# THE DEVELOPMENT OF AN AUTOMATIC WEATHER STATION FOR COLD REGIONS

by

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## AIMS OF THE PROJECT

There are few meteorological measurements available from mountainous areas because of the difficulty of operating instruments in their environments. This paper describes the development of an automatic weather station (AWS) able to operate in such conditions. The aim was to find ways of enabling all of the common meteorological variables to be measured. This was to be done using minimal power so that stations could be deployed at any site. The summit of Cairn Gorm was used as the test site. Being in the UK it was reasonably accessible and although having an altitude of only 1246 metres it has one of the harshest of cold climates.

## CONVENTIONAL AUTOMATIC WEATHER STATIONS

During the last two decades, AWS have become increasingly common. The Institute of Hydrology (IH) developed its first AWS in 1964 and licensed it for commerical production in the early 1970s (Strangeways, 1972). There are now many stations marketed throughout the world, but the IH model is typical. Its sensors comprise a conventional cup anemometer, wind vane, miniature temperature screen with wet and dry bulb platinum resistance thermometers, conventional solarimeter and net radiometer and a tipping bucket raingauge. Most AWS now incorporate data loggers, recording the data in digital form on magnetic tape or in solid state memory. The IH AWS use the Microdata M200 compact cassette logger.

## CONVENTIONAL AWS IN COLD CLIMATES

The greatest difficulty in operating a conventional AWS in cold climates is the accretion of rime ice on the sensors. Snow too is a problem. If wet it sticks to the sensors and if there is a strong wind the crystals can enter open structures. At times of no snowfall, dry ice crystals can be lifted and carried by strong winds. By either process snow can be driven into any exposed holes, temperature screens, for example becoming completely filled. The finer particles can enter holes down to less than 1mm in diameter. At the test site on Caringorm, winds regularly reach an average of 40 m $sec^{-1}$ for long periods with gusts of 80 m $sec^{-1}$. Conventional AWS are damaged by such winds. High winds also cause rime to build up more quickly than do light winds because they bring droplets at a greater rate. High winds, therefore, cause problems by several paths.

## POSSIBLE SOLUTIONS TO THE PROBLEM

The present project is not the first attempt to find ways of operating meteorological instruments in cold regions. Most attempts, so far, however, have been based either on manual de-icing or on the use of heat. The use of either is not possible in the present case because of the need to develop an AWS able to operate unattended at any remote site. Very few remote sites have any power. By way of historical background, these various approaches will be summarised.

The well-known Ben Nevis summit observatory (Paton, 1954; Wilson, 1954) operated from 1883 to 1904. It was manned continuously and recordings were taken, manually, hourly, day and night. Many attempts have subsequently been made to keep sensors ice-free by heating them, usually electrically, but heat losses are very high. An alternative is to mount the sensors in an insulated housing which opens periodically, the housing being heated only at its opening point and internally to keep the sensors just above 0°C. Gerger (1972) reports such a design and Alexeiv (1974) notes the use of an opening cover for anemometers on ships, but comments that it was cumbersome and sometimes failed. More recently Curren et al(1977); Barton and Bothwich (1982) and Barton and Roy (1983), described such a system.

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In this design the housing was opened by a motor for three minutes every half hour, exposing its wind speed, wind direction and temperature sensors. It was mains powered and consumed a peak of 1.25 kW and an average of 400 watts.

Less direct methods of ice removing have been proposed but most papers dealing with them concern techniques for helicopter blades, ship superstructures, radomes and lock walls, with only a few concerned with the problems of meteorology. Amongst these few, Gerger (1972) reports the use of double shelters for temperature sensors, the screens being covered by a mesh. The use of Telfon (PTFE) as an ice-deterring constructional material and coatings of de-icing pastes, de-icing fluids and oil are also reported, all of them being described as unsuccessful. Alexeiev (1974) also noted that coatings of vaseline were of no use nor, he reports, was any one material (metal, plastic, wood, etc) any less prone to ice accretion than any other, including PTFE. Alexeiev also reports the use of flexible covers or anemometer blades which shook ice off when they vibrated due to eddies in the wind. But his final comment is that none of these methods worked when conditions were very poor. He also draws attention to the use of impact vibration through electrical means in aircraft wing de-icing. Also in the field of aeronautics and in the keeping of radomes and lock walls ice-free, two other approaches have been reported. Ackley et al (1977) describes the use of flexing bags on radomes and bending plates on lock walls to crack ice off. Sewell (1977), (1975) describes his work on the removal of ice from helicopter blades by a flexing metal foil supported on foam rubber on the balde's leading edge.

## THE ICE ADHESION PROCESS

Sayward (1979) notes that the forces involved in adhesion are rarely those of primary chemical bonding (electron-sharing or valence forces) but those due to van der Waals forces and hydrogen bonding. The ability of optical glasses to adhere when wrung closely together is evidence of such adhesive forces which act well beyond atomic distances. Jellinek (1978) notes that a substance with which water forms a large contact angle adheres less well to ice than to those which form a small angle. Sayward (1979) explores this in search of lowered ice adhesion (for helicopters). All metals form low contact angles while polymers in general have large angles making them water-repellent (or hydrophobic). Disagreement, however, exist between writers on the usefulness of such materials, Shallabrass (1962), Alexeiev et al (1974) and Panushkin et al (1972) being of the opinion that no material was better than any other in lessening ice adhesion-to any significant partical degree that is.

