁶See in this connection, D. (Luft) 1209, "Vereisung."

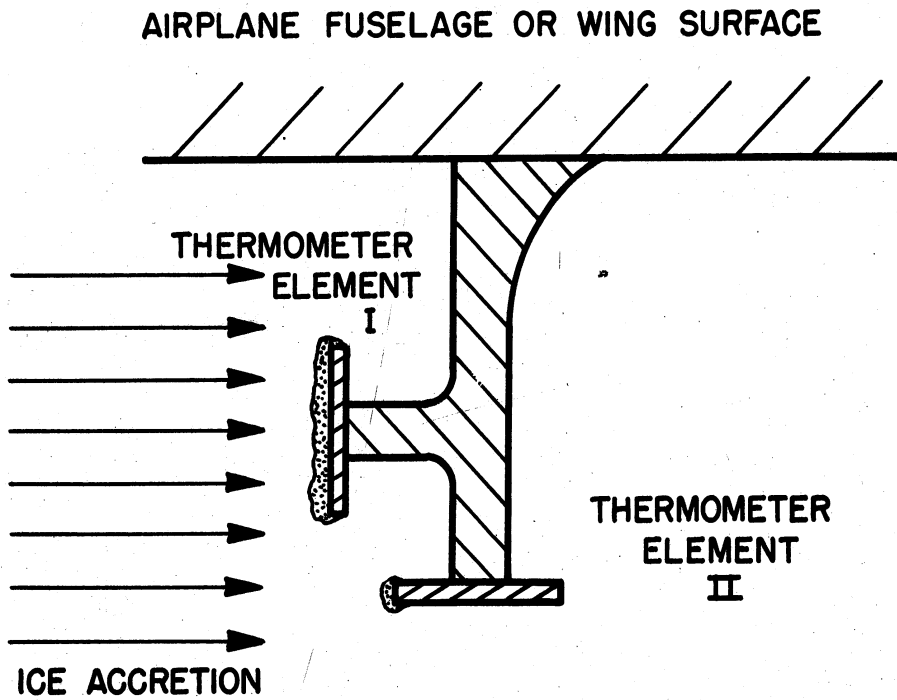


Figure 1. Schematic presentation of the transmitter of the ice warning device. Two disc-like thermometer elements are exposed to the air stream in such a way that on entering icing conditions more ice will form on one element than on the other.

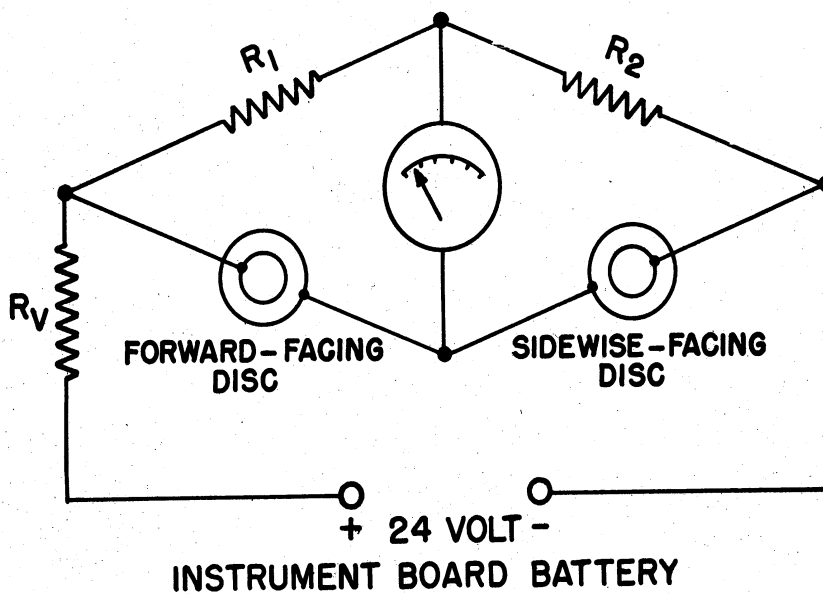


Figure 2. Bridge circuit of the ice warning device.