Surface roughness can also affect adhesion. While in some cases it might aid adhesion by providing a greater surface area and a better key, it may equally well reduce it, by causing air to be trapped in the small cavities of the rough surface acting as a contaminent.

It was against this slender background, with its disagreements and uncertainties, that work began. As experience grew, however, the situation became clearer and techniques were evolved which have proved to be very effective. These developments are now described.

## EARLY WORK

### Ice-phobic and ice-shedding materials

It seemed reasonable to suppose that ice might just possibly adhere less well to some materials than to others, despite the conflicting views expressed in the literature. A series of tests was, therefore, considered worthwhile. These were done in a climate chamber, a selection of materials being cooled to - 5°C onto which water at 0°C was sprayed and left for a few minutes to form a coating of ice. This was repeated several times to form a sufficient coating.

It was found that ice adhered strongly to all rigid samples, irrespective of material but that it was easily removed from all of the flexing materials. It was found, however, as field experience grew later, that important differences existed between the flexing materials themselves, each having its own particular response to ice formation - surface texture, type of filling material and thickness all affecting the finer structure and the amount of ice which formed and the ease with which it could be shed.

## STEPS LEADING TO THE PRESENT DESIGN

The steps leading to the design of the present cold-climate AWS (Strangeways, 1977,1981) cannot be described in detail as they occupied many years. For completeness, however, the main steps will be listed briefly, in chronological order.

1. A conventional AWS was installed at the Cairn Gorm test site to collect data at times of no icing and as a control, at times of icing, against which to compare new designs.
2. First attempts at ice prevention were based on sensors constructed of materials which flexed. Flexing was passive, being wind induced. These designs were not effective in severe conditions.
3. An attempt was next made to remove ice using ultrasonics. This was not successful.
4. A shock-induction method was next developed using a solenoid, pulsed with 100 amps for 15 milliseconds from a battery. This accelerated an iron core which struck the sensor (a miniature, sealed, temperature screen). This showed promise, but required too much power if all sensors were to be kept ice-free by this means.
5. Forced collapsing and re-inflation of a net radiometer's dome was also found to be effective in removing ice.
6. Mechanical shock-induction, by a pneumatic method, was next developed. It proved to be very effective and much more economical in power/weight ratio than the solenoid method. An aqualung was used as the source of air. (One cylinder powers the present design for about 3 weeks).
7. To develop this technique to its best advantage, minaturisation of the sensors followed (this had already begun to some extent in another context). Narrow profiles were also used, wherever possible, to present a minimum area to the wind; rime forms mostly on windward surfaces.
8. Handling high pressure air under field conditions is difficult. The prototype pneumatic system was next improved to prevent any leakage, and to ensure that it worked over the full temperature range to be experienced.
9. With a reliable pneumatic system designed, developed, installed and proven, a series of "sensor heads" were next tested on it. This work occupied several years. The first of these heads was constructed in metal, the second in acryllic.
10. There followed a series of tests in which sensor-heads of a variety of designs were tested. It was found that a combination of both shock induction and flexing was the most effective, and designs evolved in which the sensor-head was sheathed in a variety of flexing skins.
11. However, a compromise was necessary between sufficient rigidity to transmit the shock and sufficient flexibility to allow adequate flexing. The skins also had to be sufficiently tough to withstand high winds and ice (and gravel) particles striking at up to 100 mph.
12. During these tests it was found that some skins performed better than others, material, colour (filler), texture and thickness all effecting performance.

## DESIGN OF THE PRESENT AWS

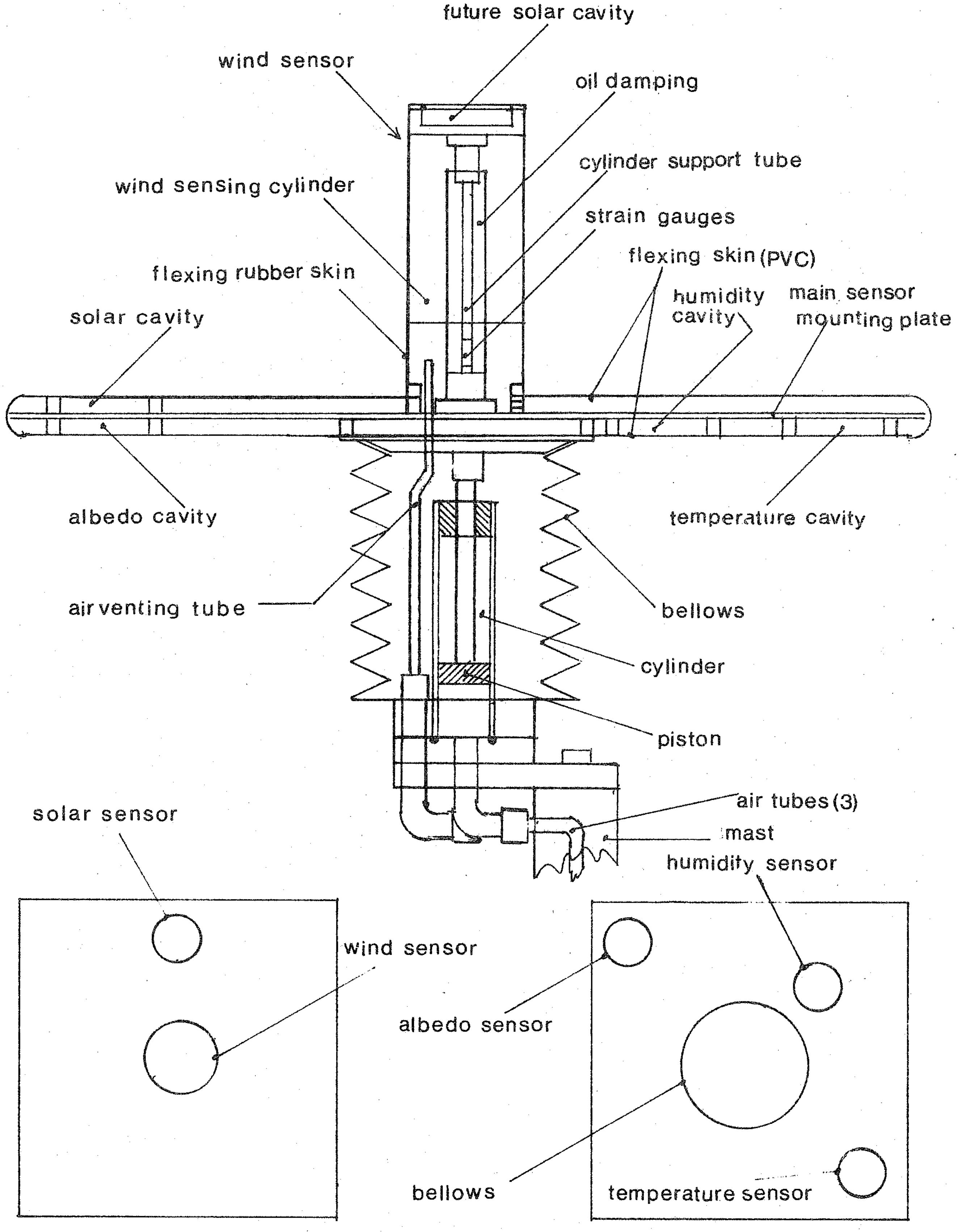
The design to be described is that of the present AWS (March 1984). It owes its form to all of the work outlined above. However, it is almost certainly not the final form; development and refinement will continue.

### General assembly

Figures 1 and 2 show the complete station. A pneumatic shock induction system, within the neoprene rubber bellows, is bolted firmly to the top of the 2 m high, rigidly-