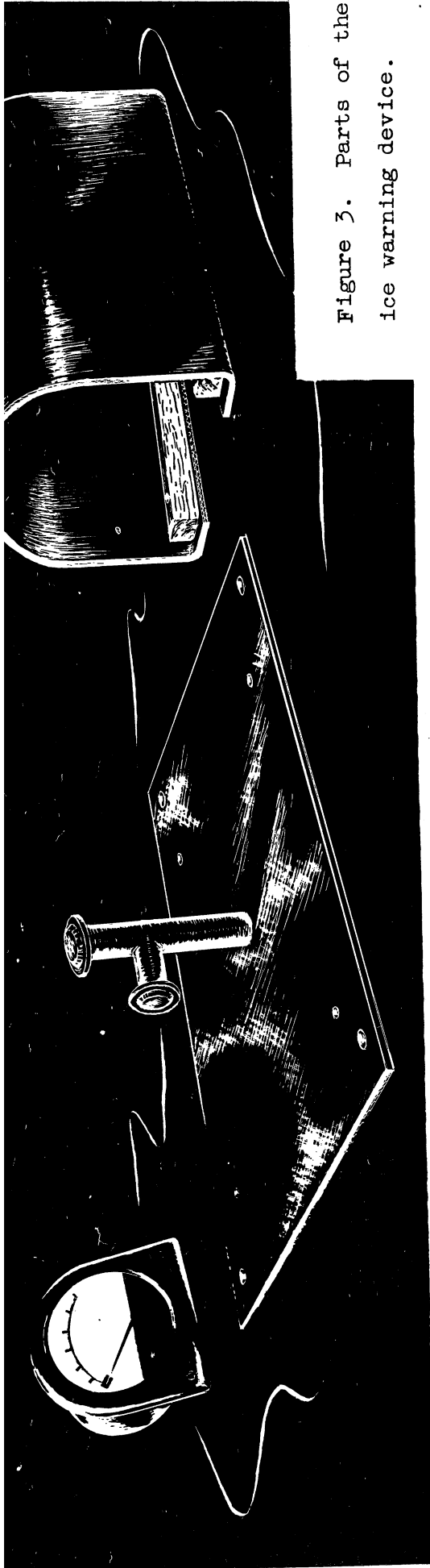


Figure 3. Parts of the ice warning device.

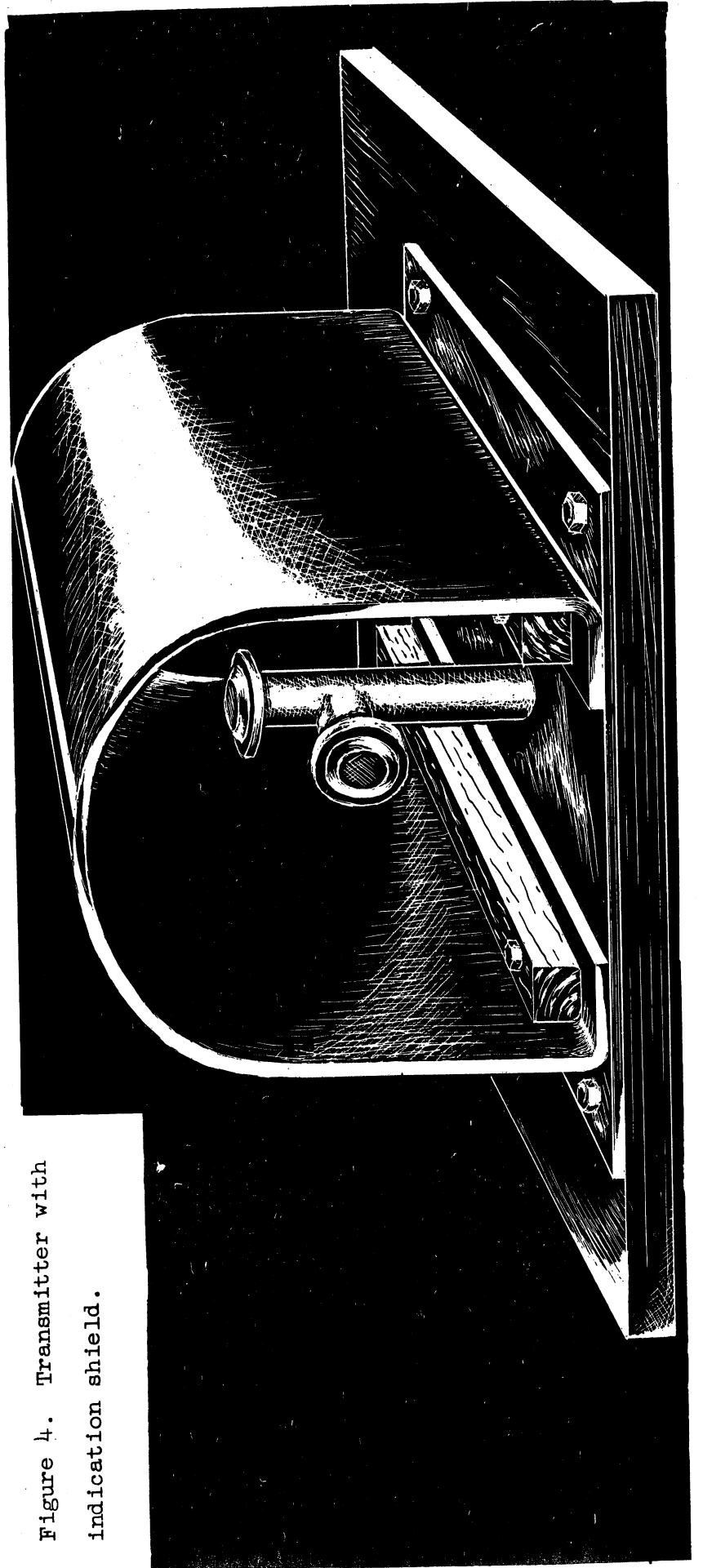


Figure 4. Transmitter with indication shield.

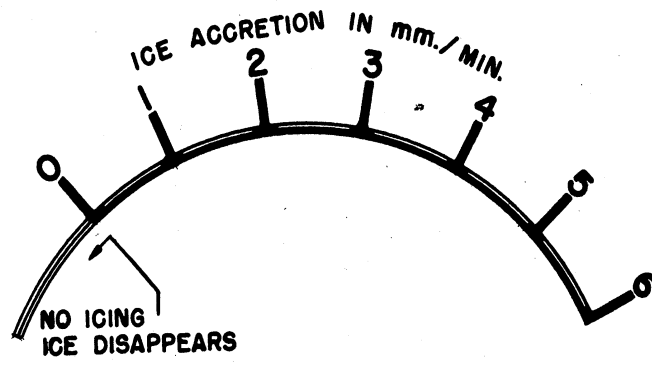


Figure 5. Scale of the indicator. Inscription on left is black, on right (region of danger) in red.

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