FIGURE 1

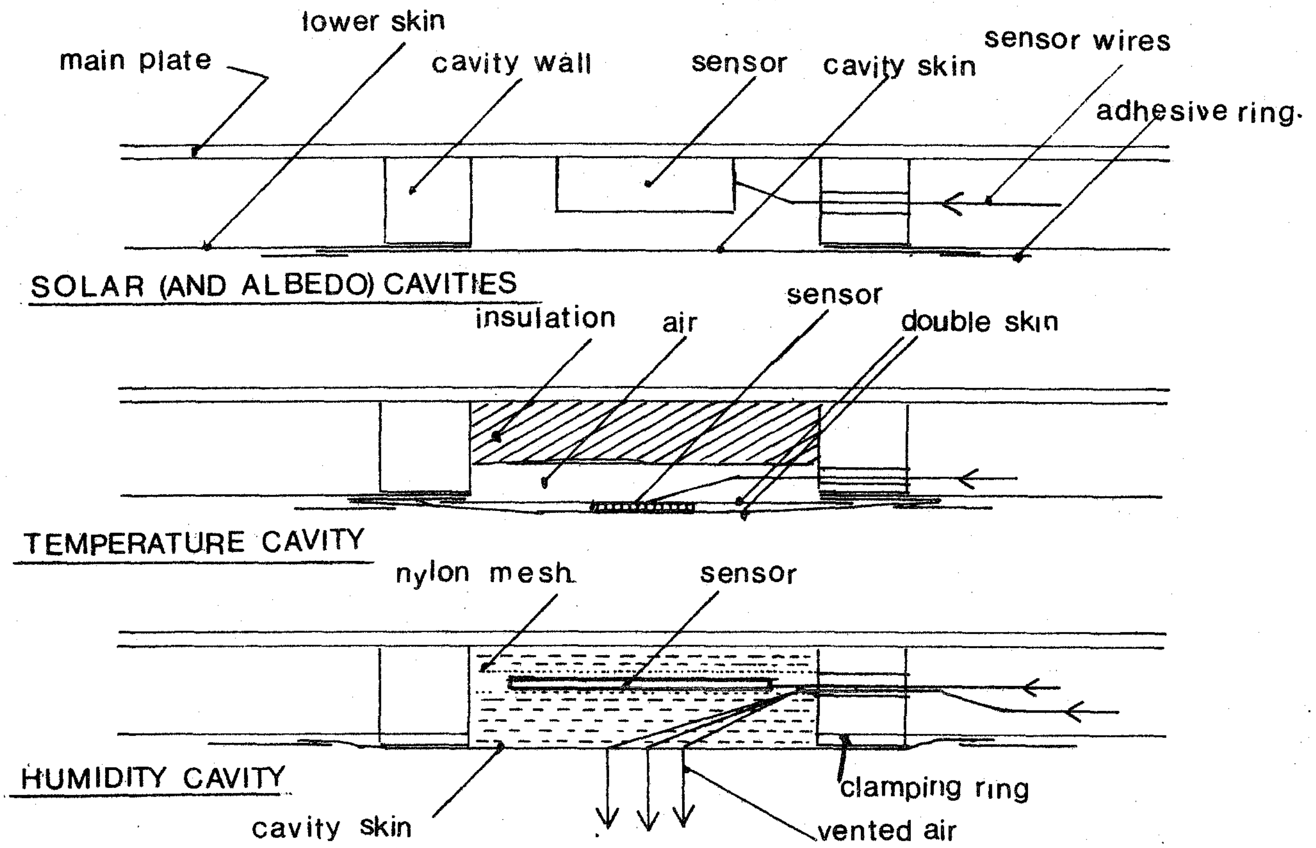
SENSOR HEAD AND PNEUMATICS



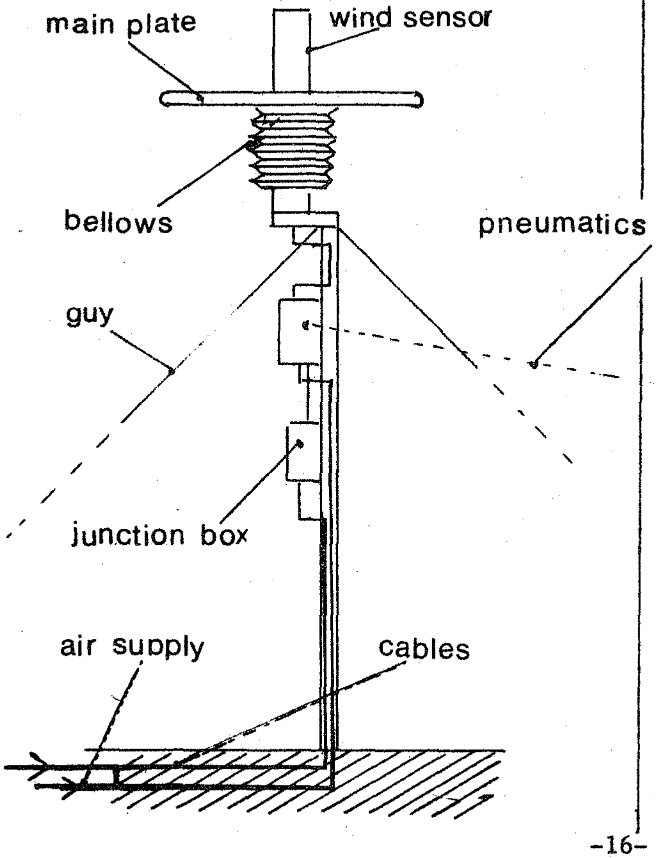
TOP SIDE

UNDER SIDE

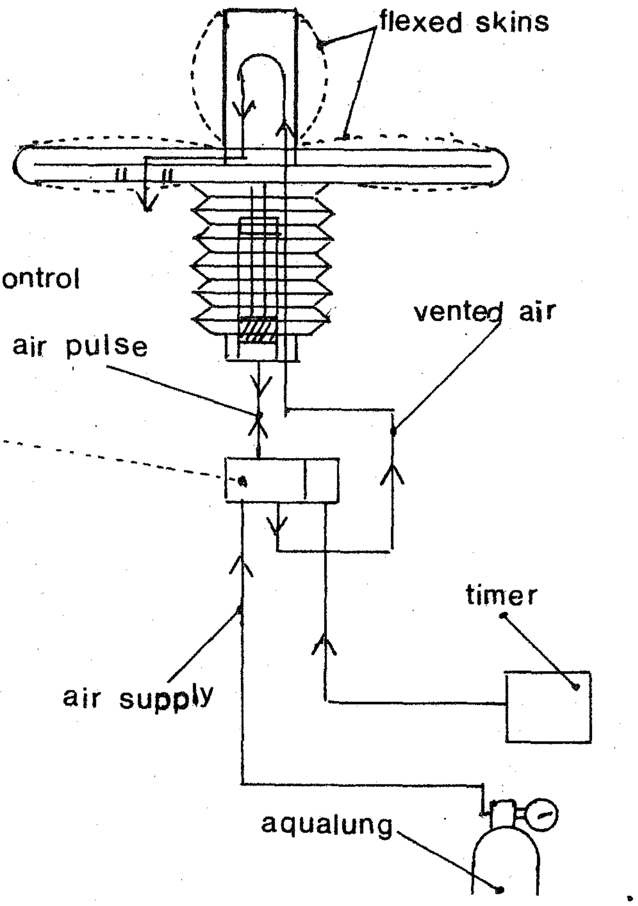
## FIGURE 4 SENSOR CAVITIES



## FIGURE 2
## GENERAL ASSEMBLY



## FIGURE 3
## PNEUMATICS CIRCUIT



guyed, mast of anodised aluminium. On the mast are two sealed boxes, one containing a pneumatic control valve which is supplied with air from the "aqualung" via a nylon tube of 6mm bore burried in the ground. The second is a junction box where sensor signals are routed to the logger and where control signals are routed from a programmable timer to the pneumatic control valve. The shock-induction system comprises a rugged pneumatic cylinder and piston assembly, topped with a circular plate onto which is bolted the sensor head.

The sensor head is constructed around a 4.5 mm thick aluminium alloy plate 450 mm squares. This plate supports all of the sensors - the wind sensor from its centre top surface and four cavities one on top and three below. These house the solar, reflected solar, temperature and humidity sensors. The upper and lower surfaces of the plate covered in a 10 mm thick sheet of foam rubber (except where the sensor cavities are), the whole being covered in black PVC sheet 0.3 mm thick. This was found, after tests extending over several winters, to be the best skin from the point of view of ice shedding and ice prevention which would also survive winds regularly reaching 40 $m.sec^{-1}$ and often carrying particles of gravel and ice at these speeds.

The best way to produce a completely watertight, but flexible, skin took some time to perfect. The head is now square (not circular as it formerly was) because of the difficulty of producing a sealed circular skin. A square skin is easily fitted by folding over the edges to meet at a point in the centre. The four diagonals are then taped with black, 76 mm wide, PVC adhesive tape. The corners posed a sealing problem for some time, until the correct technique was developed.

The sensor cavities and the wind sensor are not covered in black PVC but in materials appropriate to their function. These will be described later.

## The pneumatics

Air from the aqualung is fed to the control valve (Figure 3). On the hour, an electronic programmable timer applies a 12 volt pulse, of five seconds duration, to the solenoid which activates the control valve. This injects air, at 690 kPa (100 PSI), into the pneumatic cylinder which causes the sensor-head to move rapidly upwards for about 5 cm and then to stop abruptly. This causes ice to fly off the structure. Even without flexing, this technique is very effective on certain parts of the structure - but not on all. Since shock works by using the mass of the ice to lever the ice off, it functions best on ice which protrudes sideways rather than that on flat surfaces; flexing combined with shock overcomes this.

After five seconds the air is vented back through the same pneumatic valve. The initial firing, because the bellows are forced to expand, causes a reduction of pressure within the skin. This causes the skin to be flexed in, against the foam rubber. The vented air is now routed back to the sensor-head, directly into the wind sensor cylinder. This is covered in a thin black neoprene rubber tube which is inflated by the vented air, balloon-like. The air is then leaked, over a ten second period, into the main head, causing the PVC skin to slowly flex outwards. The air is finally vented to atmosphere from here through the humidity cavity. Being periodically flushed with dry air in this way prevents condensation occuring on the humidity sensor. The air, therefore, has three functions: it shocks, flexes and dries. The firing process occurs twice, on the hour, spaced by ten seconds. The second fire removes ice loosened, but not removed, by the first.

## The sensor cavities and skins

All of the sensors are houses within aluminium alloy rings of 76 mm external and 56 mm internal diameter by 10 mm thick, fixed to the main plate (Figure 4). Each cavity is covered by a flexing skin, which is fixed to the main skin by an adhesive ring. (In earlier designs a metal ring clamped the skins to the cavity but they collected ice which was not effectively removed by the shock since the ice was not in a position to be levered off.

The skins covering the cavities had to be chosen (a) to suit the variable being measured. (b) To ensure ice sheding occurred. (c) To be able to resist damage by flying particles in the wind and fatigue through wind vibration.

### *Solar radiation cavities*

The skin used for both the solar and reflected solar radiation sensor cavities is 0.1 mm thick polythene sheet, with white filler. White polythene is both a better shedder of ice than clear polythene (due to its filler) and it also acts as a diffuser of the radiation. The latter allows a flat disc of it to be used, in place of the more usual dome, allowing easier removal of ice. This could no doubt be criticised, but the error introduced by using a flat diffusing disc appears to be small (see later).

### *Temperature cavity*

The temperature cavity is thermally insulated, by means of expanded polystyrene and an air gap to prevent the temperature sensor from being heated by radiation absorbed by the black skin. The sensor is covered in a skin of silvered polythene, as Figure 4 shows. shows.

### *Humidity cavity*

This sensor is sandwiched between several layers of nylon mesh, giving it protection against shock-induction, while also allowing air to circulate freely to it. The main skin is sealed against the cavity, preventing air from the body of the head getting into the cavity, except as required. The cavity must perform a difficult balancing function: It must allow air to enter from the outside in sufficient amounts to ensure that the air in the cavity is representative of that outside, while also sufficiently isolated from the outside to enable the dry air, vented hourly from the pneumatics through the cavity, to do its job of preventing condensation, by temporarily reducing the RH in the cavity. But the skin must also allow the cavity to return to, or at least to approach, closely, the humidity of the air outside for accurate measurements of humidity to be made later in the hourly cycle. This balance can only be arrived at by experiment. It is necessary to prevent condensation for two reasons. Condensation, especially if it later freezes, damages the sensor and once condensation has occurred in the cavity it is also very difficult to remove it; a "diode-pumping" type of process occurs.

The skin is the critical element. A wide variety of fine-woven materials (nylon for example) and sintered plastic sheets were first tested, but all became heavily iced. Water repellent paints did not reduce this tendency. The most successful solution has been a polythene skin similar to that used on the radiation cavities, perforated with small holes. The number and size of these holes has been varied in a series of tests to arrive at the optimum. A relatively small number are in fact required, especially in the high wind conditions of Cairn Gorm, and diameters of around 0.3 mm are adequate.

### *Wind Sensor Cavity*

The wind sensor differs from the other sensors in not being protected within its cavity, since it must protrude into the airstream. It is, therefore, the most vulnerable of the sensors and the most difficult of the de-icing problems. The cavity, in this case, simply provides a space in which to fix the support tube of the drag-force anemometer. (Why this type of sensor was chosen will be discussed later). From this tube is suspended its sensing cylinder. This is covered in a thin neoprene rubber tube, sealed top and bottom to additional cavity-like rings. These rings have recessed grooves into which rubber O rings seat, gripping and sealing the rubber skin. As explained in the section on pneumatics, air, vented from the firing cylinder, is routed directly to the wind sensor, inflating the rubber tube so as to remove the ice more forcibly than on the less vulnerable horizontal skins which need to flex less.

## The sensors

### *The solar radiation sensor*

The solar cavity could accommodate a conventional thermopile solar sensor but in an experimental situation, where damage could occur, it is preferable to use a cheap sensor. Throughout the project, therefore, a light sensitive silicon diode has been used (Chappel, 1976).

While a thermopile net sensor would also fit into a (dual) cavity (one above the other), the danger of damage again advised it - until the design was finalised. It is more difficult to measure net than solar radiation and so there was less reason to risk damage to a net sensor than to a solar until the de-icing techniques were developed. In the meantime, as a part substitute, a solar sensor has been used in a downward facing cavity, to measure reflected solar radiation for the calculation of albedo.

### *The temperature sensor*

This is a conventional, miniature, platinum resistance thermometer, measuring 20 mm x 5 mm x 0.5 mm. It offers no problems and is low on cost.

### *The humidity sensor*

In contrast, the choice of humidity sensor offers many problems. The wet and dry method cannot be used, for obvious reasons, so one of the new electrical sensors must be used in its place. These change in electrical impedance with relative humidity. However, many have problem of one sort or another and none appear ideal (McKay, 1978). All known sensors were considered, several tested and one is currently used, (the Phys Chemical PCRC 11). It is not claimed that it is the best, nor that it will be used indefinitely. It was simply the best to use at the time: it is relatively rugged; preliminary field tests suggested it gave consistent results (unfortunately it takes a year or more to be certain of this) and a suitable logger interface circuit had been developed for a similar type of sensor (gypsum blocks). The sensor consists of a substrate of ion exchange resin which varies in resistance with relative humidity. Interleaved conductors, deposited on the substrate, allow this resistance to be measured. Its dimensions are 42 mm x 23 mm x 2 mm.

### *The wind sensors*

These sensors pose even more difficulties than do those for humidity. The options open for consideration were: cups and fans, hot "wires", ultrasonics, pitot tubes, pendulums, pressure plates and drag force anemometers. The cup anemometer is difficult to better in normal situations and because of this a brief study was carried out into the feasibility of designing a flexing micro-cup anemometer and micro vane for direction. Several designs were tried and while the vanes were very successful none of the cup systems were. All hot wire and ultrasonic systems take too much power. Pitot tubes would become ice-filled. A pendulum, contained in a flexible skin, was tested briefly but failed - due to the fact that the shock could not be transmitted effectively to the free moving pendulum. The drag force type was felt to offer the best chance of success and it also had the attraction of being static and of requiring no power (Norwood, 1966). It was also able to give both speed and direction from one sensor. Most effort has, therefore, been devoted to advancing this design.

It consists of a cylinder, of 76 mm diameter, supported on a thin-walled tube which bends slightly under the pressure of the wind. Four straingauges, spaced around the tube at 90° intervals, give measurements of wind pressure in the N-S and E-W direction, recorded separately on two logger channels once every five minutes. The angle and vector size, representing direction and pressure magnitude are calculated in the computer to give hourly means. The pressure is related to the wind speed by the equation

$$F = \frac{1}{2} A e V^2 C_D$$

where

$F$ = drag force in newtons
$A$ = cross-sectional area of drag body in $m^2$
$e$ = air density in $Kg/m^3$
$V$ = air speed in m/s
$C_D$ = drag coefficient of the drag body (dimensionless)

### Precipitation/melt

The measurement of rainfall presents no new problems and a tipping bucket raingauge is used (in milder times of no snow cover). To minimise the effect of wind, on catch, the gauge is mounted with its funnel at ground level.

The measurement of snow is a topic already well covered both in practice and in the literature by others and is a distinct and separate problem from that of icing on sensors. A brief note is in order, however, since precipitation measurement is a part of any weather station.

No attempt is being made, in the present project, to measure either snow as it falls or where it lies. Both are well researched by others. Snowmelt is, however, being measured, to provide "input" data. The latter, too, of course, is also a topic dealt with by others (Colbeck, 1976) and a literature search demonstrates the problems: non-homogeneous percolation of melt-water due to the presence of ice layers and to variations in ice crystal size and distribution and also an incomplete understanding of the percolation process.

With this background, some tentative practical investigations have been started, in snowpacks in Cairn Gorm, in order to gain first hand, practical, experience of the processes and problems involved. The purpose is to look at how meltwater might best be collected, in particular at times of non-saturated flow. Once collected the water can be measured by a tipping bucket. This work is not yet complete, occupies only a very small proportion of project-time and will, therefore, not be reported, beyond noting that it is being done.

## PERFORMANCE

### Ice Prevention

Towards the end of the northern winter of 1984 the ice-detering and removal techniques had been developed to the stage where they worked well in all conditions.

### The Sensors

A detailed evaluation of sensors will only be possible when sufficient stations can be manufactured to allow at least one to be made available for operation alongside a conventional AWS in a lowland, warmer, site. Until a design is well advanced, the cost of such replication and of the operation of duplicate stations cannot be justified. Two stations are now in use and have been for two years. One is always operational on Carin Gorm, the other being updated in the laboratory in the light of experience gained with that in the field, for subsequent exchange. Exchanges occur two or three times each winter. The design is now sufficiently advanced, however, to allow the final designs to be drawn up and several stations manufactured. In the meantime, however, the sensors have been tested individually.

#### *Solar radiation*

A series of manual tests were carried out on this sensor, in which the output of a thermopile solarometer (Kipp) was compared with that of the light sensitive diode. Readings were taken at times of relatively stable radiation conditions, at various times of the day an under different weather and cloud conditions. In all about 100 comparisons were made in this first assessment of performance. Tentaive conclusions are that the diode follows the thermopile output closely. The two conditions where the degree of divergence is greatest are when there is thin, high altitude, cloud, which absorbs part of the spectrum detected by the thermopile but not the diode (infrared) and secondly, when the angle of radiation is low. The latter is probably due to a flat disc rather than a dome being used to protect the sensor. The error is relatively small, and occurs when radiation levels are, in any case, low. Tests in a climate chamber were carried out to determine the extent of the diode's temperature dependence. This was found to be low.

The same comments apply to the reflected solar radiation sensing diode. However, just as the diode does not agree fully with the thermopile sensor, due to the changing spectral composition of the incoming solar radiation (through modification by the atmosphere), so too it is important to remember that the reflectivity of the ground varies across the spectrum. Reflectivity depends on the nature of the soil, its water content, vegetation and other cover such as, in this case, snow. The spectral response of the diode must be releated to this in interpreting its measurements.

#### *Temperature*

The temperature measurements of the station operating on Cairn Gorm have been compared, for several years, with measurements taken manually, alongside the station, using a mercury thermometer. In general, agreement is to within 0.5°C. No problems are anticipated with this variable.

*Humidity*

a humidity sensor has been operated in the summit station, in order to develop the cavity skin design. However, its evaluation as a sensor has been carried out, primarily, at Wallingford. In these tests a PCRCII sensor was installed in a box covered in fine gauze in a conventional temperature screen. Its resistance was logged every five minutes for 12 months. The data were compared with that from an adjacent standard AWS which uses the wet and dry method for humidity. From these comparisons, graphs were prepared relating the PCRCII logger reading to percent relation humidity. The results showed some spread but in general they were consistent.

It is difficult at this stage and without more log term rests, to state exactly what absolute accuracy can be achieved. Throughout the project, however, the aim has been to obtain measurements where none have previously been possible. If the humidity can therefore, be placed in a band 5% wide, this will be considered more than adequate for the present, for example 75-80. In time, with experience, a more exact knowledge of accuracy will be possible.

However, one long term effect has been noted which could be a problem with the PCRCII sensor. After one year's operation in the field its conducting tracks flaked off in several places and the calibration shifted. This was also noted on sensors used on the summit, and others have noted the same. It may be necessary, therefore, to change the sensors regularly or, preferably, to find out why it happens and, if possiblem to stop it. It is recognised that it may be caused by some particular way in which we are using the sensors and more tests will be necessary before any conclusion is reached.

*Wind speed and direction*

A working wind sensor was installed on Cairn Gorm only recently and little data are availabel from it yet. (A dummy cylinder has been tested, however, for the whole of the recent winter, with different rubber skins, in order to find the best). Tests on the wind sensor have, however, been carried out in the laboratory and in a wind tunnel. Laboratory tests comprised the application of loads to the centre of the cylinder, to simulate the pressure of the wind up to 200 km/hr. The response was a good straight line. The temperature stability of the straingauge assembly was also tested in a climate chamber and found to be good. Wind tunnel tests were carried out up to 160 km/hr and showed the expected square law response ($F \alpha V^2$). The sensor's capability of detecting the angle of the wind pressure was also tested in both laboratory and wind tunnel and a good cosine response was found to exist.

The data from Cairn Gorm are still too few to allow an evaluation of the accuracy of velocity measurements but the direction indicated has so far agreed closely with that made by an observer standing by the station with a hand-held anemometer. As in the case of humidity, the first aim of the project is to be able to quote values of windspeed in bands. In this case, for example, as falling somewhere in a 10 km/hr wide band. Wind direction will, at first, be expressed as falling in one of 16 bands, ENE, NE, etc. All indications are that the sensor is working according to theoretical predictions.

## CONCLUSION

An automatic weather station has been developed which will operate in mountainous and other cold environments where icing is a problem (Figure 5). It will also withstand very high winds. It needs only an aqualung to de-ice the sensors by shock induction and flexing. The final design will be relatively low in cost. The designs have been tested, for several years, continuously, at a site in the Cairngorm mountains. The station measures solar and reflected solar radiation, temperature, humidity, wind speed and direction, precipitation and (tentatively) snowmelt. The performance of the sensors has been compared with that of conventional types, exposed in the conventional way.

## ACKNOWLEDGEMENTS

Thanks go to Jo and Mollie Porter, who have carried out the bulk of the field work for the project for several years, often under difficult conditions. Without their frequent visits to the test site and their enthusiasm, the project could not have progressed at the pace it has.

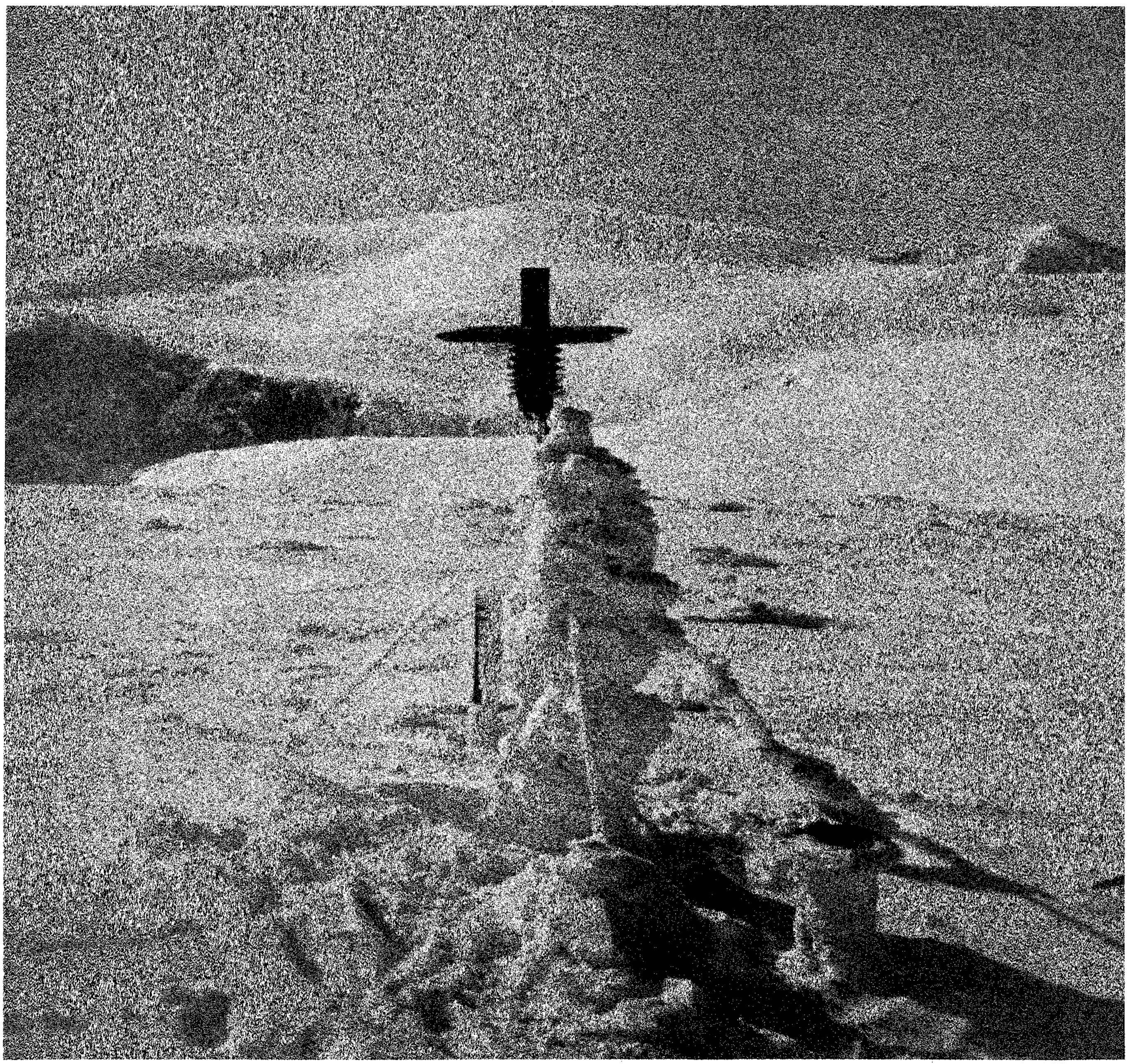


Figure 5. Cairn Gorm weather station (March 1984) showing de-icing capability of the sensor-head and wind cylinder.

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